ASSESSING POTENTIAL WASTE DISPOSAL IMPACT FROM PRESERVATIVE TREATED WOOD PRODUCTS

Timothy G Townsend[1], Brajesh Dubey[1] and Helena Solo-Gabriele[2]

[1]Department of Environmental Engineering Sciences, University of Florida,
PO Box 116450 Gainesville, FL 32611, USA

[2]Department of Civil, Architectural and Environmental Engineering,
University of Miami, Coral Gables, FL 33124, USA

ABSTRACT

The management of discarded treated wood products upon disposal is one of the many factors that should be considered when evaluating a new wood preservative or when comparing wood preservatives as part of a life cycle assessment. Future environmental ramifications of disposal, as well as regulatory requirements and costs, must be assessed and weighed. This paper presents an overview of the factors that must be evaluated when assessing the disposal issues associated with discarded treated wood products. The discussion is based on current US regulations and policy, but the general approach toward evaluating disposal issues will be valid for most countries. A primary consideration is whether a wood preservative has the potential to cause a treated wood product to be a hazardous waste. Only a limited number of compounds can cause a solid waste to be a regulatory hazardous waste, and since the costs of hazardous waste management are high, this should be examined critically. Discarded treated wood products that are not hazardous may still pose environmental and regulatory concerns. Impact on landfill disposal, combustion systems, and wood recycling operations should be addressed. The concepts described in the paper are illustrated by examining four treated wood types: chromated copper arsenate, alkaline copper quaternary, a commercially available borate-treated product and a hypothetical treated wood product containing a silver-based biocide.

Keywords: treated wood, disposal, landfills, combustion

INTRODUCTION

Many factors must be considered when selecting chemical wood preservatives for full-scale commercial application (Milton, 1995). The wood preservative must meet the requirements for preventing biological deterioration of treated wood products in aggressive environments. A method must be available to introduce the preservative chemical(s) efficiently into the wood product, and the preservatives should demonstrate an ability to remain in the wood for an extended period of time. Other factors that must be considered include appearance and odor of the preserved wood, the impact of the preservative on wood product mechanical properties, and the cost of the preservative treatment. Favorable ratings with respect to each of these characteristics resulted in chromated copper arsenate (CCA) being the primary wood preservative used in North America in recent decades.

The recent switch from CCA to other wood preservatives for many treated wood products (US EPA, 2002) resulted from another factor – concern over potential impact on human health and the environment. In the past decade, questions were raised with respect to human exposure to CCA-treated wood products during manufacture and use, contamination of soils underneath or adjacent to treated structures, and possible impact on water supplies and aquatic organisms (Cooper, 1991; Weis et al., 1993; Merkle et al., 1993; Breslin, 1996; Stilwell and Gorny, 1997; Adler-Ivanbrook, 1998; Lebow et al., 1999; Solo-Gabriele et al., 2002; Solo-Gabriele et al., 2003; Lebow et al., 2003; Townsend et al., 2003a; Townsend et al., 2003b). The management of discarded CCA-treated wood at the end of its useful life has also been raised as an issue of possible concern (McQueen and Stevens, 1998; Solo-Gabriele and Townsend, 1999). Common management practices for discarded CCA-treated wood include disposal in landfills and combustion in waste-to-energy (WTE) systems. Potential adverse effects posed by these practices include elevated metal concentrations in landfill leachate and groundwater (Jang and Townsend, 2001; Townsend et al., 2001; Weber et al., 2002; Jang and Townsend, 2003a; and Jambeck et al., 2003) and WTE combustion ash (Solo-Gabriele et al. 2001). An unexpected concern that surfaced in Florida is the inclusion of CCA-treated wood in landscape mulched produced from processed C&D debris (Tolaymat et al., 2000; Townsend et al., 2003c).

The registration or standardization of a new chemical wood preservative with regulatory agencies such as the US EPA or with an industry organization such as the American Wood Preservers' Association (AWPI) requires demonstration of preservative efficacy and must address environmental and human safety during normal use. Issues pertaining to ultimate disposal are not, however, always considered. In light of the lessons learned with CCA, it would be prudent for developers and manufacturers of new preservative chemicals to evaluate possible disposal issues (as one part of the overall preservative evaluation). Assessing possible impact on disposal can be a confusing process. This paper was written to provide an overview of current US regulations and policies that would apply to a treated wood product upon disposal and to outline steps that could be helpful in assessing future disposal impacts. The information could be used to evaluate a proposed preservative formulation or it could be used by those comparing different treated wood products, for example, as part of a life-cycle assessment.

SOLID WASTE REGULATIONS PERTAINING TO TREATED WOOD

In the US, a solid waste is any discarded or abandoned material that is not otherwise exempted from the regulations. The primary statute governing solid waste in the US is the Resource Conservation and Recovery Act (RCRA). The regulations developed under the authority of RCRA provide a framework for the management of wastes that pose an unacceptable risk to human health and the environment when improperly managed. RCRA defines a subset of solid wastes as hazardous wastes. Any solid waste, unless otherwise exempted, may potentially be a hazardous waste by either being included on a list of defined hazardous wastes (listed hazardous wastes) or by meeting a certain physical or chemical characteristic (characteristic wastes). The RCRA regulations provide specific and rigorous requirements for managing hazardous wastes and it is the generator's responsibility to determine whether their solid waste is hazardous. The costs associated with hazardous waste management are greater than those for non-hazardous solid wastes. The US EPA has published several documents that provide an overview of the requirements of RCRA (US EPA, 2000).

The regulatory requirements for solid wastes that do not meet the definition of a hazardous waste are less well defined. Non-hazardous solid wastes are typically grouped into a number of different categories, including municipal solid waste (MSW), construction and demolition (C&D) debris and industrial wastes. While federal location and design requirements have been promulgated for MSW landfills, industrial waste and C&D debris disposal are regulated at the state level; the regulatory requirements vary dramatically among states. In Florida, for example, C&D debris can be disposed in unlined landfills, while in New Jersey, C&D debris can only be disposed of in a lined facility. Non-hazardous solid wastes are often disposed in manners other then landfilling. The beneficial use of waste materials is becoming commonplace, and again, regulations governing such activities are governed at the state level.

The regulatory requirements that must be addressed when disposing of treated wood products depend on how the materials are managed (e.g., are they disposed in a lined or unlined landfill). The following sections address hazardous waste determination, disposal in lined landfills, disposal in unlined landfills, effects on WTE systems, and impacts on beneficial use applications.

