Augmented Sorting of Recovered Wood Waste Using Stain and X-ray Technologies

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LIST OF ABBREVIATIONS AND ACRONYMS

ACQ	Alkaline Copper Quat
CBA	Copper Boron Azole
CCA	Chromated Copper Arsenate
C&D	Construction and Demolition
FDEP	Florida Department of Environmental Protection
MSDS	Material Data Safety Sheet
PAN	1-(2-pyridylazo)-2-naphthol, an orange-red solid with a molecular formula $C_{15}H_{11}N_3O$
pcf	Pounds per Cubic Foot
XRF	X-Ray Fluorescence

ABSTRACT

Dimensional waste wood is frequently contaminated with wood treatment preservatives including chromated copper arsenate (CCA). In many instances visual identification of CCA-treated wood is difficult, in particular when the wood is soiled or weathered. As a consequence, wood treatment preservatives frequently contaminate dimensional waste wood, thereby limiting recycling options for Construction and Demolition (C&D) wood waste. The objective of the current study was to evaluate the use of visual sorting and two augmentation technologies (PAN Indicator Stain and X-ray Fluorescence, XRF) for identifying CCA-treated wood within recovered wood waste. The study was conducted at a mid-sized wood waste recycling facility located within the Town of Medley, Florida. Experiments were conducted on two types of C&D wood: source separated loads which contained only C&D wood and commingled loads which contained both C&D wood along with other C&D material which was processed through a picking line.

Results showed that visual sorting was effective for removing the small amounts of treated wood present in relatively uncontaminated piles of source separated C&D wood (<1% treated wood). For piles of source separated wood that were contaminated with 50% treated wood, visual sorts were not accurate and benefited from augmented sorting using PAN indicator stain. For commingled loads of C&D wood, visual sorts and visual sorts augmented with PAN indicator were not effective due to the excessive amount of dust and dirt on the wood which inhibited the visual identification of the wood color and also inhibited the performance of the stain. For the case of commingled C&D wood, the handheld XRF units were found to be the augmentation technology of choice due to their ability to detect preservative treatment, even when the wood was dirty and wet. For relatively uncontaminated loads, visual sorting was estimated to cost $22 per U.S. ton without augmentation and $44 per U.S. ton with PAN stain augmentation. For more contaminated loads, visual sorting augmented with PAN stain was estimated to cost $84 per U.S. ton, and for commingled wood, visual sorting augmented with hand-held XRF units was estimated at $103 per U.S ton. The bulk of these costs were associated with labor. Efforts should focus on developing on-line sorting systems for commingled C&D wood. These on-line systems should be able to increase the through put of a particular XRF unit due to more rapid analysis times and should also greatly decrease the amount of labor required thereby reducing costs.

ACKNOWLEDGEMENTS

Funding for this project was received from the Town of Medley through the Florida Department of Environmental Protection Innovative Recycling Grants Program. This project was a collaborative effort between several different organizations including the Town of Medley, Florida Wood Recycling, the University of Miami, and the University of Florida. We thank the many individuals who assisted with the administration of this project, the organization of our Technical Awareness Group meetings, and with the field work and sorting exercises.

MAIN REPORT

I. MOTIVATION

Numerous studies have shown that recovered wood waste, in particular C&D wood waste (a.k.a. sawn wood), in many instances is contaminated with wood treatment preservatives (Tolaymat et al. 2000; Solo-Gabriele et al. 2004), the most predominant of which is chromated copper arsenate (CCA). The amount of arsenic, chromium, and copper contained in the wood is high varying from 1,000 to 10,000 mg/kg for each metal. Given the high concentrations in the wood product, even small quantities of CCA-treated within recycled wood waste would cause significantly elevated metals concentrations. For example, if the goal is to meet Florida SCTL residential guidelines for land application of recycled materials, the amount of CCA-treated wood that can be commingled with untreated wood must be less than 0.05% or in other words there must be less than 1 pound of arsenic-treated wood per U.S. ton of wood processed (Townsend et al. 2003). If the goal is to produce a wood fuel, with a resultant ash that does not fail US regulatory requirements for hazardous waste (e.g. Toxicity Characteristic) then the tolerance is 5% (5% CCA-treated wood and 95% untreated wood) (Solo-Gabriele et al. 2002).

