12 Reuse and Disposal

Carol A. Clausen and Stan T. Lebow

Although preservative-treated wood is a durable construction material, it is eventually removed from service. The typical fate of treated wood removed from service varies depending on the original application and the type of preservative used. Currently, most treated wood removed from service in the United States is placed in landfills (Clausen 2003). Treated wood is not listed as a hazardous waste under federal law, and it can be disposed of in any waste management facility authorized under state and local law to manage such material. There is no doubt that as volumes of waste increase worldwide, landfill space diminishes, and associated costs increase, alternative disposal strategies for treated waste wood will become more attractive (Connell 1999).

As with many materials, the reuse of treated wood may be a viable alternative to disposal. In many situations, treated wood removed from its original application retains sufficient durability and structural integrity to be reused in a similar application. Generally, regulatory agencies also recognize that treated wood can be reused in a manner that is consistent with its original intended end use. Regulatory restrictions on preservative-treated wood directly impact retired or removed utility poles. The regulatory status of a pole removed from service must be determined to satisfy requirements for disposal (Mayer and Smith 1997). For example, if the pole is discarded, it must be treated as waste. Next, it must be determined whether or not the pole constitutes hazardous waste. The typical disposal method will be in a municipal or hazardous landfill or possibly incineration for co-generation of energy. However, if the pole is slated for reuse as fencing or landscape timber, it does not qualify as waste and is not subject to further classification. Secondary uses are common for utility poles (Mayer and Smith 1997).

Preservative-treated waste can be generally categorized as one of four types: creosote, pentachlorophenol, inorganic arsenicals, or alkaline copper preservatives. Each treatment category creates unique environmental and processing concerns warranting recycling options or processes that are designed for the treatment chemical, rather than the treated commodity (DeGroot and Felton 1995). There has been significant progress in developing options for reusing, recycling, or disposing of treated wood waste at the end of its initial or subsequent service life. However, technical problems and regulatory uncertainties have inhibited the development of a recycling industry for treated wood waste that is analogous to the growing non-treated wood recycling industry (Davis 1993). Typical and atypical disposal options and their feasibility will be discussed later in this chapter.

12.1 Logistics

12.1.1 Collection

Collection and recovery of treated wood waste have been the primary hindrance to implementation of recycling technologies. Treated wood is widely used in residential and nonresidential applications and is dispersed liberally in the United States. While preservative treatments have markedly extended our forest resource, treated waste wood is a bulky material with low value, which makes transportation and collection economically questionable even if systematic collection existed. Residential treated waste is usually not collected in a manner that separates preservative-treated material from other types of treated (e.g., paint, adhesives) or untreated construction waste.

The authors are, respectively, Project Leader and Research Scientist, U.S. Forest Products Laboratory, Madison, WI 53726.

The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin. This article was written and prepared by U.S. Government employees on official time, and it is therefore in the public domain and not subject to copyright.

The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

On the other hand, large quantities of relatively uniform composition, such as utility poles, highway fencing, and guard rails can more easily be collected following planned or scheduled removal and replacement (Connell 1999).

Few centralized collection sites exist. A collection system would have to be located in relatively close proximity to the source of treated waste (which is obviously more feasible for urban areas), have the capability to economically separate wood treated with various preservatives, sort preservative-treated materials from other construction wastes, and be associated with a viable recycling facility.

12.1.2 Waste composition

Lumber and timbers represent the greatest volume of treated wood, followed by ties and poles. Taken together, these commodities represent over 85% of the treated wood volume currently in service. Of an estimated 160 million utility poles in North America, approximately 80 million are treated with penta, 32 million with creosote, and 48 million with inorganic arsenicals (Morrell 2003). Based on survey results from utilities in the western United States, the pole replacement rate ranges from 0.5% to 0.7% per year (Mankowski et al. 2002). While the number of poles coming out of service for a particular treatment will shift as the preservative market evolves, the treated wood commodity continues to grow overall at a steady rate. Seventy-five percent of all wood treated between 1980 and 2004 will have been treated with inorganic arsenicals. Nearly all used chromated copper arsenate-(CCA) treated wood will consist of southern pine poles or lumber (DeGroot and Felton 1995).

An estimated 1.3×106 m^3/y of creosote-treated railroad sleepers and 2×106 m^3 of utility poles treated with penta and creosote came out of service and were available for recycling in 1996 (Felton and DeGroot 1996). Large quantities of material that is relatively uniform in composition can more easily be collected after planned or scheduled removal of commodities such as utility poles, highway fencing, and guard rails (Connell 1999). However, a great deal of treated waste wood is part of an assortment of mixed construction and demolition waste, including fasteners, paint, adhesives, etc. Due to its prominent use over the last three decades, CCA-treated wood will represent the largest single type volume of waste in the foreseeable future. Figure 12.1 shows the major product categories treated with waterborne preservatives, oil-borne preservatives, and creosote solutions (Micklewright 1998). While total volume of treated wood commodities has climbed steadily since Micklewright's report, the approximate distribution of major products and treatment types has remained relatively stable, with lumber and timbers accounting for 65%–70% of the total treated volume produced (98% treated with waterborne preservatives), crossties, switch and bridge ties accounting for 10-12% of the total volume (nearly 100% treated with creosote), and poles accounting for 8%–10% of the total volume of treated wood (50% treated with oil-borne preservatives and 15% treated with creosote). Other significant commodities including fence posts, plywood, pilings, specialty products, and landscape timbers each represent 1%–3% of the total volume of treated products. The distribution of products being put into service is an indicator of the type of treated wastes that will be coming out of service during the next few decades.

12.1.3 Transportation

The costs of transporting any bulky waste material to landfills continues to rise. For any recycling or reuse program to be successful, the economics of transporting waste wood needs to be weighed against the value of the secondary use or product and the costs, if any, of landfilling the waste.

12.1.4 Sorting

Preservative-treated wood in the waste stream greatly lowers the overall quality of waste wood, resulting in limitations to recycling wood waste in general (Solo-

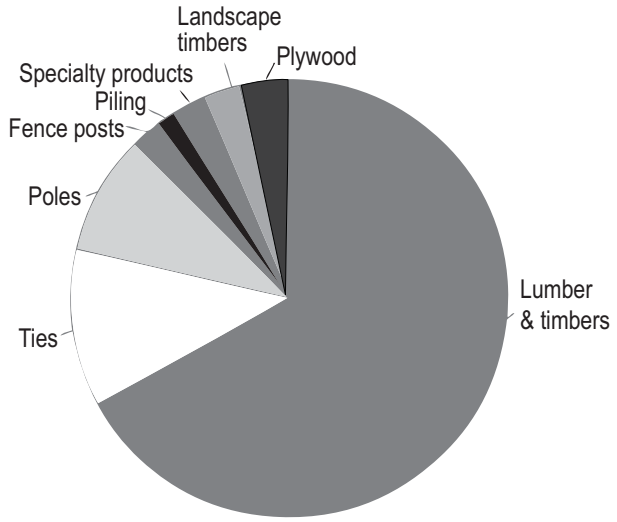

Figure 12.1 Relative volume of major product categories treated with waterborne preservatives, oilborne preservatives, and creosote solutions. Adapted from: Micklewright (1998).

Gabriele et al. 2003). Sorting, identifying, and differentiating waste wood, particularly weathered or dirty waste wood, is difficult at best. Except for wood treated with creosote, once treated wood has weathered, most treatments are impossible to visually distinguish from one another or from untreated wood. One of the most extensive programs to date on techniques to sort, identify, and differentiate treated wood waste was conducted by Solo-Gabriele et al. (2001). They evaluated the feasibility of visual sorting commingled and source-separated construction and demolition debris (C&D) wood, as well as using chemical stains, laser spectroscopy, and x-ray fluorescence to differentiate CCA-treated wood from other waste wood. Other research conducted by So et al. (2003) examined the use of near infrared (NIR) spectroscopy to identify waterborne and oil-borne preservatives. A brief description of these techniques and their findings follows.

12.1.4.1 Chemical stains

Several modified staining techniques have been evaluated for their ability to identify copper or arsenic in treated wood, with an emphasis on separating CCA-treated waste from other types of waste wood. Stains for identifying copper, such as chrome azurol, 1-2-(-pyridylazo)-2-naphthol (PAN) indicator, and rubeanic acid, have typically been used to determine the penetration of CCA preservative into freshly treated wood. Similarly, arsenic stains, such as stannous chloride and ascorbic acid stain have been used to detect the presence of phosphate in water. Of the copper stains tested, PAN was found to react quickly with metals in wood and produce a distinct magenta to red color reaction that could be easily identified in the field (Solo-Gabriele et al. 1999, Solo-Gabriele and Townsend 2002, Blassino et al. 2002). PAN stain was shown to be a useful tool for separating untreated wood from relatively uniform, source-separated, CCA-treated material. This method was less accurate for separating mixed materials because of false positive reactions with debris on the wood surface, as well as the interference of moisture resulting in failed reactions in wet wood (Jacobi et al. 2007b).

Both of the arsenic stains tested resulted in a blue color reaction if arsenate was present in wood. However, the presence of phosphate in untreated wood caused interference to varying degrees. The interference was minimized for the stannous chloride method by modifying the reaction to amplify the presence of arsenate, while diminishing the phosphate reaction (Omae et al. 2007). The resulting method was considerably more laborious than a spray technique, due to a requirement that sawdust or shredded wood be tested in solution.