Determination of hazardous waste status

As described above, a solid waste may be a hazardous waste either through listing or by meeting a characteristic. Discarded treated wood products are not listed hazardous wastes. The characteristic that would most likely result in discarded treated wood being hazardous is the toxicity characteristic (TC). The TC is determined by performing a leaching method known as the toxicity characteristic leaching procedure (TCLP, US EPA, 1996)). The TCLP utilizes a buffered organic acid solution as an extraction fluid, and was designed to simulate contaminant leaching under acid-forming conditions in a MSW landfill environment (Francis et al., 1984; Francis et al., 1986). The acid used is acetic acid, an organic acid formed during the anaerobic decomposition of MSW organic matter (e.g., food waste, paper products). The test involves leaching one hundred grams of the waste with two liters of the extraction solution. The waste sample must first be size reduced to less than

0.95 cm. After mixing for 18 hours on a rotary extractor, the resulting leachate is filtered and analyzed for pollutants of concern.

When evaluating the impact of a treated wood product on disposal, TCLP results may prove useful on several fronts. They may provide an indication of the treated wood's propensity to leach preservative chemicals in an MSW landfill. The TCLP's applicability for this objective will be discussed in the next section. TCLP results can also be used to determine whether the discarded treated wood product might be a TC hazardous waste. To do so, the TCLP leachate concentrations are compared to the TC threshold concentrations in Table 1. If the concentration in the TCLP leachate (mg/L) exceeds the threshold concentration, the waste is characterized as hazardous by the TC. It should be noted that the list only contains a limited number of elements or compounds. To assist in a quick evaluation for determining whether a treated wood product even has the possibility of being a TC hazardous waste, the total concentrations (mg/kg) above which sufficient chemical exists to be a hazardous waste are included in Table 1 as well. These concentrations were determined by assuming that 100% of the element or compound leaches during the TCLP. Total concentrations above those listed in Table 1 do not mean that the waste will be hazardous, just that it has the *potential* to be hazardous. For example, creosote and pentachlorophenol (PCP) treated wood products may contain total concentrations of cresol or PCP greater than listed, but the TCLP leachable concentrations have been reported to be less than the TC threshold concentrations (EPRI, 1991).

Arsenic and chromium are the two metals in CCA encountered on the list, each having a TC threshold concentration of 5 mg/L. Copper is not a TC compound, and thus discarded treated wood can not be a TC hazardous waste for copper under federal rules. New CCA-treated wood samples have been found to exceed the TC limits for arsenic on many occasions (Townsend et al., 2003a). CCA-treated wood is, however, excluded from the definition of a hazardous waste under RCRA (U.S. EPA, 2001, 40 C.F.R., 261.4(b)(9)). No other treated wood products are excluded from the definition of hazardous waste. It is also important to note the exclusion is not necessarily adopted by every state, and that CCA-treated wood remains a solid waste under RCRA and must meet all other applicable requirements (as will be discussed in subsequent sections).

The manufacturer of a new preservative containing one of the elements or compounds on the TC list should compare the total concentration (based on preservative concentration and retention level in the wood) to the concentrations in Table 1 to determine whether it has the potential to be a TC hazardous waste. If such a potential exists, the manufacturer should perform testing to determine whether concentrations leached using the TCLP are exceeded. Results produced from experiments on test samples of treated wood products would most closely represent conditions where the wood product was disposed as scrap construction lumber. Treated wood exposed to environmental weathering does lose some preservative through leaching and abrasion, raising the possibility that weathered samples (which represent the majority of material disposed) will leach less. Research on weathered CCA-treated wood, however, demonstrated that weathered samples exhibit a similar propensity to leach arsenic in comparison to new samples (Solo-Gabriele et al., 2003). .

In the US, states have the option to develop more stringent regulations than that required under federal rules. A notable example that affects the possible characterization of treated wood products as a hazardous waste in the US is California and its rules related to hazardous waste characterization. In addition to using the TCLP to determine hazardous waste status, California employs a method known as the Waste Extraction Test (WET). It contains a solvent that tends to leach more metals than the TCLP (WET uses citric acid), and the number of elements that must be evaluated is greater (CCR, 1998). Table 2 presents California's Soluble Threshold Concentration Limit (STCL). Table 2a presents the California limits for inorganic elements or compounds, while Table 2b presents the limits of the organic compounds. If the WET leachate concentration of any chemical in Table 2 exceeds the STCL, the solid waste is a hazardous waste unless otherwise exempted. In a similar fashion as Table 1, Table 2 presents the total concentrations above which a waste has the *potential* to leach enough chemical to exceed the STCL. Finally, wastes in California that exceed the Total Threshold Limit (TTL) concentration, regardless of how much leaches, are hazardous wastes unless exempted.

Evaluating impact on lined landfills

Discarded treated wood that does not meet the definition of hazardous waste under RCRA, or treated wood that fails TCLP but is produced by an exempt generator category (such as a household, or a non-household generator of less than 100 kg per month), may legally be disposed in a lined Subtitle D landfill (under federal rules). Subtitle D refers to a section of RCRA dealing with non-hazardous solid wastes. MSW must be disposed in a Subtitle D landfill (design requirements found in 40 CFR 258), but many of these landfills also accept C&D debris, WTE ash and industrial waste. Subtitle D landfills are lined to protect the groundwater, and the leachate that is produced is collected and treated. In many cases, states have adopted liner requirements more stringent than Subtitle D; several states also require liners for C&D debris landfills.

It is important to note that while it is legal under federal solid waste rules to dispose of treated wood in a lined landfill, landfill operators are not required to accept the material. Reasons why landfill operators might be reluctant to accept discarded treated wood products include problems with handling and compaction (which are not a function of the preservative type) and potential impacts on leachate quality. A majority of landfills haul their leachate to off-site treatment facilities, and in many cases pretreatment standards are imposed. Elevated concentrations of pollutants can result in excessive strength charges for the landfill operator, or possibly in the treatment facility declining to accept the leachate. Some wastewater treatment facilities may also regulate metal concentrations because of concerns over impact on biosolids quality.