Because of the strict regulatory levels for arsenic, compliance with the regulatory guidelines is difficult, especially given that CCA-treated wood is very common within C&D wood waste representing up to 30% of the C&D wood waste stream (Blassino et al. 2002). As a result, sorting of CCA-treated wood will be required if C&D waste wood is to be recycled. Identification of CCA-treated wood is not always easy, in particular for wood that has been weathered (Solo-Gabriele et al. in press). Thus in order to maintain the viability of the C&D wood recycling market, technologies should be implemented to effectively sort and remove CCA-treated wood from recycled C&D wood waste.

II. BACKGROUND

The simplest form of sorting C&D wood is based upon "visual" methods. Visual identification is based upon several factors including a judgment concerning the possible original use, noting "identifiers" for treated wood, and noting the color of the wood. Original intended use of the wood is important since wood is almost exclusively treated when used for outdoor settings, industrial applications, and some indoor settings (e.g. in contact with the foundation of a home or exterior concrete walls). Thus if a load contains the remnants of an exterior structure, such as portions of a fence or a dock, then that load likely contains treated wood, and should be sorted accordingly. Other criteria for noting the original use include noting the dimensions of the wood. In general, wood characterized by very large dimensions had likely been used for industrial applications and are almost exclusively treated. Examples include railroad ties which are 8 inches x 8 inches m x 3 feet or more, and utility poles which are typically 1 foot in diameter or more. In some cases, landscape timbers which are also typically treated can be identified by their shape which in many cases is characterized by rounded edges for decorative purposes. Also, wood characterized by dimensions of 4 inches by 4 inches or more are commonly used as structural components and in many cases are treated. Notable "identifiers" in wood waste include end-tags and incisions (Figure 1). End tags typically list the type of chemical contained in the wood. If the wood is incised, it is also treated. Incising is a process by which uniform cuts are made in the wood to improve the penetration of the preservative chemical during treatment. Incising is typically used for denser wood species, such as Douglas Fir, which is primarily used in the Western U.S (Figure 1). In some cases treated wood can be identified by its color, which if not treated, typically has a light yellow hue. If treated with a CCA or other non-arsenic but copper containing preservative (e.g. ACQ and CBA) the wood would be characterized by an olive color which is faint for lower retention level wood and very distinct for wood treated at high retention levels (Figure 2). However, once CCA-treated wood has been weathered in many cases the color of the wood is almost indistinguishable from weathered untreated wood. This is particularly the case for wood treated at low retention levels (0.25 and 0.40 pounds of chemical per cubic foot of wood, pcf) which was the most common retention level used for residential uses of treated wood in the U.S. (Figure 3).

Sorting based upon visual methods is helpful but not adequate for situations where the wood is weathered and the use of the wood is unknown. Given the low tolerances for CCA-treated wood within recycled wood, augmentation technologies will likely be a requirement for the production of recycled C&D wood that meet regulatory guidelines. "Augmentation" in this study refers to the visual sorting method as described above supplemented by another technology to assist in the identification of treated wood. The two augmentation technologies evaluated through this study were PAN Indicator Stain and hand-held XRF.

Earlier research has shown that a chemical stain (PAN Indicator) is a useful tool for identifying CCA-treated wood within C&D wood waste (Blassino et al. 2002). When PAN stain is applied to the wood, the wood stains a magenta color if treated with copper and orange if untreated (See Figure 4). The stain is not capable of distinguishing between CCA and other copper-containing preservatives. This stain was chosen over other stains because of the distinctive colors produced which contrast with the natural color of wood and the rapid reaction time (12 seconds for dry wood).

The second technology, X-ray Fluorescence (XRF), was preliminarily evaluated through an Innovative Recycling Grant that was awarded earlier to Sarasota County during 2000 and 2001 for evaluating x-ray and laser technologies for sorting CCA-treated wood during a pilot-scale on-line operation. During this Sarasota study the x-ray technology was found have certain advantages over the laser system (Solo-Gabriele et al. 2004), in particular with respect to its capability to detect CCA in wet and painted wood. (Go to http://www.eng.miami.edu/~hmsolo/sarasota/index_sara.htm for more details). The x-ray instrument used in the Sarasota County study (ASOMA Model 400) was large and bulky weighing about 25 pounds. Since the work in Sarasota County, smaller more portable hand-held units (3.5 pounds) have since become available. These newer units (Figure 4) are capable of identifying up to 15 metals including arsenic, chromium, copper, lead, and mercury within seconds. Prior to the current study the performance of the new more portable hand-held x-ray units for sorting wood waste had not yet been documented during either manual sorting or sorting through the traditional picking-line process.