Another method evaluated commercially available test kits for detection arsenic in drinking water. The kit was modified to convert arsenic from sawdust samples into arsine gas for a colorimetric reaction. The test kit was able to consistently provide positive reactions for sawdust from CCA-treated wood and negative reactions with untreated wood. Disadvantages included laborious sample preparation, long reaction time, and the need for trained personnel to conduct the analysis due to the generation of arsine gas. However, at a relatively low cost of $15–$35 USD to analyze 100 samples, the test kit may be useful for small applications or for use with other detection methods (Omae et al. 2007). Sorting techniques using chemical stains are very effective at spot-checking wood waste quality and differentiating CCA-treated wood on a small scale of a few tons or less, but they become economically impractical on a larger scale.

12.1.4.2 Laser spectroscopy

Laser-induced breakdown spectroscopy (LIBS) uses a high-powered laser directed at a wood sample surface to vaporize a small portion of that surface (Solo-Gabriele et al. 2006). The laser beam is directed towards the sample through a series of mirrors and lenses. At a set distance from the laser housing, the surface of the sample that is vaporized creates a micro plasma, and the light (i.e., energy) released from the microplasma is characterized by different wavelengths. Different wavelengths correspond to different elements; the intensity of a given wavelength emission is proportional to the amount of corresponding element that is present in the wood sample. It was determined that CCA-treated waste could be best determined by measuring chromium (to represent CCA) and calcium (to represent wood) peaks from the signal. Pilot-scale field trial results showed that LIBS was capable of high sorting efficiencies for treated wood with an analysis time of 5 s per sample. However, coatings suppressed the signals for chromium and calcium, and excessive moisture interfered with CCA detection.

12.1.4.3 X-Ray fluorescence

X-ray fluorescence technology (XRF) commonly used by the wood treating industry to check the quality of a treatment was evaluated by Blassino et al. (2002). An industrial instrument, the Spectro-ASOMA Model 400, utilizes a hand-held probe connected to a computer to detect the

presence of copper, chromium, and arsenic. Arsenic gave the strongest signal, with an average analysis time of 2 s per sample. In field trials where the head of the probe was mounted under a conveyer unit, the instrument could readily detect the presence of chromium, copper, and arsenic in wood. This method could differentiate between CCA-treated waste and other preservatives, such as ACQ and CBA, and could detect CCA in weathered or rotted material. Moisture, surface coatings, and defects in the wood (i.e., knots) did not interfere with XRF analysis. In a subsequent study using a handheld XRF device to analyze mulch samples for the presence of arsenic, it was reported that XRF analysis was effective for identifying mulch containing higher than 75 mg/kg arsenic (Jacobi et al. 2007a).

12.1.4.4 Near infrared (NIR) spectroscopy

Near infrared technology that is utilized by the forest products industry for property determination was coupled with multivariate analysis and evaluated as a potential method for analyzing treated wood. In preliminary studies, milled samples of treated wood were scanned using a Nexus FTIR spectrometer at wavelengths between 1000 and 2500 nm. The technique was able to differentiate wood treated with CCA, ACZA, and ACQ preservatives and also achieved separation according to wood species and assay zone (So et al. 2003, 2004). The NIR scanning system was then customized to develop a near infrared visual and automated numerical analysis (NIRVANA) to enable scans of cross sections of treated timbers using ACQ as a model system (So et al. 2006). NIRVANA was able to assess ACQ-treated timber to provide rapid and detailed analysis of the treatment. Subsequent research has also reported that NIR spectroscopy can successfully predict the borate retention in pine sapwood cubes (Taylor and Lloyd 2007). Research is continuing to assess the use of NIR to identify a range of preservatives and preservative concentrations in solid wood. A potential advantage of NIR spectroscopy, relative to elemental analysis techniques such as LIBS or XRF, is its ability to identify wood treated with organic (carbon-based) preservatives, although the low retentions used with some of the newer organic preservative systems may limit NIR applicability.

12.1.5 Practicality

On a large scale, Solo-Gabriele and others estimated that facilities handling greater than 8,000 tons of wood waste per year can separate CCA-treated wood from the waste stream economically with laser and x-ray detection systems (Solo-Gabriele et al. 2001). Preliminary results predict that NIR spectroscopy is promising as a rapid, nondestructive, portable, and relatively low-cost method for identifying both inorganic and organic preservatives (So et al. 2003), but more information is needed on its economic feasibility as a sorting method, and field trials are needed to assess the suitability of NIR separation of treated wood waste on a pilot scale.

12.2 Disposal Options

If one considers treated wood waste as a valuable resource, then more possibilities exist for disposal options that result in secondary commodities or energy generation. Regulatory questions, economics, and perceptions that the wood was once toxic have hindered development of a recycling industry for post-consumer treated wood (Felton and DeGroot 1996, Smith and Shiau 1998, Clausen 2002). Regulatory guidelines may change with time, but currently, treated wood is not considered hazardous waste and can be disposed in landfills. It will be extremely difficult for any alternative disposal option to economically overcome landfilling unless (1) regulations change, (2) landfill space becomes scarce, or (3) tipping fees are imposed that make alternative disposal options economically feasible. In an example of an economic assessment of Florida recycling efforts, stockpiling, and handling of construction and demolition wood was estimated at $5.00 USD/ton (Holton 2001), while visual sorting of source-separated wood was estimated to cost between $21 and $96 USD/metric ton, primarily due to the cost of labor (Jacobi et al. 2007b). Sorting untreated wood from CCA-treated material using a hand-held XRF raised the cost estimate to $113 USD/metric ton (Jacobi et al. 2007b). These estimates can be compared with Class I solid waste landfills tip fees at approximately $42.50/ton (Holton 2001). The perception that treated wood will always contain toxic components is the most difficult challenge to overcome for any remediation or recycling process. While remediation and recycling represent sustainable approaches to disposal of treated wood waste, the reality is that the most common methods for managing treated waste are landfill and combustion.

12.2.1 Landfill

The most common disposal method for treated-waste wood in the U.S. is landfilling in a C&D facility. However, C&D debris disposal is regulated by state agencies, so requirements can and do vary from state to state. A review

by Clark et al. (2006) showed that 23 states require liners for C&D disposal facilities, while 27 states require groundwater monitoring. In fact, worldwide, CCA-treated waste wood is typically classified as non-hazardous according to local definitions, so C&D landfilling remains the most economical option for disposal. Landfill access and availability nationwide provide a local option for disposal without adding to waste transportation costs.

There are several classifications of landfills. Depending on the hazard level of the waste to be contained in the landfill, they will either have a single, composite, or combination of multiple liners. Construction and debris landfills, if lined, have a single liner composed of clay, geosynthetic, or geomembrane materials, and are engineered to isolate construction and demolition debris from the environment (Hughes et al. 2005). Materials appropriate for C&D landfills include wood, concrete, asphalt, bricks, glass, and shingles, but exclude treated lumber, municipal waste, and paint. Composite liner systems (geomembrane in combination with clay) are more effective at limiting leachate migration into soil and are required for municipal solid waste (MSW). MSW may accept C&D waste, but not hazardous waste. Hazardous waste consists of materials that were once toxic, corrosive, ignitable, or reactive and pose a threat to human health and the environment if not properly managed. Hazardous waste must be disposed in a secure hazardous waste landfill. A secure hazardous waste landfill consists either of two single liners, two composite liners, or a single plus a composite liner (Hughes et al. 2005).

Older landfills were typically unlined and unregulated, and often contain a mixture of hazardous and non-hazardous waste. Because of the growing environmental concerns nationwide, some states, including Minnesota, have banned treated wood waste from unlined landfills; other states, such as Florida currently allow disposal of CCA-treated wood waste in Class I, II, or III landfills and C&D debris disposal facilities. Most Class III landfills and C&D facilities are unlined. Recently, changes to Florida's guidelines require that operators of unlined facilities "implement a program to remove CCA-treated wood from the waste stream prior to final disposal or use" (FDEP 2007, p. 3-4). Chemical leaching from any hazardous materials disposed in an unlined landfill risks contamination of groundwater and soil in the surrounding area.

While disposing of treated wood in landfills may currently be the most appropriate option for disposal in the U.S., landfill space is finite. The number of U.S. landfills declined from an estimated 20,000 in 1970 to 2,800 in 1995 because of landfill closures forced by stricter regulatory programs (Repa 2005). Accordingly, landfill ownership has shifted from the public sector to the private sector. At the same time, overall national disposal capacity has increased during the past decade.

12.2.1.1 U.S. regulatory guidelines

Treated wood that is removed from service and has no secondary application is considered solid waste and is generally not classified as hazardous waste in the U.S. at the federal level (Felton and DeGroot 1996). Penta- and creosote-treated wood typically pass the toxicity characteristic leaching procedure (TCLP) limits in the U.S. Code of Federal Regulations 40 part 260 (EPRI 1991, Goodrich-Mahoney et al. 1994). Because the chemical components of CCA are bound to the wood structure, CCA-treated wood is excluded from this limit. Implementation of the Environmental Protection Agency's (EPA 1995) Universal Waste Rule simplified recycling regulations for certain hazardous wastes, with the intention of increase recycling (Felton and DeGroot 1996).