The TCLP provides one method that may be used to assess the impact of treated wood disposal on lined landfill leachate quality. As previously described, the TCLP was designed to simulate conditions occurring in a MSW landfill when acids are produced from decomposing organic waste. Most landfills do not, however, contains acids at concentrations equivalent to the TCLP. If such concentrations were to occur, they would only be for a relatively short time. Based on this observation, one would expect that the TCLP would overestimate pollutant release compared to actual landfill environments. This has been observed in the case of lead (Jang and Townsend, 2003b), but others have found elements such as arsenic and chromium (metalloids that exist as oxy-anions) often leach more in landfill leachates compared to the TCLP. Jambeck et al. (2004) reported the largest arsenic and chromium concentrations to occur early in a simulated MSW landfill's life when the acid concentrations were highest (and pH was lowest). A whole host of other chemical, biological, and physical factors impact the migration of a chemical from the landfilled waste to the leachate collected from the liner system, and these can not all be accounted for using one single test such as the TCLP.

Evaluating impact on unlined landfills

Many states do not require liners for C&D debris landfills. Notable examples include Florida, Texas and California. The legality of disposing of treated wood in an unlined C&D debris landfill depends on the state. Some states prohibit the disposal of certain treated wood products in C&D debris landfills, while others allow it. When evaluating disposal of waste components not specifically discussed in a regulation, state regulators often have policies that prohibit the disposal of wastes that have a potential to leach and cause an impact on groundwater. Leaching tests can be used to evaluate the risk presented by a waste co-disposed in an unlined landfill to contaminate groundwater. The TCLP may be used if the landfill is contains putrescible organic matter that would result in the production of organic acids. If a landfill contains only inert debris, another test often recommended is the Synthetic Precipitation Leaching Procedure (SPLP). The SPLP is similar to the TCLP, but a simulated rainwater is used instead (pH = 4.2). The SPLP tends to be less aggressive towards metal leaching compared to the TCLP and WET (the TCLP and WET contain buffered weak acids, while SPLP is unbuffered and contains only small amount of nitric and sulfuric acids). When the EPA evaluated SPLP and TCLP results for lead based paint debris, they assumed that TCLP would be representative of MSW landfills while the SPLP was more representative of C&D debris landfills (FR, 1998).

A common approach used by the states to assess whether a waste poses a potential risk to groundwater when disposed of in unlined landfill is to run the SPLP on the waste and compare the results, not to TC limits, but directly to groundwater criteria. Table 4 presents examples of water quality criteria for many compounds. It is important to note that there may be many compounds with numerical standards or limits. The drinking water standards are usually included, as well as other compounds that have health based limits established. Table 4 illustrates that concentrations are much lower than the TC and STCL thresholds presented earlier. When evaluating a new preservative for potential impact on groundwater, water quality criteria such as the drinking water standards or other health based standards (such as presented in the Table 4) should be consulted. If leaching data are available, the results can be compared to assess whether groundwater contamination might be an issue. When comparing and contrasting different treated wood products, the ratio of leachate concentration to water quality limits for chemicals of interest may provide a sense of the relative risk posed by each product. When leaching data are lacking, the treated wood products can be assumed to leach the same fraction of preservative chemicals, and these concentrations can be compared to their respective groundwater limits.

Assessing impact on combustion operations

A common form of managing waste wood is through combustion. This occurs both as combustion of bulk loads of wood (e.g. utility poles, railroad ties) and loads of mixed C&D wood. From an environmental standpoint, the combustion of treated wood poses potential problems with respect to air emissions and ash generation. Facilities that combust wood will in nearly all cases have some form of air pollution control equipment (APC). The type of APC needed depends on the type of emission hazards presented by the preservatives in the wood and the regulatory requirements. Proper combustion techniques can be used to destroy organic preservative compounds used in wood. Several facilities in the US routinely combust pentachlorophenol and creosote treated wood; issues with dioxin and furan emissions are controlled by maintaining proper temperature and gas mixtures. The control of metals, however, requires additional pollutant removal systems such as bag houses, chemical scrubbing and carbon injection. Some metals will be more prone to air emission problems. Arsenic, for example, volatizes and is thus an issue when CCA-treated wood is combusted (Hirata et al. 1993; McMahon et al. 1986, Pasek and McIntyre 1993). Thermodynamic chemical modeling techniques (Iida et al., 2004) or basic data on the volatility of chemical species from a chemical reference book can be used to assess the potential of inorganic compounds to present an air emission problem.

The presence of preservative treated wood can also have a major impact on the management requirements for the resulting ash. Organic preservatives should not prove to be a large problem as they will likely be destroyed in well-operated combustion systems, but inorganic preservative compounds will magnify in concentration. When examining the possible impacts of a preservative treated wood on combustion ash, the first step should be to determine whether the preservative can cause the ash to be a hazardous waste. This is the same procedure discussed for the wood itself. A mass balance may be performed to estimate the final ash concentration of the element of , and this could be compared to the values presented in Table 1 to assess whether or not the ash has the potential to be a hazardous waste. But because of the large concentrations of preservatives used in treated wood and the degree of magnification that occurs in the combustion process, most treated wood samples that contain a TC element will have the potential to cause the ash to be hazardous. Research on the impact of CCA-treated wood on ash properties (Solo-Gabriele et al. 2002) found all samples of CCA-treated wood ash to exceed the TC limit for arsenic. It was estimated that at levels of approximately 5% CCA-treated wood in a mixture of wood, the ash would fail the TCLP. A basic knowledge of how certain element tend to leach from combustion ash might give the preservative developer some idea whether leaching is likely, but the amount of leaching that actually occurs can be very waste specific.

Even if the ash is not a hazardous waste, elevated metals concentrations might limit reuse options from the ash or dissuade subtitle D landfill operators from accepting the ash. The same considerations discussed above for lined landfill operators would be evaluated. Many states have guidelines for determining when solid wastes such as WTE ash can be beneficially used in the environment. These steps are discussed in the next section.

Land application issues

Another potential disposal route for discarded treated wood products is land application. Treated wood might impact land application of waste through two primary pathways: landscape mulch and combustion ash. Many C&D debris landfills and recycling facilities recycle recovered C&D wood for use as landscape mulch, and this may contain treated wood (Tolaymat et al., 2000). A second route is the land application of ash as discussed above. When evaluating land disposal of wastes, it is customary to compare the results from leaching tests such as the SPLP directly to water quality standards in the same manner as described above for unlined landfill disposal (Saranko et al. 1999, WDNR 2003). SPLP results from mulch or ash would be compared directly to quality criteria such as those in Table 3, and if the measured concentrations were above the levels in the table, a potential risk of leaching when land applied is indicated.