Figure 1: Treated Wood "Identifiers" in C&D wood waste. End tags show the type of chemical contained in treated wood (left). Wood that contains incisions (right) is also treated.

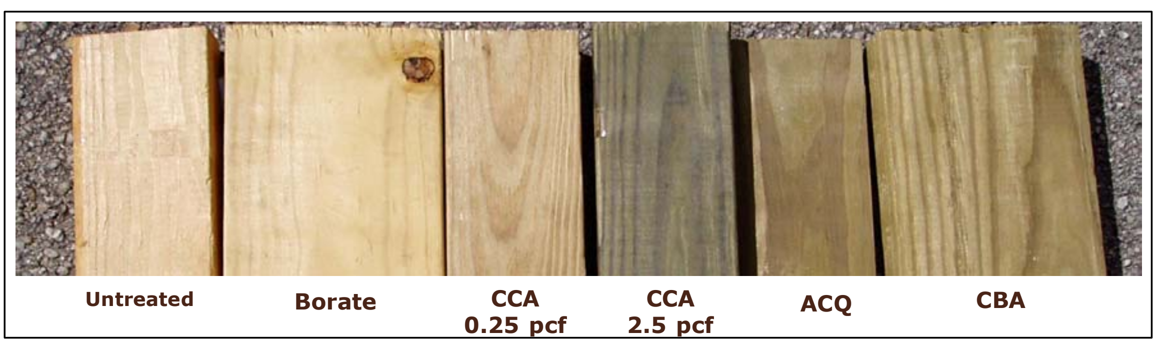

Figure 2: Untreated and Treated Wood with Various Wood Chemical Formulations. Wood Preservatives that Contain Copper Impart a Green Color to the Wood. Wood treated with less chemical (e.g. 0.25 pcf, pounds per cubic foot) has a lighter olive green color in comparison to wood treated with a greater amount of chemical (e.g. 2.5 pcf). The copper based alternatives to CCA, ACQ and CBA, also impart an olive green color to the wood. Borate treated wood does not contain copper and so this chemical does not impart a green color.