Many states follow federal guidelines for classification and disposal of treated wood. However, in addition to federal regulations, states and local agencies may impose their own regulations on disposal of treated wood products (WWPI 2008). For example, California has adopted its own regulations on the designation of hazardous waste that exceed federal regulations. The California Environmental Protection Agency has issued variances on state legislation, however, that allow the disposal of treated wood as nonhazardous material if provisions are met (WWPI 2008). These provisions provide for reuse or recycling and allow for disposal in solid waste landfills that meet particular requirements for leachate collection, liners, and waste discharge management, depending on the commodity. Additionally, some local Regional Water Control Boards in California impose their own restrictions on waste management facilities. Minnesota has imposed a ban on treated wood waste entering unlined landfills (MPCA 2009), and recent changes by Florida Department of Environmental Protection dictate that CCA-treated wood waste should not be recycled as mulch or used for fuel unless the combustion facility is authorized to accept CCA-treated wood (FDEP 2007). Washington and Oregon have separate rules for the designation and disposal of treated wood, but revisions to state regulations in 1994 have effectively excluded treated wood waste from those rules (WWPI 2008).

12.2.1.2 International regulatory guidelines

Worldwide, regulatory guidelines for the disposal of treated wood vary greatly. Within the European Union, regulations vary from highly regulated to virtually no regulation at all (Humar et al. 2006). Currently, most treated wood is disposed in landfills, but there is a movement to reduce biodegradable waste as directed under the EEC Landfill Directive (1999). Aims of the Landfill Directive in the order of priority include (1) reducing waste generation, (2) reusing waste materials, (3) recycling waste materials, (4) recovering waste for energy or composting, and (5) disposal through incineration or landfilling. While untreated wood waste will continue to be disposed by incineration or landfill, CCA- and creosote-treated wood are classified as hazardous waste under this directive.

No specific regulations govern the disposal of CCA-treated wood in Japan although the Japan Construction Materials Recycling Act of 2001 requires CCA-treated wood to be disposed in an appropriate manner (Hata et al. 2006). Most treated wood waste is currently incinerated, due to limited landfill space and limitations on recycling technology.

Overall, no strict regulation for the disposal of CCA-treated wood is in place in Australian states (Hata et al. 2006). Small quantities of CCA-treated wood are generally accepted in landfills. Disposal of larger quantities of treated waste must occur at designated authorized landfill sites, and industrial sources of CCA-treated waste may require additional approval from state or local governments. Reviews by the EPA's for each state may result in future restrictions on landfills (Taylor et al. 2004).

Currently there are no regulations regarding the disposal of treated wood in India (Hata et al. 2006), and discarded CCA-treated wood products, which are not classified as hazardous waste, are mixed with other types of wood waste and recycled (50%), incinerated (35%), or disposed of in landfills (15%). Most common disposal options are incineration (Japan, Korea) and landfill (Australia), while recycling and reuse occur less often, due to difficulties in separating treated wood from other wastes (Hata et al. 2006).

12.2.1.3 Tip fees

Cost offsets for alternative disposal programs need to take landfill tip fees into consideration. Landfill tipping fees in the U.S. increased at a rate of 7% annually until 1998, when the fees leveled off at about $32 per ton (Repa 2005). Further increases are likely in the future. Landfill tip fees historically have been lower than incinerator tip fees, and this trend is not expected to change in the future (Figure 12.2).

12.2.1.4 Landfill capacity

One of the concerns associated with landfill disposal of treated wood is that large volumes of CCA-treated wood removed from service could strain landfill capacities (Felton and Degroot 1996, Solo-Gabriele and Townsend 2002, Jambeck et al. 2007). However, at this point, it is difficult to associate the disposal of treated wood with shortages in landfill capacity, despite predictions that volumes of CCA-treated wood removed from service could peak as early as 2008 (Jambeck et al. 2007). The impact of treated wood on landfill volume may be obscured because treated wood represents only a small fraction of the total volume of wood placed in landfills each year, and an even smaller fraction of overall volumes of waste (Falk 1997).

12.2.1.5 Groundwater contamination

Several laboratory leaching or lysimeter studies have suggested that the release of arsenic and heavy metals from treated wood in landfills could potentially lead to groundwater contamination (Solo-Gabriele and Townsend 2002, Townsend et al. 2004, Jambeck et al. 2006). Disposal practices in the state of Florida were considered a potential worst-case scenario for groundwater contamination because of the large volumes of treated wood used in Florida, the naturally occurring high water tables in that state, and because Florida allows the disposal of wood waste in unlined landfills (Solo-Gabriel and Townsend 2002, Townsend et al. 2004). However, a recent study of groundwater monitoring data did not indicate that arsenic from unlined C&D landfills leached into nearby groundwater (Saxe et al. 2007). A broader review of the composition of

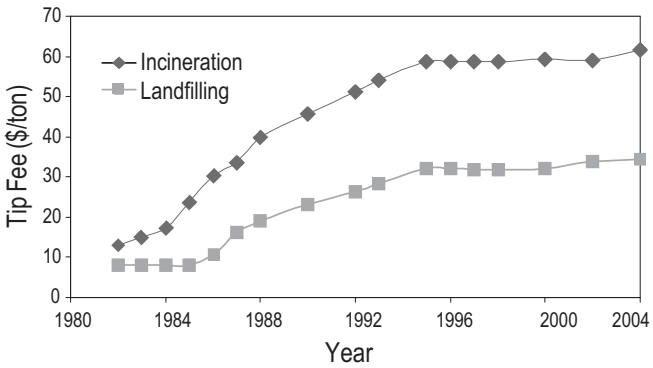

Figure 12.2 U.S. landfill vs. incineration tip fees (Repa 2005).

landfill leachates also reports that releases of arsenic and heavy metals from landfills is low, possibly because of the precipitation and complex formation processes that take place within the landfill (Kjeldsen et al. 2002). The apparent disconnect between laboratory studies and field observations may result from difficulties in simulating landfill leaching conditions. Because leaching from treated wood is a function of surface area, leaching from small blocks or small particles, such as those used in the EPA's TCLP, is many times greater than that from commodity-size material removed from service (Lebow et al. 2000, Lebow et al. 2006). The lack of moisture and water movement in landfills is also likely to limit leaching in comparison to wood immersed in a leaching solution. Much of the moisture present in landfills comes from the waste source. While the estimated average moisture content of landfill waste is 22%, the moisture content of landfilled wood averages 15%. Thus, in a typical "dry" landfill there is not sufficient moisture for wood products to decay (Micales and Skog 1997). It is also possible that it is too soon to observe the effects of treated-wood disposal in landfills. In their review of studies on landfill leachates, Kjeldsen et al. (2002) postulate that it may take many thousands of years before any enhanced release of heavy metals from landfills is observed.

There remains the major disadvantage that landfill disposal does not derive any benefit from either the wood fiber or the preservative components. Considering landfill disposal as a viable option does provide a baseline for comparing the relative costs and benefits of other disposal methods, however. Although recycling or reusing treated wood is intuitively appealing, it is possible that some alternative approaches could have greater environmental impacts than landfilling. Most of the proposed alternatives will require substantial energy inputs for sorting, transportation, and communition, and most will also create air- or waterborne emissions as byproducts of processing.

12.2.2 Incineration/Co-generation

Disposal of treated wood via combustion offers the advantage of waste volume reduction while generating electricity. Wood has a good calorific value and provides a useful fuel, if combustion conditions are optimal for complete combustion with low emissions into the atmosphere (Connell 1999). Combustion has been a viable option for creosoted sleepers, poles, and timbers for many years (Conlon 1992, Kempton 1992, Webb and Davis 1992). There are a number of facilities licensed to incinerate creosote-treated wood throughout the U.S. (Morrell 2003). Unlike creosote incineration, penta combustion can produce dioxins; most facilities that burn wood carefully limit the percentage of penta-treated wood that they burn in order to avoid exceeding emission limits (Smith 1992, Karakash and Lipinski 1998). A fair amount of research on the combustion of CCA-treated waste has evaluated the release of arsine into the atmosphere and the amount of copper, chromium, and arsenic retained in the ash from laboratory to industrial scale (Curzon and Eisner 1953, Watson 1958, Dobbs and Grant 1976, Dobbs et al. 1978, McMahon et al. 1986). The primary problem with the combustion of wood treated with inorganic arsenicals is the production of arsine gas. In a laboratory study, Pasek and McIntyre (1993) proposed conditions for the incineration of CCA-treated wood in which arsenic volatilization would approach zero. Those conditions are limited air flow and combustion temperatures in excess of 1100°C. Another study that evaluated emissions from burning waterborne, copper-based non-arsenicals at 800°C, determined that the environmental impact of gases consumed and released from this type of treated waste were comparable to those of untreated wood (Cornfield et al. 1993). The other option is to trap and remove vaporized arsenic with scrubbers. Martusky (1992) and Martusky and Strecher (1992) proposed that gasifier and fluidized bed reactors have the potential for high quality combustion with low emissions, the reduction of toxic halogen compounds, and limited heavy metal emissions. The trade-off for reduced volume is ash containing high levels of metals that must be disposed of.

