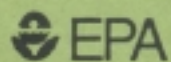


United States
Environmental Protection
Agency

Control Technology Center

October 1996

EPA-600/R-96-119a



WOOD PRODUCTS IN THE WASTE
STREAM-- CHARACTERIZATION
AND COMBUSTION EMISSIONS
Volume 1. Technical Report

control technology center

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**Wood Products in the Waste Stream - Characterization and Combustion
Emissions**
Volume 1, Technical Report

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ABSTRACT

Waste wood, an alternative to the combustion of fossil fuels, has raised concerns that if it is "contaminated" with paints, resins, preservatives, etc. it may generate unacceptable environmental impacts during combustion. Given the difficulty of separating the waste wood and the possible size of the resource, it is important to identify the problems associated with combustion. This project is designed to:

- Identify the quantity and quality of waste wood;
- Summarize of regulatory issues affecting the processing and combustion of waste wood for energy;
- Characterize waste-wood processing and combustion facilities;
- Characterize representative waste-wood samples; and
- Collect and analyze emission data from operating combustion facilities.

Waste wood is wood separated from the solid-waste stream and processed into a uniform-sized product that is reused for other purposes such as fuel. Specific types of waste wood described include:

- Pallets;
- Construction and demolition waste;
- Wood treated with paints or stains;
- Wood containing glues, binders, or resins;
- Wood containing plastics or vinyl;
- Wood treated with preservatives such as creosote, chloropentaphenol and chromium copper arsenate; and
- Wood treated with pesticides or fungicides.

This study, completed in mid-1992, describes research about technical, public policy, and regulatory issues that affect the processing and combustion of waste wood for fuel.

The project's purpose was to provide environmental regulators, project developers, and others with data to make informed decisions on the use of waste wood materials as a combustion resource. Potential environmental problems and solutions were identified.

A specific project result was the identification of combustion system operation parameters and air pollution control technologies that can minimize emissions of identified air and solid waste contaminants from combustion of waste wood.

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EXECUTIVE SUMMARY

Defining "Clean" and "Treated" Wood

This study, completed in mid-1992, emphasizes understanding the differences in air emissions and ash characteristics from the combustion of "clean" wood compared to "treated" wood. Clean and treated wood are produced by a variety of municipal, commercial, industrial, agricultural, construction, and demolition activities. Treated wood is commonly referred to as "urban," "recycled," "treated," "dirty," and/or "demolition" wood. "Clean" wood is a by-product of harvesting activities connected with forest management, commercial logging, and site conversion. Harvested wood may be in the form of chips or stumps.

In most states evaluated in this study, the source and type of wood fuel affects the environmental permitting of facilities. Each state or province has either developed definitions for different wood fuels, or classifies combustion facilities according to the type of wood fuel burned. For this study and the final report, wood fuel types are divided into "clean" or "treated" wood. "Clean" wood is untreated and uncontaminated natural wood.

- "Clean" wood is generated by primary wood-products industries and some secondary wood-products industries. The resulting mill residue may consist of bark, chips, edgings, sawdust, shavings, or slabs. "Clean" wood is also generated by municipal, commercial, industrial, agricultural, construction, and demolition activities. This wood often ends up in the solid-waste stream, and consists of used pallets, dimensional lumber, and other untreated wood.
- "Treated" wood, or wood that has been treated, adulterated, or chemically changed in some way, includes material treated with glues, binders, or resins, such as plywood, particleboard, and wood laminates. "Treated" wood also includes material treated with paints, stains, or coatings, such as painted wood, stained wood, and plastic laminates. "Treated" wood also includes material impregnated with preservatives, such as creosote, pentachlorophenol, and chromated copper arsenate (CCA), in railroad ties, marine pilings, utility poles, and exterior-grade plywood. Construction and demolition waste may contain "treated" wood.

In this report, wood is referred to as "waste wood" when it is in its pre-processed form, and as "processed wood" when it has been prepared for fuel.