Leaching risk is not, however, the only concern for land applied wastes. Direct human exposure must also be evaluated. Table 4 presents generic soil screening levels that are used to determine whether a land applied material (that is similar to soil in nature) poses a risk under a given set of exposure scenarios. The values in Table 4 represent risk-based soil screening levels in Florida (referred to as the soil cleanup target levels, SCTLs), and most states have similar lists. The risk of a land applied waste on direct exposure is examined by comparing the measured concentration of chemicals of concern to the screening levels; exceedances indicate a possible risk. It should be noted that unlike water quality criteria, the clean soil criteria in some cases vary dramatically among states. Arsenic is one example, with acceptable concentrations for soil in residential areas in some states to be less than 1 mg/kg, while in other states the value is greater than 50 mg/kg. Differences from state to state result from differences in natural background concentrations and the toxicity and exposure assumptions used to develop the criteria.

Both land application scenarios (landscape mulch and combustion ash) require assumptions regarding the amount of treated wood present in the wood mix. The potential of different treated wood products to pose a land application risk can be performed by assuming the fraction of a treated wood product to occur in a C&D debris wood mix, calculating the concentration of preservative chemical in the mix, and comparing these results to values such as those presented in Table 4. In the case of the wood ash scenario, the fraction of ash remaining after combustion would require estimation. In a similar manner as indicated for the unlined landfill discussion above, the ratios of the predicted concentrations to the risk-based criteria could be compared to assess the relative impact among different treated wood products.

CASE STUDY: EVALUATION OF FOUR TREATED WOOD PRODUCTS

To illustrate the principles discussed above, four different preserved wood types were evaluated and compared with respect to their potential environmental and regulatory impact upon disposal. The preservatives include CCA, alkaline copper quatenary (ACQ), a boron-containing preservative (Envirosafe™), and a hypothetical silver-based preservative.

Description of Wood Types Evaluated

Table 5 summarizes the wood preservative types examined, their major components and the concentrations of the major preservative components. The CCA-treated wood product evaluated was treated with Type C CCA to a retention level of 0.25 pcf . The ACQ-treated wood product was treated with ACQ type D to a retention level of 0.25 pcf. The retention level for both the CCA- and ACQ-treated wood products is that required for above-ground contact, and thus represents the minimum retention level standardized by the AWPA. The third wood product evaluated was a boron-based formulation currently marketed under the trade name of Envirosafe Plus™. Its primary component is disodium octaborate tetrahydrate (DOT). Typical boron concentrations measured in preliminary tests by the authors is on the order of 1,000 mg/kg. The fourth wood product evaluated is not based on any existing product, but assumes that treatment solution contains silver. Silver has recently been suggested as a possible promising wood treatment chemical (Silver Institute, 2003) and it is reportedly being researched. The concentration of silver in the wood was assumed to be 1,000 mg/kg. This value was not selected based on any proposed formulation, but rather because it falls in the magnitude of the major components in the other wood preservatives. It simply provides a conentration with which the waste disposal assessment can be conducted. The results of the waste disposal assessment are presented in the following sections, and are summarized in Table 6.

Hazardous Waste Determination

Of the components of the four wood preservatives evaluated, arsenic, chromium and silver are the only ones found in Table 1 (the RCRA TC limits), and thus only CCA-treated wood and the silver-based biocide treated wood have the potential to be a TC hazardous wastes under US federal rules. The information presented in Table 1 and Table 5 shows that CCA-treated wood does contain enough arsenic and chromium to potentially be a TC hazardous (when total concentrations are compared). Leaching tests do, in fact, show that the TC level for arsenic is typically exceeded (Townsend et al., 2001). However, as described earlier, the RCRA regulations exclude CCA-treated wood from the definition of hazardous waste. That data in Tables 1 and 5 also indicate that the silver-based treated wood product contains enough silver to potentially be a hazardous waste, but it would depend on how much leached. Since no such data are available, and product developers would be recommended to conduct such tests.

When the California hazardous waste rules are applied, the ACQ treated wood product also becomes characterized as a hazardous waste. Not only does it contain enough copper to potentially exceed the STCL using the WET, but the total concentration itself exceeds the TTLC. The silver-based wood product would also exceed the TTLC under the preservative concentrations assumed. To the authors' best knowledge, no treated wood product other than CCA-treated wood is excluded from the definition of hazardous waste in California.

Impact on Lined Landfill Leachates

Both CCA-treated wood and ACQ-treated wood have been shown to leach quantities of arsenic, copper and chromium that might present a concern with respect to elevating leachate concentrations from lined landfills (Townsend et al., 2001; Townsend et al., 2003a). Previous work comparing metal mobility in the TCLP versus leaching with actual landfill leachates shows that arsenic and chromium tend to leach more (Hooper et al., 1998) in actual landfill leachates relative to TCLP. This observation was not made for copper. Arsenic and chromium have also been found to occur at greater concentrations than copper in leachates from simulated landfills (Weber et al., 2002; Jang and Townsend, 2002; Jambeck et al., 2004). These observations were believed to be a result of copper's propensity to precipitate (e.g., with sulfides) and the fact that arsenic and chromium may exist as anions in solution under typical leachate pH conditions. It could be argued from these observations that CCA-treated wood presents a greater problem for lined landfill disposal than ACQ-treated wood. TCLP or other leaching data on the particular borate treated wood examined were not available, though previous studies have shown borate-treated wood to often be readily leachable. No data were found regarding leaching from other silver-containing wastes where TCLP leachate concentrations were compared to those concentrations produced using actual landfill leachates as an extraction solution. TCLP testing on the borate-treated wood and the silver-treated wood would be a valuable first step in assessing potential impacts on lined landfills, but based on observations with copper from CCA-treated wood, it is likely that additional testing would be needed to assess the true likelihood of elevated boron and silver leachate concentrations.