The three types of thermochemical processes for converting wood waste into energy—incineration, gasification and pyrolysis—are reviewed in detail by Helsen and Van den Bulck (2006). Some of the advantages and disadvantages of each process are described in Table 12.1 (Helsen and Van den Bulck 2006). Incineration generates energy for immediate use as heat or power that has a relatively low efficiency compared to thermochemical processes that produce secondary fuels. One of the disadvantages of incineration is the requirement for an appropriate gas-cleaning system to control air emissions. Arsenic collected from a scrubber can technically be recycled for reuse in a CCA treatment solution. Ash containing arsenic, copper, and chromium could be recycled by chemical or electrochemical processes (Syrjanen and Kangas 2001, Kristensen 2002, Linroos 2002). Incineration is a viable option for the disposal of CCA- or penta-treated wood, provided that arsenic, dioxins, or polychlorinated dibenzofurans emis-

Table 12.1 Comparative advantages and disadvantages of pyrolysis (slow and flash), incineration, coincineration and gasification utilizing CCA-treated wood waste as feedstock. *Adapted from:* Helsen, L. and Van den Bulck, E. (2005)

Technology	Disadvantages	Advantages
Slow pyrolysis	Arsenic volatilization	Lower amount of As volatilization than combustion; may be easier to capture
Flash pyrolysis	5%–18% As in the pyrolysis oil	
Incineration	Extensive gas cleaning equipment needed Problems with occupational health	Can be coupled to metal recycling processes
	Ash treatment needed	
	No production of secondary fuels; heat must be used or converted immediately	
Coincineration	Emissions are still high	Economy of scale
	Higher As concentration in the bottom ash compared to combustion	Low investment cost
	Volatile As has to be removed from larger amount of flue gas	Short-term design and installation
		Highly flexible with respect to feedstock As may be scavenged by other compounds Easy to comply with emission legislation (dilution effect)
Gasification	Requires gas cleaning equipment	Higher energy efficiency
	Critical point: all As released in metallic form and all As captured	Lesser amount of fuel to be cleaned compared to combustion
	High cost due to the need for high temperature and fine particles	No PCDD/F formation
	Not yet proven at pilot scale	Recuperation of metals and fuels possible

sions are avoided through appropriate cleaning systems, and that arsenic captured in solution, dust, or ash is recycled or disposed in a responsible manner (Helsen and Van den Bulck 2006).

An industrial-scale incineration operation, called Chartherm®, handles all types and sizes of treated wood waste, including those containing paint and adhesives (Hery 2005). Chartherm® is a three-step process involving grinding, thermally treating, and separation of ash. The process reportedly produces carbon with a calorific content of 6500 kcal/kg that can be used as fuel. Separated waste containing the heavy metals is reduced to less than 3% of the initial wood mass by the Chartherm® process.

While arsenic recovery from coincineration ash and emissions is equally problematic to arsenic recovery from incineration, coincineration may present the best thermochemical solution for treated wood waste (Helsen and Van den Bulck 2006). Many coincineration plants exist, so that adaptation with scrubbers can be achieved with a relatively low investment. Coincineration accepts a variety of wastes and can serve to dilute CCA metals in a mixed fuel stock, making it easier to comply with air emissions standards.

Gasification generates fuel gas with variable heating value depending on the type of gasification. Gasification generally yields higher energy with lower environmental impact than incineration. Gasification of treated wood waste requires a gas-cleaning system to remove arsenic from CCA-treated waste, but the resulting syngas to be cleaned will be less than for an incineration process (Nurmi 1996). High-temperature gasification (1100°C to 1500°C) may cause formation of metallic arsenides, which are easier to capture than the trivalent form and can be recycled. The high temperature needed for this process is a disadvantage unless the syngas that is produced can be used to provide the heat required to drive the process. Gasification of treated waste wood has not been scaled up to a pilot scale.

Pyrolysis generates one of three products: solid charcoal, pyrolysis oil, or pyrolysis gas, depending on the temperature and heat rate used. Low temperature and slow heating results in high charcoal production, while high temperature and fast heating rates result in high liquid production.

Much literature exists on pyrolysis, gasification, and incineration combustion of CCA-treated wood and has reported on the fraction of arsenic, copper, and chromium released to the atmosphere and retained in the ash (Helsen and Van den Bulck 2005). Research varies from laboratory

scale to industrial scale and includes both pure sources of CCA-treated wood and mixtures with other wood sources or industrial wastes.

While the arsenic volatilization rate reported varies considerably depending on temperature, residence time, time of heating, air flow, and the impregnation process, there is general agreement that arsenic is the problematic compound in any thermochemical conversion process. The release of arsenic is controlled by the reduction of pentavalent arsenic to trivalent arsenic. The reduction of pentavalent arsenic to trivalent arsenic is hastened by the presence of reducing compounds in pyrolyzing wood, and, once that happens, arsenic trioxide will be released at temperatures as low as 200°C (Helsen and Van den Bulck 2006). Arsenic capture devices include alkali-impregnated filters, scrubbers, or sorbents such as fly ash, activated carbon, or mineral materials like hydrated lime or limestone.

The ideal goal is to capture and recycle the metals while generating energy, though these technologies have not yet been proven. The bottom line is that before adopting any thermochemical technology, the high initial cost of facility, reactor, and scrubbers must outweigh the high cost of collecting and transporting the waste wood. In comparison, the cost of landfilling treated wood waste material is currently inconsequential.

12.2.3 Compost/fungal remediation

Composting municipal waste involves a complicated succession of microbes, including anaerobic and aerobic bacteria, mold, and decay fungi. Since preservative-tolerant anaerobic and aerobic bacteria, mold, and decay fungi can be readily isolated from soil (Cole and Clausen 1997), one can assume that treated wood may also undergo a unique microbial succession involving this subset of soil microbes. Although treated wood in the anaerobic environment of a landfill does not readily deteriorate, metals may be more easily released by the indigenous microbial population in a landfill. Those same preservative-tolerant microbes have been isolated and studied for the potential to compost treated waste wood.

Hence, fungal remediation is simply sophisticated composting. Many decay fungi are tolerant of preservatives and produce significant quantities of oxalic acid. Because oxalic acid reacts with copper to form an insoluble precipitate, metal tolerant decay fungi possess the ability to chemically extract copper, chromium, and arsenic from CCA-treated wood. Metal tolerant fungi were first used by Peek et al. (1993) to remove copper, chromium, and arsenic from CCA-treated wood. The objective of their study was to compost the residual fiber once the metallic components were removed, thereby reducing the volume of waste. Leithoff and Peek (1998) showed that while this method of remediation worked well in the laboratory under sterile conditions, scale-up trials were less successful.

The disadvantages of fungal remediation are as follows: (1) reduced wood volume results in highly concentrated arsenic, copper, and chromium, since the metals are released but presumably not altered; (2) there is no published information to confirm the valence state (i.e., toxicity) of metals released from treated wood by this process; (3) the process lacks precise control over the inoculation, incubation, temperature, and moisture required for batch-to-batch consistency; (4) growth of decay fungi is slow; (5) the process lacks methods to prevent contamination by molds that can quickly outcompete growth of decay fungi—molds are readily able to grow on treated wood; and (6) wood fiber would be deteriorated by decay fungi during the remediation process, and therefore, the process lacks the ability to recycle wood fiber into secondary products.

12.2.4 Reuse/recycle

12.2.4.1 Secondary use

Reuse or giveaway programs have played an important role in disposal of used utility poles or rail sleepers for decades, but the practice is becoming restricted (Felton and DeGroot 1996, Morrell 2003). Some utility companies are requiring recipients of used materials to sign a liability release form that outlines proper handling procedures for these used commodities. There are numerous, safe, secondary uses for large, treated commodities such as poles, posts, and sleepers. But legitimate concerns exist because of the lack of education about the chemicals in the wood. Primary concerns include burning, and inappropriate use near water or in enclosed spaces. Reusing wood treated with pentacholorophenol, either in a giveaway program or recycled product, technically has to follow the EPA's directive for the use of the original product (DeGroot and Felton 1995). That directive prohibits frequent or prolonged contact with bare skin; use in residential, industrial, or commercial interiors (with some exceptions); in containers for storing animal food; or in cutting boards or countertops. Creosote-treated sleepers would be subject to similar restrictions. Although the reuse of creosote-treated timbers

is common, it is not encouraged. Creosote-treated wood is also frequently burned for energy generation. Since wood treated with waterborne arsenicals may be used in building interiors and is permissible in situations where there is frequent contact with humans, reuse programs face fewer restrictions, with the exception of the dangers of burning CCA-treated wood. For example, active reuse of CCA-treated timber in horticultural or agricultural applications is common in the U.S. and some European countries. A number of reuse and recycling options are described below and some tangible products from applying those processes to CCA-treated wood are shown in Table 12.2.

12.2.4.2 Size reduction: Remilling and comminution

There are several categories of size reduction that are particularly applicable to large, uniform commodities such as timbers or poles. Remilling refers to resawing or shaving the shell treatment off large commodities, such as treated poles or large timbers, to yield an untreated core that can then be further reduced into secondary untreated products or retreated for a secondary application (Clausen 2003). Comminution refers to the reduction of wood into particles or flakes by grinding or pulverizing large commodities with a hammer mill. Comminuted material can then be remediated to remove the preservative treatment or reconstituted (i.e., refabricated) into secondary composite products without removing the preservative treatment.