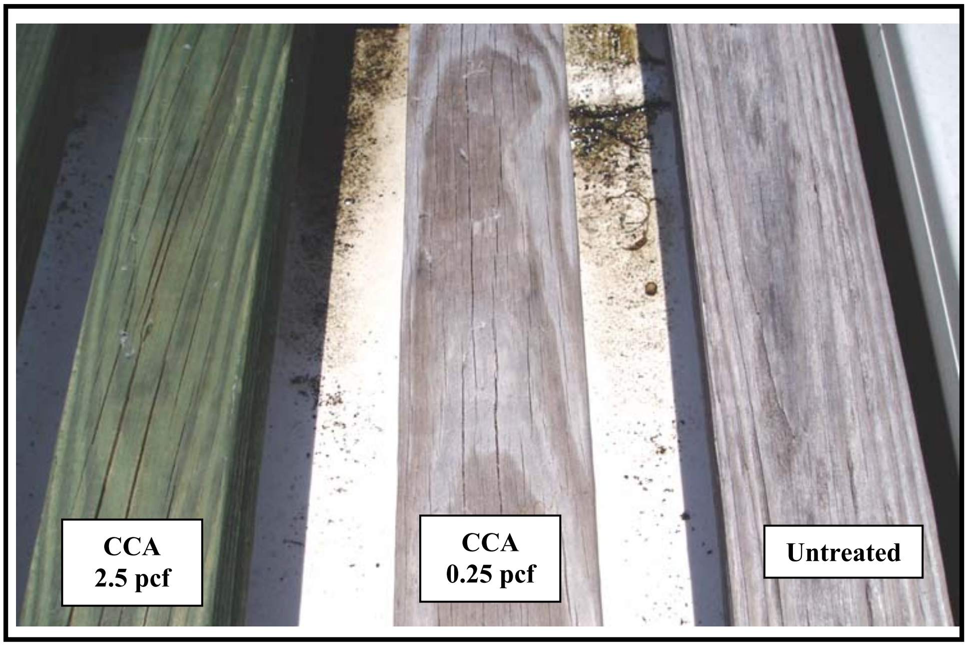

Figure 3: Wood Color after 3 Years of Weathering. Once CCA-treated wood at the 0.25 pcf level is weathered, the green color tends to turn towards a silver grey tone typical of weathered untreated wood. At this point it is difficult to identify CCA-treated wood based upon color alone. Weathered CCA-treated wood treated with high concentrations of CCA, 2.5 pcf, retains its green color. Historically most CCA-treated wood used for residential applications has been treated at the lower retention levels of 0.25 and 0.4 pcf.

Figure 4: Illustrations of Augmentation Technologies Used in this study. PAN Indicator Stain (left) and hand-held XRF units (right).

III. OBJECTIVES

The objective of the current study was to document the performance of visual methods and two "augmentation" technologies for sorting recovered wood waste. Performance was documented with respect to efficacy of the sorting technology along with the associated costs. The visual method of sorting was based upon noting the possible prior use of the wood, identifiers of wood treatment, and the green hue associated with copper treated wood. The "augmentation" technologies evaluated included, PAN Indicator stain, and hand-held x-ray units. Two types of C&D wood waste were evaluated, source separated C&D wood and commingled C&D wood that was separated from other C&D waste on a picking line. A total of 20 tons of each type of C&D wood waste (total of 40 tons) was evaluated as part of this project. During the sorting process labor, chemical use, and consistency between the augmentation methods were documented on a per piece and per weight of wood basis. The cost analysis included the evaluation of labor costs, chemical costs, and capital costs associated with the XRF units.

IV. PROJECT ADMINISTRATION

A considerable amount of effort during this project focused on project administration. The Town of Medley project manager was Roy Danziger, Town Finance Director, in consultation with Melvin Wolfe, Town Attorney. The host facility for this project was Florida Wood Recycling. Harvey Schneider, President of Florida Wood Recycling, was the primary contact at the host facility. The principal investigators for the University team included Helena Solo-Gabriele of the University of Miami College of Engineering, and Timothy Townsend of the University of Florida Department of Environmental Engineering Science. Helena Solo-Gabriele served as the lead administrator of the project for the University Team.

The details of project administration include the efforts in disseminating information (section IV.1), coordinating field work with student participation (IV.2) and management of the budget (IV.3).

IV.1 INFORMATION DISSEMINATION

Information was disseminated on this project through presentations at professional meetings, a web site, through written documents, and through a high school outreach activity. It is important to keep in mind that information dissemination is an on-going process and will continue beyond the end-date of the project as the University researchers continue to publish and present the final results of this project. The information activities presented herein correspond to those activities through December 31, 2005.

Presentations

Presentations of the study were provided at two different types of meetings. The first consisted of a set of TAG (Technical Awareness Group) meetings organized by the project team established for this study. TAG meetings are designed to obtain feedback from representative individuals from industry, regulatory agencies, and academia. These TAG meetings are open to the public. The first TAG meeting was held on October 22, 2005 in Gainesville, Florida and was attended by about 30 individuals. The second TAG meeting was held on August 18, 2005 in

Medley, Florida and was attended by about 40 individuals. Powerpoint presentations and minutes of the TAG meeting are posted at www.eng.miami.edu/~hmsolo/medley.

The second type of presentations were before conferences organized by other organizations. Presentations which discussed the interim results of this study are listed below. Of note is that funding for international travel came from other sources. Furthermore, the research team participated in the FDEP sponsored Joint CCA TAG Meeting and 62-701 Rule Workshop which was held in Orlando, FL, on November 17, 2005.

- "Recycling Potential of Wood Waste." October 2005. National Conference of the Mulch and Soil Council, Washington D.C.

- "Wood Waste Management Practices in the US." September 2005. Second European Cost E31 Conference, Management of Recovered Wood Strategies Towards a Higher Technical Economical and Environmental Standard in Europe. Bordeaux, France. Keynote presentation.