Impact on Unlined Landfill Leachates

The potential impact of discarded treated wood products on groundwater at unlined landfills can be evaluated by comparing leaching test results to groundwater criteria. As described previously, the TCLP can be used, but the SPLP is a more common approach for unlined C&D debris landfills. SPLP leaching results are available for both CCA- and ACQ-treated wood. In a side-by-side comparison, CCA-treated wood leached 8.9, 2.5, 4.1 mg/L of As, Cr, and Cu respectively, while ACQ treated wood leached 29 mg/L of Cu (Townsend et al., 2003a). The respective drinking water standards for As, Cr and Cu are 0.05, 0.1, and 1.0 mg/L, though the As standard is being lowered to 0.01 mg/L in the near future. In absence of data on all four products, a comparison was made assuming that 5% of the preservative chemicals leach from each treated wood product during a SPLP analysis. The resulting leachate concentrations were then divided by the relevant water quality criteria presented in Table 3. The results are presented in Table 6. The treated wood products with the greatest ratio (i.e., the leachate concentration exceeding the water quality criteria by the greatest amount) was CCA (due to arsenic), followed by the silver-based preservative, then ACQ, and finally the borate-treated wood. This analysis provides an initial indication of the relative risk posed by each of the wood products in unlined landfills. Many other factors would confound the true impact on groundwater (e.g., the fraction leaching over time, the mobility of the chemical in environment), and additional work could be performed to refine this analysis (e.g., conducting leaching tests, performing groundwater modeling).

Impact on Waste to Energy Systems

When evaluating impact on combustion systems, both air emissions and ash quality should be considered. Of the metals in CCA, arsenic is likely to volatilize to the greatest extent (Iida et al., 2004). This would indicate that in a side by side comparison with between CCA- and ACQ-treated wood, the CCA-treated wood product would pose a greater concern with respect to combustion. Data would need to be gathered on the potential air emission issues associated with boron and silver.

Based on the previous discussion concerning the potential for the treated wood products to be a hazardous waste, ash from the combustion of wood containing CCA-treated wood and wood treated with the silver-based biocide could be hazardous wastes. The exclusion from the definition of hazardous waste that CCA-treated wood has for the wood itself does not apply to ash. Assuming that a wood mix containing 10% treated wood was burned, and that 5% of the wood fuel remained as ash, the fraction of As and Cr that would have to leach from ash from the combustion a CCA contaminated fuel mix would be 2.9 % and 2.6 %, respectively (as presented in Table 6).. The fraction of silver that would have to leach would be 5 %.

Land Application Issues

Two methods were used to evaluate the potential impact of the four treated wood products on land application. In one analysis, the treated wood products were assumed to comprise 10% of the weight of a landscape mulch mix, the resulting concentrations of the preservative elements were calculated. These concentrations were then divided by the risk-based soil criteria in Table 4. The results are presented in Table 6. CCA-treated wood was found to exceed the soil criteria by the greatest amount (by 213 times; a result of arsenic), followed by ACQ (3.5 times). The ratio calculated for both the boron-based and the silver-based treated wood products was less than one indicating that at a contribution of 10%, the inclusion of the wood products did not result in an exceedance of the soil criteria. The wood mix could contain 100% of the borate-treated wood and not exceed the soil criteria for boron, and 39% of the silver-treated wood and not exceed the soil criteria for silver. The reader is reminded that the soil criteria used for this example were taken from those currently used in Florida, US, and may not be representative of criteria in other locations.

In a second analysis, the concentrations of the preservative elements in the ash described in the previous section (10% treated wood in wood fuel, 5% ash residue after combustion) were compared to the risk-based soil criteria in a similar fashion as done for the land applied mulch. The results are presented in Table 6. Ash from the combustion of wood mixture containing CCA-treated wood was found to exceed the soil criteria by the greatest amount (by 4,275 times; a result of arsenic), followed by the ACQ mixture (by 69 times), and finally the silver-based preservative mixture (by 5.1 times). The ratio calculated for ash from the boron-based treated wood product was less than one indicating that at a contribution of 10%, its inclusion did not result in an exceedance of the soil criteria. The ash could contain 35% of the borate-treated wood and not exceed the soil criteria for boron.

SUMMARY AND CONCLUSIONS

The management of discarded treated wood products upon disposal should be considered when evaluating a new wood preservative or when comparing wood preservatives as part of a life cycle assessment. This paper presented an overview of the factors that must be evaluated when assessing the disposal issues associated with discarded treated wood products. Factors that should be evaluated include whether the discarded wood products have the potential to be a hazardous waste, and what the impacts on lined landfill leachate quality, unlined landfill groundwater quality, combustion systems, and landscape mulch might be. The assessment strategy was illustrated by considering four treated wood products, three existing products (CCA, ACQ, and a borate treatment) and one wood product treated with a hypothetical silver-based treating solution. The results provided an indication of the relative impact of the treated wood products on waste disposal. The approach provides a tool that can be used to evaluate possible waste disposal issues, but its utility depends on the quality of the data available for the assessment. Clearly, especially for the newer treated wood products, additional data would be necessary for a complete evaluation. Where the assessment approach may be most useful with respect to new products where the data are lacking is in the comparison of different treated wood products, as part of, for example, a life cycle assessment.

Acknowledgments

The authors acknowledge the Florida Center for Solid and Hazardous Waste Management for their continued support of research on treated wood.

REFERENCES

Adler-Ivanbrook, L. and Breslin, V.(1998) Accumulation of Copper, Chromium and Arsenic in Blue Mussels (Mytilus Edulis) From Laboratory and Field Exposures to Wood Treated with Chromated Copper Arsenate Type C. *Environmental Toxicology and Chemistry*. 18(2): 213-221.

American Wood Preservers' Institute (1997) The 1996 wood preserving industry production statistical report. *American Wood Preservers' Institute, Fairfax, Virginia*.

Brantley, A., and Townsend, T. (1999). "Leaching of Pollutants from Reclaimed Asphalt Pavement." *Environ. Engineering Science.*, 16(2), 105-116.

Breslin, V. and Adler-Ivanbrook, L. (1996) Release of Copper, Chromium and Arsenic from CCA-C Treated Lumber in Estuaries. *Estuarine, Coastal and Shelf Science* 46, 111-125.

CCR, C. C. O. R. *California Code of Regulations, Title 22 Chapter 11, Article 5, Appendix II.* **1998**.

Cooper P. (1991). Leaching of CCA from Treated Wood: pH effects. *Forest Products Journal*, 41(1): 30-32.

EPRI (1991). Pentachlorophenol-treated wood poles and cross arms: Toxicity characteristic leaching procedure results. Report summary EN7062S *Electric Power Research Institute, Palo Alto, CA.*

FR, Federal Register 63 (1998) 70190

Francis C., and Maskarinec, M (1986) Field and Laboratory Studies in Support of a Hazardous Waste Extraction Test, DE86 *007068, U.S. Environmental Protection Agency, Oak Ridge, TN.,*1986.