A significant portion of the waste wood resource is large poles and timbers that are suitable for remilling (Felton and DeGroot 1996). Because the heartwood of most wood species is not penetrated during the treatment process, removal of the outer shell treatment results in untreated wood cores of more durable heartwood that can be utilized in secondary applications. This is particularly true for wood species with little sapwood in proportion to the heartwood, such as western redcedar. Large commodities, such as poles have the potential to be remilled into high-value decking, posts, or sawn lumber (Cooper 1993). In one example, a remanufacturing program evaluated the viability of lumber recovery from out-of-service western redcedar and Douglas-fir poles (McLearn et al. 2008). Another example of remilling is that of a Canadian utility company shaving the sapwood off penta-treated western redcedar utility poles using commercial equipment (Ainsle and Rasmussen 1994). Shaved poles are then retreated and returned to service.

Comminution of treated waste wood prepares the material for biological or chemical remediation or fabrication into composites. Except for flakes, which require large, uniform commodities, the comminution of treated wood into particles or fibers can be achieved with current technology to reduce wood (Davis 1993, Smith and Boley 1993). The primary drawbacks to comminution of treated wood are energy use and the creation of airborne particles. The limits for exposure to compounds in preservative-treated wood are regulated by the Occupational Safety and Health Administration (OSHA). Wood dust particles from arsenically treated wood share similar low-concentration exposure limits with untreated western redcedar. Additional concerns exist for worker exposure to fumes if heat generated by the blades of the comminution equipment vaporizes organic preservatives or if high press temperatures during composite fabrication vaporize organic preservatives (Felton and DeGroot 1996). Additionally, metal fasteners and hardware pose a major problem for milling equipment and must be removed before processing. Some comminution processes are water-based and may require wastewater treatment before discharge.

12.2.5 Reconstitute

Recycling treated waste into composite products is an attractive option that is technically feasible, according to the results of a questionnaire about attitudes in the wood composite industry (Smith and Shiau 1998). This technology is generally limited to wood waste treated with inorganic arsenicals because the hydrophobic nature of creosote and penta-treated wood inhibit the ability of the adhesive to wet the surface of normally hydrophilic wood fibers (Felton and DeGroot 1996). During the 1990s, a great deal of research was conducted on reconstituting comminuted treated wood with untreated wood, cement, or

Table 12.2 Tangible products from reused CCA-treated wood (Clausen 2003).

Method	Products
Size reduction	
Shaving, resawing, remilling	Decking, poles, posts
Reconstituted composites	
Wood/wood composites	Flakeboard, OSB, particleboard, MDF, glulam
Wood/cement composites	Sound barriers, structural forms
Thermoplastic composites	Specialty products
Remediation	
Chemical extraction, bioleaching, chelation	Composite products, paper products
Liquefaction	Polyurethane products

plastic in various proportions to create secondary products. Successes in creating reconstituted products from treated waste wood have been mixed. Primary concerns are worker safety and potential environmental problems from secondary products both during service and following service.

12.2.5.1 Wood/cement composites

Because of their good insulation and mechanical properties, cement-bonded composites are widely used in interior and exterior commercial and industrial building applications (Clausen 2003). The hydration properties of cement make it compatible for bonding with CCA-treated southern yellow pine (Hsu 1994, Smith and Shiau 1996, Huang and Cooper 2000); and the resulting particleboard possessed good mechanical properties (Hsu 1994, Schmidt et al. 1994, Huang and Cooper 2000, Zhou and Kamdem 2002). A study by Qi and Cooper (2000) revealed higher than normal leaching of chromium from wood/cement composites. They showed that trivalent chromium was apparently converted to the more leachable and toxic hexavalent form of chromium, which accounted for approximately 80% of the chromium leached from the composites. Considerable research has since been conducted on the ratio of wood to cement, addition of super-plasticizers, injection of CO_2 to accelerate cure rate, and altering the water/cement ratio to control chromium leaching (Cooper et al. 2003). Advances in this technology have improved leaching properties of metals, and the particleboard has inherent resistance to decay, fire, and weathering, and has high dimensional stability (Huang and Cooper 2000, Clausen 2003, Cooper et al. 2003). The disadvantages of this method of recycling CCA-treated waste wood include the long cure time for the composite and continuing concern over leachable hexavalent chromium from the product.

12.2.5.2 Wood/wood composites

Poor bonding of treated wood with commercial adhesives has hampered the development of composite products from CCA-treated waste wood (Vick 1995, Vick et al. 1996). Munson and Kamdem (1998) reported on the potential for waste CCA-treated red pine poles to be reconstituted into particle board. They showed that 50% CCA furnish can be used without adversely affecting panel properties. This finding was supported by subsequent research evaluating flakeboard prepared from varying ratios of CCA-treated and untreated southern pine (Shupe and Hse 2003). The resulting composite could be used for sheathing or flooring where there is an increased risk of decay. Flakeboards have also been produced from recycled CCA-treated southern pine, using polymeric methylene diphenyl diisocyanate (pMDI) or phenol-formaldeyde (PF) adhesives and common flaking techniques (Mengeloglu and Gardner 2000). Their research showed that flakeboard bonded with pMDI displayed significantly better mechanical properties and internal bond strength than did boards bonded with PF resin. In a similar study on flakeboard fabrication with CCA-treated wood, Vick et al. (1996) showed that mechanical properties were enhanced by spraying the flakes with a 5% solution of hydroxymethylated resorcinol primer prior to spraying and blending with PF resin.

12.2.5.3 Wood/plastic composites

CCA-treated wood flour has been blended with high-density polyethylene and compression molded into composite boards (Kamdem et al. 2004, Kamdem 2006). Boards were subjected to a battery of tests for physical and mechanical properties (MOE, MOR, compression strength, thickness swelling, internal bond) and leach tests. The physical and mechanical properties of wood-plastic composites in their study were acceptable. The amount of arsenic, chromium, and copper leached increased during the first 400 h, then decreased to negligible levels after 1000 h. Leached arsenic greatly exceeded the allowable limit for drinking water and would have to be addressed for further development of this technology.

12.3 Remediate

12.3.1 Chemical, biological and thermal extraction

A number of researchers have evaluated chemical extraction primarily as a means of removing copper, chromium, and arsenic from CCA-treated wood. Chemical extraction with acids and oxides essentially reverses the CCA fixation process by increasing the solubility of the metals (Clausen 2003). Numerous studies showed that oxalic, citric, acetic, nitric, formic, and sulfuric acids removed varying amounts of metals from CCA-treated wood (Cooper 1991, 1993; Kim and Kim 1993; Pasek and McIntyre 1993; Stephan et al. 1993, 1996; Clausen and Smith 1998; Kazi and Cooper 1998). Warburton (1990) and Honda et al. (1991) found that CCA components could be completely digested with sulphuric acid under specific conditions of temperature and wood component size. Many of the reported tech-

niques require days or weeks to effectively remove metals from treated wood. Kazi and Cooper (1998) succeeded in removing 94% of the metals from treated sawdust with hydrogen peroxide heated to 50°C. Kakitani et al. (2006, 2007) reported nearly 100% extraction in a matter of hours in sodium oxalate and oxalic acid at 75°C.

The chronic problem with all chemical extraction procedures is ensuring equivalent extraction efficiency for all three metal components. Traditionally, chemical extractions have efficiently removed arsenic and chromium, particularly at pH 1.4 to 2.4, whereas copper extraction is more efficient at pH 2.2 to 5.2. Sabo et al. (2008) successfully incorporated a pH shift into a two-stage thermochemical remediation process for CCA-treated spruce flakes to address this issue. Hydrothermal treatments, which utilize temperatures in excess of 300°C and pressure in excess of 100 bar, have shown promise in removing both creosote and pentachlorophenol from treated wood (Catallo and Shupe 2003, Catallo et al. 2004, Catallo and Shupe 2008). The use of acidified water and slightly higher temperatures and pressures resulted in the removal of 48%–88% of metals from CCA-treated wood (Catalo et al. 2004, Catallo and Shupe 2008). A more comprehensive review of chemical extraction technologies can be found in Shupe and Hse (2006).

Another approach is extraction utilizing microorganisms that are tolerant of heavy metals to bioleach metals from treated wood. Bioleaching or bioremediation of treated wood depends on a number of variables: the microorganism(s), preservative treatment, wood geometry, culture conditions, and duration. It was demonstrated by Clausen (2000) that oxalic acid extraction followed by bioleaching with a metal-tolerant bacterium removed 80%–100% of CCA components into a liquid medium, where they could be recovered and reused. The resulting remediated wood was fabricated into particleboard and flakeboard panels with properties that met ANSI standards (1993). The main advantage of all extraction techniques described here—chemical, biological and thermal—is the complete recovery and reuse of the CCA components and the wood fiber resource. The primary disadvantages—the cost for chemicals, growth medium, and energy to heat the process—have hindered development of this technology. Some of these technologies have been demonstrated on a pilot scale (Sabo et al. 2009, Clausen and Kenealy 2004).