- "Management of Wood Treated with Metals-Based Preservatives." September 2005. Second European Cost E31 Conference, Management of Recovered Wood Strategies Towards a Higher Technical Economical and Environmental Standard in Europe. Bordeaux, France. Of note, during this meeting, Helena Solo-Gabriele took an XRF unit with her to Bordeaux, France where she held demonstrations of the unit at the CTBA [Centre Technique du Bois et de l'Ameublement, Technical Center for Wood and Furniture] and a local C&D recycling center in France.

- "Disposal and Management Options for Wood Waste Containing Metals-Based Preservatives". The International Symposium on the Environmental Impacts of Preservative Treated Wood for Achieving Healthy Environments, Kyoto, Japan. March 2005. Of note that during this meeting, arrangements were made for Innov-X representatives to provide a demonstration of the XRF unit. Innov-X participated by setting up a table with the unit and literature. Helena Solo-Gabriele provided the wood samples.

- "Technologies for the Management of Wood Waste Containing Metals-Based Preservatives." February 2005. Environment and Wood Preservation 6th International Symposium sponsored by the Centre Technique du Bois et de l'Ameublement (Technical Center for Wood and Furniture) and the International Research Group on Wood Preservation. Cannes-Mandelieu, France.

- "CCA Management Issues." December 2004. 19th Annual Hazardous Materials Management Conference on Household and Small Business Waste, sponsored by the North American Hazardous Materials Management Association (NAHMMA). Miami, FL. (Dual presentation with Drs. Townsend and Solo-Gabriele)

Web Site

A web site has been developed for this project and has been posted on the internet at http://www.eng.miami.edu/~hmsolo/medley. This web site includes a brief description of the project, contact information for the core project participants, a copy of the proposal, minutes and Powerpoint presentations of all meetings, project progress reports, and the final project report. A link to this web page has been established through www.ccarsearch.org, which is the web page that the research team has established to post information addressing other related research projects. Also of interest is that Innov-X initiated a Press Release describing the project and now also markets the XRF units specifically for wood preservative identification (http://innov-xsys.com/applications/environmental.html).

Written Documents

The report included herein will serve as an important means by which the results of the project will be disseminated to those interested. In order to facilitate distribution of this report, it has been posted on the web at http://www.eng.miami.edu/~hmsolo/medley. The interim results of this study have also been published within *Construction and Demolition Recycling*, a lay industry-focused journal (See Appendix A.1). The final results of this study have been submitted for publication within *Waste Management* which will serve as an alternate means for distributing the bulk of the technical results (See Appendix A.2). Furthermore the interim results from this study were also included as portions of conference proceedings. The citations to the publications focusing on this work plus the relevant conference proceedings are provided below.

- Solo-Gabriele, H., Jacobi, G., Dubey, B., and Townsend, T., 2005. Warning Signs: certain chemical preservatives are unwelcome contaminants in the mulch and wood fuel markets. Construction & Demolition Recycling, September/October: 24-32.

- Jacobi, G., Solo-Gabriele, H., Townsend, T., Dubey, B., Evaluation of Technologies for Sorting CCA-Treated Wood (in review).

- Solo-Gabriele, H.M., and Townsend, T., 2005. Technologies for the Management of Wood Waste Containing Metals-Based Preservatives. IRG/WP 05-50224-16. Paper prepared for the 6th International Symposium on the Environment and Wood Preservation, Cannes-Mandelieu, France, 7-8February 2005. International Research Group on Wood Preservation, Stockholm, Sweden.

- Solo-Gabriele, H.M., Shibata, T., Townsend, T.G., 2005. Disposal and Management Options for Wood Waste Containing Metals-Based Preservatives. Proceedings of the the International Symposium on the Environmental Impacts of Preservative Treated Wood for Achieving Healthy Environments, Kyoto, Japan. P. 1-4.

- Solo-Gabriele, H., Townsend, T., Jacobi, G., Fernandes, J., Lam, E., and Dubey, B., 2005. Wood Waste Management Practices in the U.S. with Emphasis on the management of Wood Treated With Metals-Based Preservatives. Proceedings of the Second European Cost E31 Conference, Management of Recovered Wood Strategies Towards a Higher Technical Economical and Environmental Standard in Europe. Conference Held in Bordeaux, France. Published by University Studio Press, Thessaloniki, Greece.