Francis, C., Maskarinec, M., and Goyert, J. (1984). Mobility of Toxic Compounds from Hazardous Wastes, *OENL-6044, U.S. DOE., Oak Ridge, Tennessee*.

Hageman, P., Briggs, P.,Desborough, G., Lamothe, P.,and Theodorakos, P (2000) Synthetic Precipitation Leaching Procedure (SPLP) *Leachate Chemistry Data for Solid Mine-Waste Composite Samples from Southwestern New Mexico, and Leadville, Colorado Denver CO*, Department of Interior USGS.

Hirata, T., Inoue, M., and Fukui, Y. (1993). "Pyrolysis and Combustion Toxcicity of Wood treated with CCA." *Wood Science and Technology*, 27, 35-47.

Iida, K., Pierman, J., Tolaymat, T. Townsend, T. and Wu, C, Y.,(2004) "Control of Heavy Metal Emissions and Leaching from Incineration of CCA-Treated Woods Using Mineral Sorbents", *Journal of. Env. Eng.*, 130(2), 184-192

Jambeck, J., Townsend, T and Solo-Gabriele, H (2003). The Disposal of CCA-Treated Wood in Simulated Landfills: Potential Impacts: *The 34th Annual Meeting of the International Research Group on Wood Preservation, Brisbane, Australia*, pp. 17.

Jambeck, J., Townsend, T and Solo-Gabriele, H (2004). Leachate Quality from Simulated Landfills Containing CCA-Treated Wood: *Environmental Impacts of Preservative-Treated Wood Conference Feb 8-11, Orlando, FL.*

Jang, Y and Townsend, T (2001) Occurance of Organic Pollutants in Recovered Soil Fines from Construction and Demolition Waste.. *Waste Management* 21 703-715 2001

Jang, Y and Townsend, T (2003a) Effect of Waste Depth on Leachate Quality from Laboratory Construction and Demolition Debris Landfills. *Environmental Engineering Science* 20 (3) 183-196

Jang, Y.., and Townsend. T. (2003b) Leaching of Lead from Computer Printed Wire Boards and Cathode Ray Tubes by Municipal Solid Waste Landfill Leachate. *Environ. Sci. Technol*. 37, 4718-4784.

Lebow, S., Foster, D., and Lebow, P. (1999) Release of Copper, Chromium, and Arsenic From Treated Southern Pine Exposed in Seawater and Freshwater. *Forest Products Journal*, V49, N. 7/8.

Lebow, S., Williams, R., and Lebow, P. (2003) Effect of Simulated Rainfall and Weathering on Release of Preservative Elements from CCA Treated Wood. *Environmental Science & Technology* 37: 4077-4082.

McMahon, C., Bush, P., and Woolson, E. (1986). "How Much Arsenic is Released When CCA-Treated Wood is Burned." *Forest Products Journal*, 36(1912), 45-50.

McQueen J and Stevens J. (1998) Disposal of CCA treated wood. *Forest Products Society Journal* 48(11/12): 86-90.

Merkle, P., Gallagher, D. and Solberg, T. (1993) Leaching Rates, Metals Distribution, and Chemistry of CCA Treated Lumber: Implications for Water Quality Modeling. *Paper presented at a meeting on Enviromental Considerations in the Use of Pressure-Treated Wood Products sponsored by the Carolinas-Chesapeake Section of the Forest Products Society and Virginia Tech*, May 13, 1993 in Richmond VA.

Milton, F. (1995) The Preservation of Wood: A Self Study Guide for Wood Treaters. Minnesota Extension Service. *University of Minnesota, College of Natural Resources*.

Pasek, E., and McIntyre, C.(1993) "Treatment and Recycle of CCA Hazardous Waste." *24th Annual Meeting of the International Research Group on Wood Prservation,* Stockholm, Sweden.

Silver Instititute (2003). "Legislation Introduced to Study the Effectiveness of Silver-Based Biocides for Wood Preservation." Press Release, Washington DC, February 21.

Solo-Gabriele, H., Townsend, T., Khan, B., Song, J-K, Jambeck, J., Dubey, B., Jang, Y. (2003). Arsenic and Chromium Speciation of Leachates from CCA-Treated Wood, Florida Center for Solid and Hazardous Waste Management, Gainesville, FL, Report #03-07.

Solo-Gabriele, H., Townsend, T., Messick, B., and Calitu, V., (2001) Characteristics of CCA- Treated Wood Ash. *Journal of Hazardous Materials*, 89 (2-3): 213-232.

Solo-Gabriele, H.M., and Townsend, T., (1999). Disposal Practices and Management Alternatives for CCA-Treated Wood Waste. *Waste Management Research*, 17: 378-389.

Stillwell, D., and Gorny, K.(1997) Contamination of Soil with Copper, Chromium and Arsenic Under Decks Built from Pressure Treated Wood. *Bulletin of Environmental Contaminant Toxicology.* 58:22-29.

Tolaymat, T., Townsend, T., and Solo-Gabriele, H. (2000) Chromated Copper Arsenate-Treated Wood in Recovered Construction and Demolition Debris. *Environmental Engineering Science.* 17 (1): 19-28.

Townsend, T., Solo-Gabriele, H., Stook, K., Tolaymat, T., Song, J., Hosein, N., Khan, B. (2001) New Lines of CCA-Treated Wood Research: In-Service and Disposal Issues. Florida Center for Solid and Hazardous Waste Management. Gainesville, FL, Report #01-X.

Townsend T, Solo-Gabriele H, Stook K, Ward M (2003a) Leaching and toxicity of CCA-treated wood and alternative-treated wood products. Florida Center for Solid and Hazardous Waste Management. Gainesville, FL, Report # 02-4

Townsend, T., Solo-Gabriele, H., Tolaymat, T., and Stook, K., (2003c). "Impact of Chromated Copper Arsenate (CCA) in Wood Mulch." *The Science of the Total Environment*, 309: 173-185

Townsend, T., Solo-Gabriele, H., Tolaymat, T., Stook, K., and Hosein, N., (2003b). "Chromium, Copper, and Arsenic Concentrations in Soil Underneath CCA-Treated Wood Structures." *Journal of Soil and Sediment Contamination*, 12 : 779-798.

US EPA (1996). Test Methods for Evaluating Solid Waste, SW846, 3, *Office of Solid Waste and Emergency Response,* Washington D.C.