12.3.2 Liquefaction

Liquefaction, a novel method for recycling CCA-treated waste wood, first converts the waste into a liquid using polyethylene glycol and glycerin, with heat and sulfuric acid as a catalyst (Lin and Hse 2002). Hazardous components are separated from the liquefied wood by precipitation with complexing agents. This method removes 85% of the CCA, which can be recaptured and reused for wood treatment. The resulting digested wood solution can be used in the manufacture of secondary products such as polyurethane materials. High costs for the chemical catalyst, complexing agent, and heat to drive the process are disadvantages of this technology.

12.3.3 Chelation

Chelation combines citric acid extraction with the chelating agent, ethylenediaminetetraacetic acid (EDTA). Between 95% and 100% CCA could be removed from 2 × 4s and pole sections without size reduction of the commodity (Kamdem et al. 1998). The chelation reaction takes place at low pH and temperatures ranging from 80°–100°C. EDTA, a common chelator used to bind metals into stable complexes, has been utilized to remediate heavy metal contaminated soil. Kartal (2002, 2003) also evaluated EDTA and showed that the low pH of EDTA solutions (2.2 to 3.2) facilitates copper release, suggesting that EDTA can play an important role in the remediation of waste wood that has been treated with organometallic copper formulations.

An example of similar technology has been put into practice in Europe. Due to restricted landfill options and the large number of utility poles discarded each year in Italy, a chelation process has been developed to commercial scale for the recovery of CCA from treated poles (Gasco 1996). Chemically extracted CCA is recovered and reused to prepare fresh treatment solutions, and sound sections of over 75% of the poles can be reused. Although metal recovery is outside the purview of this chapter, remediation processes that result in the recovery of metals for reuse should be beneficial to the economics and feasibility of the overall process. The primary advantages of chelation are the remediation of dimension lumber and poles without the need for size reduction, and simplified metal recovery in sludge. The primary disadvantage is the need for energy to drive the process.

12.4 Summary

While remediation and recycling methods are all technically feasible either at the bench or pilot scale, most remain economically unfeasible, and the incentive for putting them into practice is low. Centralized collection, sorting, and transportation to dedicated facilities are primary disincentives to the practical application of most alternative recycling or remediation methods. Beyond those, secondary disincentives include any manipulation of the waste, such as multi-step processes, heat or chemical additions, special handling requirements, or size reduction.

At the time of this writing, landfill and incineration remain the most economically feasible options for the disposal of treated wood waste. Regulatory changes and dwindling landfill space could alter that option in the future. Waste wood could become a valuable commodity if new technologies to improve the efficiency of converting wood to bioenergy are successful.

References

Ainsle, S., and Rasmussen, J. 1994. Life-cycle management of treated wood poles. Proceedings, International Conference on Wood Poles and Piles, Colorado State University, Fort Collins, CO, pp. 143–154.

American National Standards Institute (ANSI). 1993. Particleboard. (ANSI) A208.1-1993, National Particleboard Association, Gaithersburg, MD.

Blassino, M., H.M. Solo-Gabriele, and T. Townsend. 2002. Pilot scale evaluation of sorting technologies for CCA treated wood waste. Waste Manage. Res. 20:290–301.

Catallo, W.J., and T.F. Shupe. 2003. Hydrothermal treatment of creosote-impregnated wood. Wood Fiber Sci. 35:524–531.

Catallo, W.J., and T.F. Shupe. 2008. Hydrothermal treatment of mixed preservative-treated wood waste Holzforschung. 62:119–122.

Catallo, W.J., T.F. Shupe, and R.P. Gambrell. 2004. Hydrothermal treatment of CCA- and penta-treated wood. Wood Fiber Sci. 36:152–160.

Clark, C., J. Jambeck, and T. Townsend. 2006. A review of construction and demolition debris regulations in the United States. Crit. Rev. Env. Sci. Tec. 36:141–186.

Clausen, C.A. 2000. CCA removal from treated wood using a dual remediation process. Waste Manage. Res. 18:485–488.

Clausen, C.A. 2002. Semi-solid state bioremediation of CCA-treated wood using malted barley as a nutrient source. IRG/WP 02-50184. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Clausen, C.A. 2003. Reusing remediated CCA-treated wood. Managing the treated wood resource-II. American Wood Preservers' Association, Selma, AL, pp. 49–56.

Clausen, C.A., S.N. Kartal, and J. Muehl. 2001. Particleboard from bioremediated CCA-treated wood: Evaluation of panel properties. Forest Prod. J. 51(7/8):1–4.

Clausen, C.A., and W.R. Kenealy. 2004. Scaled-up remediation of CCA-treated wood. In: Proceedings of Environmental Impacts of Preservative-Treated Wood, Feb. 8-11, 2004, Orlando, FL.

Clausen, C.A., and R.L. Smith. 1998. Removal of CCA from treated wood by oxalic acid extraction, steam explosion, and bacterial fermentation. J. Ind. Microbiol. 20:251–257.

Cole, F., and C.A. Clausen. 1997. Bacterial biodegradation of CCA-treated waste wood. In: Proceedings Use of Recycled Wood and Paper in Building Applications. Forest Prod. Soc., Madison, WI, pp. 201–204.

Conlon, P. 1992. Crosstie disposal problem or opportunity? Proceedings of the Treated Wood Life-Cycle Management Workshop, American Wood Preservers Institute, Vienna, VA. P. 18-26.

Connell, M. 1999. Waste management options in the wood protection industry. J. I. Wood Sci. Vol. 15(1):51–58.

Cooper, P.A. 1991. Leaching of CCA from treated wood: pH effects. Forest Prod. J. 41(1):30–32.

Cooper, P.A. 1993. The potential for reuse of treated wood poles removed from service. IRG/WP 93-50001. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Cooper, P.A., Y.T. Ung, C. Huang, and X. Wang. 1998. Cement bonded boards using CCA-treated wood removed from service. *In:* Inorganic bonded wood and fiber composite materials, vol. 6, pp. 330–348.

Cooper, P.A., T. Ung, F. Kazi, and D. Qi. 2003. Two approaches to recycling of CCA treated wood: Extraction for recycling and wood cement composites. *In:* Managing the Treated Wood Resource-II. American Wood Preservers' Association Utility Solid Waste Activities Group, May 1, 2003 Boston, MA, pp. 65–76.

Cornfield, J.A., Vollam, S., and P. Fardell. 1993. Recycling and disposal of timber treated with waterborne copper based preservatives. IRG/WP 93-50008. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Crzon, G.E., and H.S. Eisner. 1953. An assessment of the hazard caused by arsenous fumes from impregnated timber in underground fires. Ministry of Fuel and Power. Research Report No. 78.

Davis, G. 1993. Investigation of alternative markets for recycled wood. RFP 92R-40-SW, Metropolitan Serv. District, Solid Waste Dept., Portland, OR.

DeGroot, R.C., and C.C. Felton. 1995. Current and future options for managing used preservative-treated wood. IRG/WP 95-50042. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Dobbs, A., and C. Grant. 1976. Report of the burning of wood treated with wood preservatives containing copper, chromium, and arsenic. Building Research Establishment, Current Paper CP 63/76.

Dobbs, A., Phil, D., and C. Grant. 1978. The volatilization of arsenic on burning copper-chrome-arsenic (CCA) treated wood. Holzforschung 32:32–35.

Electric Power Research Institute (EPRI). 1991. Pentachlorophenol-treated wood poles and cross-arms: toxicity characteristic leaching procedure results. EN 7062s, EPRI, Palo Alto, CA.

EEC Landfill Directive. 1999/31/EEC, Official Journal of the European Communities, L182, 1, 1999.

Environmental Protection Agency (EPA). 1995. The Universal Waste Rule. Federal Register 60(91):25492.

Falk, R. 1997. Wood Recycling. Opportunities for the wood waste

resource. Forest Prod. J. 47(6):17–22.

Felton, C.C., and R.C. DeGroot. 1996. The recycling potential of preservative-treated wood. Forest Prod. J. 46(7/8):37–46.

Florida Department of Environmental Protection (FDEP) 2007. Guidance for the management and disposal of CCA-treated wood. Available online at www.dep.state.fl.us/waste.

Goodrich-Mahoney, J., I. Murarka, L. Holcombe, and M. Horn. 1994. Pentachlorophenol-treated wood poles and crossarms: toxicity leaching procedure results. *In:* Proc. Environmental considerations in the manufacture, use, and disposal of preservative-treated wood. Forest Prod. Society, Madison, WI, pp. 58–65.

Gasco, F. 1996. Process to recover poles or other elements of impregnated wood and the respective impregnation substances in solution form and to regenerate said solution. European Patent Application EPO 0774330A1.

Hata, T., L. Cookson, Y-C. Jang, B. Tarakanadha, Y. Imamura, S.N. Kartal, and T. Shibata. 2006. The production and management of wood treated with chromated-copper-arsenate in Asia and Oceania with emphasis on Australia, India, Japan,and Korea. *In:* Environmental Impacts of Treated Wood, ed. T.G. Townsend and H. Solo-Gabriele. CRC Press, Boca Raton, FL, pp. 59-74.