High School Outreach

Helena Solo-Gabriele implemented a high school outreach activity focusing on treated wood on October 21, 2005. The 1 and ½ hour activity included a presentation focusing on treated wood, a video, and a hands-on activity using the PAN indicator stain. The high school activity was hosted by Ms. Lisette Icaza a science teacher at Miami Springs High School. The activity was presented before Mrs. Icaza's AP Biology, regular Biology, and an anatomy classes. Selected photos are provided in Figure 5.

Figure 5: Pictures from High School Outreach Activity

IV.2 COORDINATING FIELD WORK WITH STUDENT PARTICIPATION

Coordinating student participation with field work was a challenge at times. Safety was of utmost importance, in particular with respect to the high volume of traffic at the site. Students were required to wear bright colored vests, hard hats, and steel-toes shoes in order to participate in the sorts. Field coordination included assuring that space and wood was available. Equipment was to be transported to the work site including a large weighing scale that was stored on-site at Florida Wood Recycling. This scale was transported to the work site by fork lift. Helena Solo-Gabriele and lead student Gary Jacobi would coordinate activities with Harvey Schneider of Florida Wood Recycling. Gary Jacobi would then coordinate participation of additional students from the University of Miami. Participation of students from the University of Florida was coordinated through Tim Townsend with lead graduate student Brajesh Dubey. Overall, it is estimated that over 30 different students participated in the study, at one point or another. Harvey Schneider of Florida Wood Recycling was responsible for coordinating temporary laborer activities which primarily focused on sorting on the picking line. Furthermore, permanent Florida Wood Recycling employees would assist with some of the logistics (use of front end loader to move piles of wood) and with the actual sorts.

IV.3 BUDGETARY ASPECTS

The total cash contribution by the FDEP Innovative Recycling Grants Program toward the project was $150,000. These funds were used for the purchase a hand-held XRF unit, for the purchase of an industrial weighing scale, and for faculty, student, and temporary worker salaries. A total of 3 XRF units were available for the study as the one unit that was purchased (Innov-X, Model α-2000S) was supplemented with two additional units (Innov-X, Model I-3000C) that were donated by Innov-X. Other incidental expenditures were associated with expendable supplies, local travel, and disposal costs for the treated wood.

V. ORGANIZATION OF TECHNICAL INFORMATION CONTAINED IN APPENDICES

As part of this project a series of documents were prepared. These technical documents are included as a series of 3 primary appendices:

- Appendix A which includes the publications prepared as part of this work,
- Appendix B which includes a set of standard operating procedures along with safety, information, and
- Appendix C which includes a listing of the raw data collected as part of this study.

Appendix A includes two publications, one which was published in the journal Construction and Demolition Recycling which was written for the industry-focused lay public (See Appendix A.1). The second manuscript discusses the technical detailed results of this study. This manuscript was submitted to a journal for possible publication. The abstract of the manuscript is provided below. Please see appendix A.2 for more details.

> "Construction and demolition (C&D) wood is frequently treated with chemical preservatives which contain high concentrations of metals including arsenic, copper and chromium. Many recycling options for such wood require that the product be essentially free of preservative chemicals. The objectives of this study were to document the characteristics of the wood waste stream and to evaluate the effectiveness of sorting methods for identifying treated wood. Sorting methods evaluated included visual sorting and visual sorting augmented with the use of PAN indicator stain and/or hand-held X-ray Fluorescence (XRF) units. Experiments were conducted on two types of construction and demolition (C&D) wood: source separated loads (contained only C&D wood) and commingled loads (contained C&D wood along with other C&D material and which was processed through a picking line). Results showed that the wood waste stream on average