Federal, State, and Provincial Regulations

The project team reviewed existing federal, state, and provincial air, solid waste and energy policies, and regulations that relate to waste wood processing and combustion facilities, identified major trends in policies that affect the processing and use of waste wood for energy, and investigated ash disposal from waste-wood combustion facilities.

Major air quality regulatory issues that affect waste-wood combustion facilities include:

- Regulatory implications for permitting a "treated" or a "clean" wood combustion facility;
- The level of control and/or control equipment currently considered best available control technology; and
- Implications of the 1990 Clean Air Act Amendments for new and existing wood-combustion facilities.

Major findings developed from a review of federal and state air quality regulations include:

- Each state's air pollution regulatory agency has either developed definitions for different wood fuels or classifies facilities according to the type of wood fuel burned. Permit review procedures are generally more difficult and permit requirements more stringent for facilities burning "treated" wood (e.g. lower emission limits, additional controls, additional testing and record-keeping requirements) than for facilities burning "clean" wood.
- With the exception of California, "clean" wood-fired energy-recovery facilities are classified as wood boilers or combustion equipment compared to solid-waste combustors or incinerators. Burning "treated" wood is classified differently in some states, even when energy recovery is included.
- All wood-fired facilities in California are classified as resource-recovery facilities, along with municipal solid-waste incinerators, tire burners and sludge incinerators, subjecting them to the same level of agency review and public scrutiny as solid-waste incinerators.
- Best Available Control Technology (BACT) is required in most states regardless of whether Prevention of Significant Deterioration (PSD) applies. BACT-derived emission limits are usually much more stringent than federal New Source Performance Standards (NSPS) and state emission standards. Typical add-on control requirements for new facilities include electrostatic precipitators (ESPs) or baghouses for particulate control and selective non-catalytic reduction (SNCR) for nitrogen oxides (NO_x) control. Good combustion design, including selection of the combustor type, is usually required for carbon monoxide (CO) and volatile organic compounds (VOC) control.
- The non-attainment provisions of the 1990 Clean Air Act Amendments are not currently in effect. However, by November 15, 1992, new wood-fired combustors in areas not meeting NAAQS for ozone may require some combination of additional controls and emission offsets for VOC and/or NO_x emissions. The requirement for and/or degree of controls and offsets are functions of the classification or severity of non-attainment in the area, the quantity of VOC and NO_x emissions from the facility, and the area's mix of ambient NO_x and VOC concentrations.
- Hazardous air pollutant regulations are currently being written by the United States Environmental Protection Agency (EPA) pursuant to Title III of the 1990 Clean Air Act

Amendments. Based on discussions with EPA, wood-fired boilers are in a subcategory of sources for which Maximum Achievable Control Technology (MACT) standards will be established by November, 2000. Other relevant provisions of the 1990 Clean Air Act Amendments including Title I (attainment and maintenance of National Ambient Air Quality Standards (NAAQS)) and Title V (Permits), will be administered by State programs.

- All states in the study area have hazardous air pollutant regulatory programs that are more comprehensive than current Federal National Emission Standards for Hazardous Air Pollutants (NESHAPS). Pollutants usually associated with wood-fired facilities that are regulated include benzene, formaldehyde, acetaldehyde, and trace metals. Polynuclear aromatic hydrocarbons, dioxins and furans are also regulated, although available data (see Chapter 8) indicate that these compounds are usually not detected in significant amounts. Each state has developed acceptable ambient concentrations for hazardous air pollutants based on occupational exposure limits or toxicity studies. New Brunswick, Canada currently has draft guidelines for limiting stack emissions of formaldehyde and hydrogen chloride from wood-fired facilities.

Major solid-waste management issues that affect using wood for fuel, particularly treated wood, include:

- Characteristics of ash from waste-wood combustion facilities, and ash management and disposal methods required by federal, state, and provincial environmental regulations;
- Regulatory classification of processing and combustion facilities that prepare, burn, or intend to burn waste wood;
- Effect of recycling policies on the extent of waste wood processing for use as fuel; and
- Regulatory distinction or lack of distinction between "clean," untreated waste wood, and "treated" waste wood.