US EPA (2000). RCRA Orientation Manual EPA 530R-00-006 *Office of Solid Waste and Emergency Response, Washington D.C.*

US EPA (2002). Notice of Receipt of Requests to Cancel Certain Chromated Copper Arsenate (CCA) Wood Preservative Products and Amend to Terminate Certain Uses of CCA Products. *Office of Pesticides Washington D.C.,*.

WDNR. (2003). "Guidance on the Use of Leaching Test for Unsaturated Contaminated Soils to Determine Groundwater Contamination Potential." *PUBL RR-423-03*, *Wisconsin Department Of Natural Resources, Madison*.

Weber, J., Jang, Y., Townsend, T. and Laux, S. (2002) "Leachate from Land Disposed Residential Construction Waste." *Journal of Environmental Engineering*, 128(3):237-245**.**

Weis, P., Weis J.S. and Proctor T. (1993). "Copper, Chromium and Arsenic in Estuarine Sediments Adjacent to Wood Treated with Chromated-Copper Arsenate (CCA)*". Estuarine, Coastal and Shelf Science* 36, 71-79.

Table 1. Threshold Concentration of Contaminants for the Toxicity Characteristic under RCRA (40 CFR Section 261.31)

EPA Hazardous Waste No.	Contaminant	Regulatory Level (mg/L)	Total Concentration above which a solid waste may fail TCLP (mg/kg)
D004	Arsenic	5.0	100
D005	Barium	100.0	2000
D018	Benzene	0.5	10
D006	Cadmium	1.0	20
D019	Carbon tetrachloride	1.0	20
D020	Chlordane	0.03	0.6
D021	Chlorobenzene	100.0	2000
D022	Chloroform	6.0	120
D007	Chromium	5.0	100
D023	o-cresol	[2]200.0	4000
D024	m-cresol	[2]200.0	4000
D025	p-cresol	[2]200.0	4000
D026	Cresol	[2]200.0	4000
D016	2,4 D	10.0	200
D027	1,4-Dichlorobenzene	7.5	150
D028	1,2-Dichloroethane	0.5	10
D029	1,1-Dichloroethylene	0.7	14
D030	2,4 Dinitrotoluene	[1]0.13	2.6
D012	Endrin	0.02	0.4
D031	Heptachlor (and its epoxide)	0.008	0.16
D032	Hexachlorobenzene	[1]0.13	2.6
D033	Hexachlorobutadine	0.5	10
D034	Hexachloroethane	3.0	60
D008	Lead	5.0	100
D013	Lindane	0.4	8
D009	Mercury	0.2	4
D014	Methoxychlor	10.0	200
D035	Methyl Ethyl Ketone	200.0	4000
D036	Nitrobenzene	2.0	40
D037	Pentachlorophenol	100.0	2000
D038	Pyridine	5.0	100
D010	Selenium	1.0	20
D011	Silver	5.0	100
D039	Tetrachloroethylene	0.7	14
D015	Toxaphene	0.5	10
D040	Trichloroethylene	0.5	10
D041	2,4,5-Trichlorophenol	400.0	8000
D042	2,4,6-Trichlorophenol	2.0	40
D017	2,4,5-TP (Silvex)	1.0	20
D043	Vinyl chloride	0.2	4

[1] Quantitation limit is greater than calculated regulatory level. The quantitation limits therefore becomes the regulatory level.

[2] If o-, m-, and p-Cresol concentrations can not be differentiated the total cresol (D026) concentration is used. The regulatory level of total cresol is 200 mg/L.

Table 2A Summary of WET Limits
(Inorganic Persistent and Bioaccumulative Toxic Substances)

Contaminants[a b]	Soluble Threshold Limit Concentration (mg/L)	Total Threshold Limit Concentration wet-weight (mg/kg)	Total Concentration above which a solid waste may exceed STLC (mg/kg)
Antimony and /or antimony compounds	15	500	300
Arsenic and /or arsenic compounds	5	500	100
Asbestos	-	1.0 (as percent)	-
Barium and /or barium compounds (excluding barite)	100	10,000[c]	2000
Beryllium and /or beryllium compounds	0.75	75	15
Cadmium and /or cadmium compounds	1	100	20
Chromium (VI) compounds	5	500	100
Chromium and / or chromium(III) compounds	5[d]	2,500	100
Cobalt and/or cobalt compounds	80	8,000	1600
Copper and /or copper compounds	25	2,500	500
Fluoride salts	180	18,000	3,600
Lead and /or lead compounds	5	1,000	100
Mercury and/or mercury compounds	0.2	20	4
Molybdenum and/or molybdenum compounds	350	3,500[e]	7,000
Nickel and/or nickel compounds	20	2,000	400
Selenium and/or selenium compounds	1	100	20
Silver and /or silver compounds	5	500	100
Thallium and /or thallium compounds	7	700	140
Vanadium and /or vanadium compounds	24	2,400	480
Zinc and /or zinc compounds	250	5,000	5,000

[a] STLC and TTLC values are calculated on the concentration of the elements, not the compounds.
[b] In the case of asbestos and elemental metals, the specified concentration limits apply only if the substance are in friable, powdered or finely divided state. Asbestos includes chrysotile, amosite, crocidolite, tremolite, anthophyllite, and actinolite.
[c] Excluding barium sulfate.
[d] If the soluble chromium, as determined by determined by the TCLP is less than 5 mg/L, and the soluble chromium as determined by WET procedures equal or exceeds 560 mg/L and the waste is not otherwise identified as a RCRA hazardous waste, then the waste is non-RCRA hazardous waste.
[e] Excluding molybdenum disulfide.