Helsen, L., and E. Van den Bulck. 2005. Review of disposal technologies for chromated copper arsenate (CCA) treated wood waste, with detailed analyses of thermochemical conversion processes. Environ. Pollut. 134(2):301–314.

Helsen, L., and E. Van den Bulck. 2006. Thermal treatment technologies for treated wood. *In:* Environmental Impacts of Treated Wood, ed. T.G. Townsend and H. Solo-Gabriele. CRC Press, Boca Raton, FL, pp. 447–466.

Hery, J-S. 2005. Recycling CCA-treated poles with Chartherm. IRG/WP 05-50224. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Holton, W.C. 2001. Special Treatment: Disposing of CCA-treated wood. Environ. Health Persp. June 2001, 109(6):A274-A276.

Honda, A., Y. Kanjo, A. Kimoto, K. Koshii, and S. Kashiwazaki. 1991. Recovery of copper, chromium, and arsenic compounds from waste preservative treated wood. IRG/WP/3651. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Hsu, W.E. 1994. Cement bonded particle board from recycled CCA treated and virgin wood. *In:* Proc. Inorganic Bonded Wood and Fiber Composites Materials, ed. A.A. Moslemi, Univ. of Idaho, Moscow, ID, 4:3–5.

Huang, C., and P.A. Cooper. 2000. Cement bonded particle boards using CCA-treated wood removed from service. Forest Prod. J. 50(6):49–56.

Hughes, K.L., A.D. Christy, and J.E. Heimlich. 2005. Landfill types and liner systems. Ohio State University Extension Fact Sheet, CDFS-138-05. http://ohioline.osu.edu/cd-fact/pdf/0138.pdf.

Humar, M., R. Peek, and J. Jermer. 2006. Regulations in the European Union with emphasis on Germany, Sweden, and Slovenia. *In:* Environmental Impacts of Treated Wood, ed. T.G. Townsend and H. Solo-Gabriele, CRC Press, Boca Raton, FL, pp. 37–57.

Jacobi, G., H. Solo-Gabriele, B. Dubey, T. Townsend, and T. Shibata. 2007a. Evaluation of commercial landscaping mulch for possible contamination from CCA. Waste Manage. 27:1765–1773.

Jacobi, G., H. Solo-Gabriele, T. Townsend, and B. Dubey. 2007b. Evaluation of methods for sorting CCA-treated wood. Waste Manage. 27:1617–1625.

Jambeck, J., B. Dubey, T. Townsend, and H. Solo-Gabriele. 2006. Chapter 18 *In:* Environmental Impacts of Treated Wood, ed. T.G. Townsend and H. Solo-Gabriele, CRC Press, Boca Raton, FL, pp. 329–347.

Jambeck, J., K. Weitz, H. Solo-Gabriele, T. Townsend, and S. Thorneloe. 2007. CCA-Treated wood disposed in landfills and life-cycle trade-offs with waste-to-energy and MSW landfill disposal, Waste Manage. 27(8):S21–S28.

Kakitani, T., T. Hata, T. Kajimoto, and Y. Imamura. 2006. Designing a purification process for chromium-, copper-, and arsenic-contaminated wood. Waste Manage. 26:453–458.

Kakitani, T., H. Hata, N. Katsumata, T. Kajimoto, and Y. Imamura. 2007. Chelating extraction for removal of chromium, copper, and arsenic from treated wood with bioxalate. Environ. Eng. Sci. 24(8):1026–1037.

Kamdem, D-P. 2006. Recycling of wood treated with chromated copper arsenate into composite construction materials. *In:* Environmental Impacts of Treated Wood, ed. T.G. Townsend and H. Solo-Gabriele, CRC Press, Boca Raton, FL, pp. 367–382.

Kamdem, D-P., H. Jiang, W. Cui, J. Freed, and L. Matuana. 2004. Properties of wood plastic composites made of recycled HDPE and wood floor from CCA treated wood removed from service. Compos. Part A-Appl. S. 35:345.

Kamdem, D-P., W. Ma, J. Zhang, and J. Zyskowski. 1998. Recovery of copper, chromium, and arsenic from old CCA treated commodities. IRG/WP 98-50118. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Karakash, J., and G. Lipinski. 1998. Disposal of pentachlorophenol-treated wood by combustion, report of recent compliance testing and project status. *In:* Proceedings Northeast Utility Pole Conference, Binghamton, NY, pp. 60–62.

Kartal, S.N. 2002. Effect of EDTA on removal of CCA from treated wood. IRG/WP 02-50182. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Kartal, S.N. 2003. Removal of copper, chromium, and arsenic from CCA-C treated wood by EDTA extraction, Waste Manage. 23(6):537–546.

Kazi, F.K.M., and P.A. Cooper. 1998. Recovery and reuse of chromated copper arsenate (CCA) wood preservative from CCA-treated wastes. Proceedings of the 20th Annual Canadian Wood Preservation Association Conference, Vancouver, BC, Oct. 25–26, 1999.

Kempton, C.C. 1992. Life cycle management of treated wood products: issues and answers. *In:* Treated Wood Life Cycle Management Workshop Proceedings. AWPI. Vienna, VA, pp. 54–66.

Kim, J., and G. Kim. 1993. Leaching of CCA components from treated wood under acidic conditions. IRG/WP 93-50004. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Kjeldsen, P., M.A. Barlaz, A.P. Rooker, A. Baun, A. Ledin, and C.H. Thomas. 2002. Present and Long-Term Composition of MSW Landfill Leachate: A Review. Crit. Rev. Env. Sci. Tec. 32(4):297–336.

Kristensen, O., 2002. Gasification of CCA impregnated wood, Symposium Handling of Impregnated Waste Wood. Technical University of Denmark, Silkenborg, Denmark.

Lebow, S.T., P.A. Cooper, and P.K. Lebow. 2006. Study design considerations in evaluating environmental impacts. *In:* Environmental Impacts of Treated Wood, ed. T.G. Townsend and H. Solo-Gabriele, CRC Press, Boca Raton, FL, pp. 79–99.

Lebow, S.T., S.A. Halverson, J.J. Morrell, and J. Simonsen. 2000. Role of construction debris in release of copper, chromium and arsenic from treated wood structures. Res. Pap. FPL-RP-584. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Prod. Lab.

Leithoff, H., and R.D. Peek. 1998. Biological detoxification processes-A checklist for assessments. IRG/WP 98-50120. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Lin, L., and C-Y Hse. 2002. Removal of CCA from spent CCA-treated wood. IRG/WP 95-50192. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Linroos, L. 2002. Balance of arsenic and recycling. IRG/WP 02-50189. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Mankowski, M., E. Hansen, and J.J. Morrell. 2002. Wood pole purchasing, inspection, and maintenance: A survey of utility practices. Forest Prod. J. 52(11/12):43–50.

Martusky, R. 1992. Concept for an ideal wood waste and wood residue combustion system. Advances in thermochemical biomass conversion conference, Switzerland, 11–15 May 1992.

Martusky, R., and M. Strecher. 1992. Disposal of wood waste containing wood preservatives. Western European Institute of Wood Preservation, WE1.VOR/30. 03.92.

Mayer, M., and W.B. Smith. 1997. Wood Poles: Preservation methods and regulatory considerations. *In:* Wood Pole Compendium, GEI Consultants, Inc., Atlantic Environmental Division, Colchester, CT, pp. 16–17.

McLearn, M., R. Ochs, G. Helsing, J. Thomas, and W. Mitchell. 2008. Remanufacturing out-of-service western redcedar and Douglas-fir poles into viable products. *In:* Proceedings of the American Wood Protection Association, Birmingham, AL, 104:272.

McMahon, C., P. Bush, and E. Woolson. 1986. How much arsenic is released when CCA-treated wood is burned? Forest Prod. J. 50(2):45–50.

Mengeloglu F. and D.J. Gardner. 2000. Recycled CCA-treated lumber in flakeboards: Evaluation of adhesives and flakes. Forest Prod. J. 50(2):41–45.

Micales, J. A., and K.E. Skog. 1997. The decomposition of forest products in landfills. Int. Biodeter. Biodegr. 39(2–3):145–158.

Micklewright, J.T. 1998. Wood Preservation Statistics 1997. A report to the wood preserving industry in the United States. American Wood Preservers' Association, Granbury, TX.

Ministry of Agriculture, Forestry and Fisheries, Ministry of Economy, Trade and Industry and Ministry of Land and Infrastructure and Transport, Fundamental policy of Construction Materials Recycling Act, Official Gazette, Notification No. 1, January 17, 2001.

Minnesota Pollution Control Agency (MPCA). 2009. Treated Wood. Information on use, disposal and alternatives for businesses and homeowners. Available at: www.pca.mn.state.us

Morrell, J.J. 2003. Disposal of treated wood: option and perils. *In:* Managing the treated wood resource-II. American Wood Preservers' Association, pp. 7–14.

Moslemi, A.A. 1993. Inorganic-bonded wood composites-from sludge to siding. J. Forestry 91(11):27–29.

Munson, J.M., and D.-P. Kamdem. 1998. Reconstituted particleboards from CCA-treated red pine utility poles. Forest Prod. J. 48(3):55–62.