contained about 50% plywood, 40% lumber and timbers, and 10% of other wood types. The source separated C&D wood accepted by the facility was found to contain less treated wood (< 1%) than commingled C&D wood (9%). Out of the 9% treated commingled C&D wood over 75% was CCA-treated. For uncontaminated piles of source separated C&D wood (< 1% treated wood), visual sorting was found to effectively remove the small amounts of treated wood present. For piles of source separated wood that were contaminated (~50% treated wood), visual sorts were not accurate and benefited from augmented sorting using PAN indicator stain. The handheld XRF devices were found to be effective for sorting commingled C&D wood, as PAN indicator stain was not as effective due to the excessive amount of dust and dirt associated with commingled wood waste. Visual sorting of relatively uncontaminated source separated wood was estimated to cost $24 U.S. dollars per metric ton without augmentation with PAN stain and $48 U.S. dollars per metric ton with PAN stain augmentation. For more contaminated wood (50% treated wood), visual sorting augmented with PAN stain was estimated to cost $93 per metric ton, and for commingled wood, visual sorting augmented with hand-held XRF units was estimated at $114 per metric ton. The bulk of these costs were associated with labor. Future efforts should focus on reducing labor costs by mounting automated XRF units on conveyor systems."

Appendix B is split into 4 sections which provide additional instructions for the use of PAN stain, XRF units, and additional safety information. These documents can serve as starting points for the development of standard operating procedures for individual facilities that wish to implement these technologies. Specifically Appendix B is separated into the following sections.

- Appendix B.1 which provides additional instructions for the use of PAN stain,
- Appendix B.2 which provides additional instructions for use of the XRF analyzer,
- Appendix B.3 which provides some information concerning XRF safety, and
- Appendix B.4 which provides some information concerning overall field safety.

Additional information about XRF safety is available from Innov-X, the XRF manufacturer. In addition, it is noted that as part of this project, the XRF instruments were tested by the University of Miami Office of Radiation Safety (John Owens) on two occasions, once during the Spring 2005 in the laboratory and a second time on July 19, 2005 in the field. An ion chamber (Model 450 Victoreen) was used to detect radiation during the field tests. The Innov-X model I-3000C was used for these tests. The results of the radiation safety evaluation indicated that the X-rays from the hand-held XRF units do penetrate wood. It is thus important that hands and people not be placed on the opposite side of the wood during analysis. Also, a small amount of scatter was noted from the unit which was negligible once measurements were taken at the hand trigger. The scatter was sufficient to recommend that individuals do not hold the front metal portion of the unit when X-rays are emitted. As along as the XRF unit is held properly and pointing downwards in a direction away from people, the unit was found to be safe during the tests conducted at the University.

VI. SUMMARY AND RECOMMENDATIONS

The overall results of this study show that the useful methods of sorting treated wood out of the recycled wood waste stream differs and depends on the source and characteristics of the C&D wood load. The facility that hosted this study was able to effectively identify relatively uncontaminated loads by spot-checking source separated loads as they entered the facility. Such loads evaluated contained less than 1% treated wood. Visual sorting methods with no augmentation were found to be quick and reliable for relatively uncontaminated loads of source separated C&D wood. Augmenting the visual sort with the PAN indicator stain was most useful for source-separated loads that contained a large amount of suspect treated wood. Since source-separated C&D wood contained less dirt and dust, the stain could be applied directly to the wood with minimal interferences.

For commingled C&D wood, however, spot-checking loads as they enter the facility was not as effective as for source-separated C&D loads. On average 9% of the wood within the commingled C&D loads was treated. Visual methods including augmentation with PAN stain was found to be more time consuming and less reliable with commingled C&D wood requiring augmentation with XRF technologies. Furthermore commingled C&D wood is characterized by more pieces per metric ton and is more difficult to visually identify due to an excess of dust and dirt, and as a result is more costly to sort. The ability of the XRF units to spot check suspect wood and identify the type of treatment using an analysis time of a few seconds makes them extremely powerful tools for minimizing metal contamination of the recycled product. This is particularly important since 9% of the commingled C&D wood evaluated was treated and 77% of the treated wood portion was treated with an arsenical wood preservative (e.g. CCA).

The costs associated with sorting commingled C&D wood using hand-held XRF units is high due to labor costs. Efforts should focus on developing on-line sorting systems for commingled C&D wood. These on-line systems should be able to increase the through put of a particular XRF unit due to more rapid analysis times and should also greatly decrease labor costs. This study also showed that sorting times and accuracy depends highly on the individual sorting the wood. This difference was most profound with visual analysis. Laborers were found to work at very different speeds and at very different levels of accuracy. Improvement was noticed with experience. Employee training will thus be an important factor for facilities that wish to provide a wood product that is essentially free of CCA.

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