Table 2B Summary of WET Limits
(List of Organic Persistent and Bioaccumulative toxic substances)

Contaminants	Soluble Threshold Limit Concentration (mg/L)	Total Threshold Limit Concentration wet-weight (mg/kg)	Total Concentration above which a solid waste may exceed STLC (mg/kg)
Aldrin	0.14	1.4	2.8
Chlordane	0.25	2.5	5
DDT, DDE, DDD	0.1	1.0	2
2,4-Dichlorophenoxyacetic acid	10	100	200
Dieldrin	0.8	8.0	16
Dioxin (2,3,7,8-TCDD)	0.001	0.01	0.02
Endrin	0.02	0.2	0.4
Heptachlor	0.47	4.7	9.4
Kepone	2.1	21	4.2
Lead Compounds, organic	-	13	-
Lindane	0.4	4.0	8
Methoxychlor	10	100	200
Mirex	2.1	21	42
Pentachlorophenol	1.7	17	34
Polychlorinated biphenyls (PCBs)	5.0	50	100
Toxaphene	0.5	5	10
Trichloroethylene	204	2,040	4,080
2,4,5-Trichlorophenoxypropionic acid	1.0	10	20

Table 3 Summary of Typical Water Quality Criteria for Groundwater (selected from Florida's Groundwater Cleanup Target Levels, Florida Administrative Code 62-777)

Contaminant	Criteria (mg/L)	Total concentration above which waste potentially exceeds criteria (mg/kg)	Contaminant	Criteria (mg/L)*	Total concentration above which waste potentially exceeds criteria (mg/kg)
Antimony	0.006	0.12	Total Nitrate and Nitrite	10 (as N)	200 (as N)
Arsenic	0.05 (0.01)	1 (0.2)	Selenium	0.05	1
Asbestos	7 MFL	-	Sodium	160	3200
Barium	2.0	40	Thallium	0.002	0.04
Beryllium	0.004	0.08	Benzene	0.001	0.02
Boron	0.63	12.6	Ammonia	2.3	46
Cadmium	0.005	0.1	Vinyl chloride	0.001	0.02
Chromium	0.1	2	2,3,7,8-TCDD (Dioxin)	3×10^{-8}	6×10^{-7}
Cyanide	0.2	4	Diquat	0.02	0.4
Fluoride	4.0	80	Pentachlorophenol	0.001	0.02
Lead	0.015	0.3	Chloride	250	5,000
Mercury	0.002	0.04	Copper	1.0	20
Nickel	0.1	2	Iron	0.3	6
Nitrate	10 (as N)	200	Silver	0.1	2
Nitrite	1.0 (as N)	20	pH	6.5-8.5	-
Total Dissolved Solids	500	10,000	Odor	3 (threshold odor number)	-
Carbon tetrachloride	0.003	0.06	Chlordane	0.002	0.04
Chlorobenzene	0.07	1.4	Paraquat	0.032	0.64
Chloroform	0.0057	0.11	1,2 Dichloroethane	0.003	0.06
1,4 Dichlorobenzene	0.075	1.5	Toluene	1.0	20
Endrin	0.002	0.44	Heptachlor	0.0004	0.008
Hexachlorobenzene	0.001	0.02	Hexacholorocyclopentadine	0.05	1
Lindane	0.0002	0.004	Methoxychlor	0.04	0.8
Trichloroethylene	0.003	0.06	Toxaphane	0.003	0.06

MCL = maximum contaminant level
MFL = million fibers per liter greater than 10 micrometers
mg/L = milligrams per liter
*except odor and pH

Table 4 Summary of Typical Clean Soil Criteria for Land Application (selected from Florida's Soil Cleanup Target Levels, Florida Administrative Code 62-777)

Contaminant	Direct Exposure (mg/kg)	
	Residential	Commercial/Industrial
Arsenic	0.8	3.7
Ammonia	550	3,700
Boron	7,000	160,000
Carbazole	53	190
Chromium (VI)	210	420
Copper	110	76,000
Dioxin (2,3,7,8-TCDD)	0.000007	0.00003
Iron	23,000	480,000
Lead	400	920
Paraquat	310	4,000
Pentachlorophenol	7.7	23
Selenium	390	10,000
Silver	390	9,100
Barium	110	87,000
Benzene	1.1	1.6
Cadmium	75	1300
Carbon tetrachloride	0.4	0.6
Chlordane	3.1	12
Chlorobenzene	30	200
Chloroform	0.4	0.5
1,4 Dichlorobenzene	6	9
1,2 Dichloroethane	0.5	0.7
2,4 Dinitrotoluene	1.3	3.7
Endrin	21	340
Heptachlor epoxide	0.1	0.4
Hexacholorobenzene	0.5	1.1
Hexacholoro-1,3 butadine	6.3	12
Hexacholoroethane	34	78
Lindane	0.7	2.2
Mercury	3.4	26
Methoxychlor	370	7,500
Nitrobenzene	14	120
Pyridine	13	95
Toxaphane	1	3.7
2,4,5 Trichlorophenol	6000	82,000
2,4,6 Trichlorophenol	72	180
Vinyl Chloride	0.03	0.04

Table 5. Summary of Preservative Types Evaluated

Wood Preservative	Preservative Components	Typical Concentrations of Components
CCA[1]	Chromium, Copper and Arsenic	Chromium = 1,900 mg/kg Copper = 1,100 mg/kg Arsenic = 1,710 mg/kg
ACQ[1]	Copper, Boron; Didecyl ammonium chloride (DDAC)	Copper = 3,800 mg/kg Boron = 480 mg/kg DDAC = 2,900 mg/kg=
Borate Preservative (Envirosafe™)[2]	TWP-27 (a patented formulation) with 0.84% Boron and 2.4% Silicon	Boron = 1,000 mg/kg Silicon = 2,800 mg/kg
Silver Based Preservative[3]	Silver based biocide	Silver = 1,000 mg/kg

[1] The concentrations for CCA and ACQ correspond to 0.25 pcf retention level
[2] Typical concentration measured in authors' laboratories
[3] Hypothetical scenario, not based on any proposed formulation

Table 6. Results of Waste Disposal Assessment

Evaluation Criteria	CCA (0.25 pcf)	ACQ (0.25 pcf)	Borate (0.28 pcf as DOT)	Silver-Based Preservative
Potential to be a Federal TC hazardous waste?	Yes	No	No	Yes
Potential to be a California TC hazardous waste?	Yes	Yes	No	Yes
Ratio of Leachate Concentration to Water Quality Criteria (5% chemical leaching)	As =86 Cr =48 Cu =2.8	Cu =9.5 B = 2	B = 4.2	Ag = 25
Ratio of Mulch Concentration to Soil Screening Level (10% treated wood in mulch)	As = 213 Cr = 0.9 Cu = 1	Cu = 3.5 B = 0.007	B = 0.014	Ag = 0.26
Ratio of Ash Concentration to Soil Screening Level (10% treated wood in wood fuel, 5% wood remains as ash)	As = 4275 Cr = 18 Cu = 20	Cu = 69 B = 0.14	B = 0.28	Ag = 5.1
Percentage of element that would have to leach from the ash to be a federal TC hazardous waste (10% treated wood in wood fuel, 5% wood remains as ash)	As = 2.9% Cr = 2.6%	Not applicable	Not applicable	Ag = 5%