Nurmi, A.J. 1996. Disposal of CCA treated waste wood by combustion: an industrial scale trial. IRG/WP 96-50068. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Omae, A.L., H.M. Solo-Gabriele, and T.G. Townsend. 2007. A chemical stain for identifying arsenic-treated wood products. J. Wood Chem. Technol. 27:201–217.

Pasek, E.A., and C.R. McIntyre. 1993. Treatment and recycle of CCA hazardous waste. IRG/WP 93-50007. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Peek, R.D., I. Stephan, and H.B. Leithoff. 1993. Microbial decomposition of salt treated wood. IRG/WP 93-50001. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Qi, D., and P.A. Cooper. 2000. Leaching of chromium and other CCA components from wood-cement composites made with spent CCA treated wood. IRG/WP 00-50153. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Repa, E.W. 2005. NSWMA's 2005 Tip Fee Survey. NSWMA Research Bulletin 05-3.

Sabo, R., C.A. Clausen, and J.E. Winandy. 2008. Thermochemical remediation of preservative-treated wood. IRG/WP 08-50254. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Sabo, R., C.A. Winandy, J.E., Clausen, C.A. and A. Basta. 2008. Remediation and Recycling of WBP- Treated Lumber for Use as Flakeboardcomposites. *In:* Proceedings of the American Wood Protection Association, Birmingham, AL. 104:256–266.

Saxe, J.K., E.J. Wannamaker, S.W. Conklin, T.F. Shupe, and B.D. Beck. 2007. Evaluating landfill disposal of chromated copper arsenate (CCA) treated wood and potential effects on groundwater: Evidence from Florida. Chemosphere 66(3):496–504

Schmidt, R., R. Marsh, J.J. Balatinecz, and P.A. Cooper. 1994. Increased wood-cement compatibility of chromated treated wood. Forest Prod. J. 44(7/8):44–46.

Shupe, T.F., and C.Y. Hse. 2003. Recycling of decommissioned CCA-treated wood into value-added engineered wood products. *In:* Proceedings from the 3rd Annual Special Waste Conference, December 10-12, New Orleans, LA, pp. 75–79.

Shupe, T.F., and C.Y. Hse. 2006. Recycling of preservative-treated wood using chemical extraction technologies. *In:* Environmental Impacts of Treated Wood, ed. T.G. Townsend and H. Solo-Gabriele, CRC Press, Boca Raton, FL, pp. 383–400.

Smith, G. 1992. Reduction, handling, and burning of treated wood. Proceedings of the Treated Wood Life-Cycle Management Workshop, American Wood Preservers' Institute, Vienna, VA, pp. 139–143.

Smith, M., and G. Boley. 1993. Engineering and economic analysis of processing used wood pallets, etc. to fuel. NTIS #53-5680-3-440. USDA Forest Service, Forest Prod. Lab., Madison, WI.

Smith, R.L., and R-J Shiau. 1996. Steam processing of treated waste wood for CCA removal: Identification of opportunities for reuse of the recovered fiber. Report prepared for the Tennessee Valley Authority, Virginia Tech. and Hicksons Ltd. Virginia Tech. and Blacksburg, VA.

Smith, R.L., and R-J Shiau. 1998. An industry evaluation of the reuse, recycling, and reduction of spent CCA wood products. Forest Prod. J. 48(2):44–48.

So, C-L., T.L. Eberhardt, S.T. Lebow, and L.H. Groom. 2006. A preliminary study of preservative retention and penetration in ACQ-treated timbers using near infrared spectroscopy. *In:* Wood Protection 2006, ed. M.H. Barnes, Forest Prod. Soc., Madison, WI, pp. 367–370.

So, C.L., S.T. Lebow, L.H. Groom, and T.G. Rials. 2004. The application of near infrared (NIR) spectroscopy to inorganic preservative-treated wood. Wood Fiber Sci. 36(3):329–336.

So, C-L., S.T. Lebow, L.H. Groom, and T.F. Shupe. 2003. An evaluation of the use of near infrared (NIR) spectroscopy to identify water and oil-borne preservatives. *In:* Managing the treated wood resource-II. American Wood Preservers' Association, pp. 39–47.

Solo-Gabriele, H., Townsend, T., Calitu, V., Messick, B., and M. Kormienko. 1999. Disposal of CCA-treated wood: An evaluation

of existing and alternative management options. Final Technical Report #99-06. Available at: www.ccaresearch.org.

Solo-Gabriele, H., A. Omae, T. Townsend, and D. Hahn. 2006. Identification of wood treated with waterborne metal-based preservatives. *In:* Environmental Impacts of Treated Wood, ed. T.G. Townsend and H. Solo-Gabriele, CRC Press, Boca Raton, FL, pp. 329–347.

Solo-Gabriele, H., and T. Townsend. 2002. Issues with the use and disposal of CCA-treated wood in Florida. *In:* Enhancing the durability of lumber and engineered wood products. Forest Prod. Soc., February, 11-13, 2002. Kissimmee, FL, pp. 217–222.

Solo-Gabriele, H., T. Townsend, and D. Hahn. 2003. Sorting technologies for CCA-treated wood waste. *In:* Managing the treated wood resource-II. American Wood Preservers' Association, pp. 31–38.

Solo-Gabriele, H.M., T. Townsend, D. Hahn, N. Hosein, G. Jacobi, J. Jambeck, T. Moskal, and K. Iida. 2001. On-line sorting technologies for CCA-treated wood. Florida Department of Environmental Protection, Innovative Recycling Grants Program, Tallahassee, FL.

Stephan, I., H.H. Nimz, and R-D Peek. 1993. Detoxification of salt-impregnated wood by organic acids in a pulping process. IRG/WP 93-50012. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Stephan, I., H. Leithoff, and R-D Peek. 1996. Microbial conversion of wood treated with salt preservatives. Mater. Organismen 30:179–200.

Syrjanen, T., and E. Kangas. 2001. Recycling of pressure impregnated timber and preservatives-Incineration Techniques. *In:* IRG symposium of Environment and Wood Preservation, Cannes-Mandelieu, France. Intl. Res. Group on Wood Preserv., Stockholm, Sweden.

Taylor, A., and J. Lloyd. 2007. Potential of near infrared spectroscopy to quantify boron concentration in treated wood. Forest Prod. J. 57(1/2):116–117.

Taylor, J., K. Van Langenberg, D.D. Freischmidt, and S. Zoobi. 2004. Wealth from waste wood: Literature review, CSIRO Forestry and Forest Products Client Report No. 1454.

Townsend, T., T. Tolaymat, H. Solo-Gabriele, B. Dubey, K. Stook, and L. Wadanambi. 2004. Leaching of CCA-treated wood: implications for waste disposal. J. Hazard. Mater. 114:75–91.

Vick, C.B. 1995. Coupling agent improves durability of PRF bonds to CCA treated southern pine. Forest Prod. J. 45(3):78–84.

Vick, C.B., R.L. Geimer, and J.E. Wood Jr. 1996. Flakeboards from recycled CCA treated southern pine lumber. Forest Prod. J. 46(11/12):89–91.

Warburton, P. 1990. Internal Rpt. R1/1, Hickson Timber Products Ltd.

Watson, C.C. 1958. The contamination of fish by arsenic from smoke derived from preservatised wood. New Zeal. J. Sci. 1(3):369–372.

Webb, D.A., and D.E. Davis. 1992. Spent creosote-treated railroad crossties-alternatives and their reuse. Proc. Treated Wood Life-Cycle Management Workshop, American Wood Preservers' Institute, Vienna, VA, pp. 109–138.

Western Wood Preservers' Institute. 2008. Management of Used Treated Wood Products: Addendum for the western United States. Available online at wwpinstitute.org/pdffiles/western-statesdisp.pdf.

Zhou, Y., and D-P Kamdem. 2002. Effect of cement/wood ratio on the properties of cement-bonded particleboard using CCA-treated wood removed from service. Forest Prod. J. 52(3):77–81.

Managing Treated Wood in Aquatic Environments

Edited by

Jeffrey J. Morrell, Kenneth M. Brooks, and Caryn M. Davis

FOREST PRODUCTS SOCIETY

The opinions expressed are those of the authors and do not necessarily represent those of the Forest Products Society.

Copyright © 2011 by the Forest Products Society.
FPS Item No. 7213-11
ISBN 978-1-892529-59-6

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, or otherwise, without prior written permission of the copyright holder. Individual readers and nonprofit libraries are permitted to make fair use of this material such as to copy an article for use in teaching or research. To reproduce single or multiple copies of figures, tables, excerpts, or entire articles requires permission from the Forest Products Society and may require permission from one of the original authors.

Printed in the United States of America.

11071500

The information contained in this guide is based on up-to-date, scientific and economic information and is intended for general information purposes. No warranty or representation, either expressed or implied, are made as to the reliability or accuracy of the information; nor do the organizations assume any liability resulting from use of or reliance on the information by any party. This document should not be construed as a specific endorsement of warranty, direct or implied, of treated wood products or preservatives, in terms of performance, environmental impact, or safety. The information contained in this publication should not be construed as a recommendation to violate any federal, state or municipal law, rule or regulation, and any party using or producing pressure-treated wood products should review all such laws, rules or regulations prior to using or producing treated wood products.

Additional materials and references are provided throughout this document and are all available at WWPInstitute.org.