The effects of solid-waste policies and regulations on processing and using waste wood for fuel are:

- Ash from waste-wood combustion is not currently defined by the federal government in either the U.S. or Canada as having hazardous waste characteristics. However, some states require testing ash produced by waste-wood combustion facilities to determine its characteristics and potential toxicity. The Toxicity Characteristics Leaching Procedure (TCLP) is commonly used. Ash that fails the TCLP test is classified as hazardous material, and must be handled and disposed of accordingly. There are no ash characterization requirements in New Brunswick province. Federal "guidelines" have been developed only for municipal solid waste (MSW) ash in Canada.
- Fuel processed from waste wood and ash from waste-wood combustion are usually defined at the state or provincial

level as solid waste which affects the classification of waste-wood processing facilities and combustion facilities. For example, some states and provinces view waste-wood combustion essentially the same as MSW incineration and regulate and permit a waste-wood combustion facility similar to a MSW incinerator. Other states distinguish wood-fired facilities from MSW incinerators, and do not regulate and permit them in the same way. How a waste-wood combustion facility is classified by a state can greatly affect the level of regulatory review, type of permitting process, and overall public acceptance.

- State and provincial recycling policies usually do not define processing and using waste wood for fuel as recycling. For states or provinces that require that certain materials, such as wood, be recycled, policies may restrict or prevent the amount of waste wood that is processed for fuel. In addition, public and regulatory acceptance may be problematic for processing and combustion facilities if they are considered as only "disposing of waste" rather than recovering or recycling wood for energy.
- Some states and provinces have, or are beginning to establish, preferences for certain types of combustion activities due to: the recognition in some states of key differences in combustion and emissions performance between waste wood and MSW; favorable net environmental impacts of processing and using waste wood for energy compared with some fossil fuel sources; and the impact of processing waste wood for energy on decreasing pressure on existing solid waste disposal capacity.

Types and Amounts of Waste Wood Available for Fuel

This study compiled data on the types and amounts of waste wood currently generated and used for fuel in the eight-state, one-province study area to estimate the amount of wood separated from the waste stream and processed into fuel. This wood is derived from a variety of forest harvesting, municipal, commercial, industrial, agricultural, construction, and demolition activities. Identifying the types and amounts of waste wood that may contain non-wood materials or "contaminants," such as paint, stain and preservatives is emphasized. Information from state energy offices, forestry and wood use experts, solid-waste managers, forest products industries, and published research on forestry and waste-wood resources is included.

Major categories of waste wood that may be available for fuel, particularly those potentially containing materials that may limit or prevent their use, are identified. The different types of waste wood generated and used for fuel in the study area are identified. Typical wood products likely to be found in the waste stream are discussed.

The three major categories of waste wood include "urban wood waste," mill residue, and harvested wood waste. "Urban wood waste" is presented in quotes because it is commonly used by energy and solid-waste planners; however, it does not have a consistent definition. Urban wood waste generally refers to wood found in the solid-waste stream that is generated by municipal, commercial, industrial, agricultural, construction, and demolition practices.

Of the three major categories of waste wood, urban wood waste is most likely to contain treated wood products. To a lesser extent, treated wood may also be present in mill residue produced by secondary wood products industries. Within the eight-state, one-province study area, it is estimated that urban wood waste and secondary mill residue comprise approximately 19 percent of total waste wood generation. It is important to note this estimate represents a snapshot of waste wood generation in 1990. Historical data or trends were not developed or analyzed for this study.

Of the total amount of waste wood estimated used for fuel in the study area in 1990, 17 percent was derived from urban wood waste and secondary mill residue. The remaining 83 percent came from harvesting operations and mill residue from primary wood products industries. The study revealed that data on the amount of specific types of treated wood products in the waste stream are not readily available at the federal, state, or provincial levels. Some information is available on the regional level; however, the regions are inconsistent among various data sources. Key factors that affect the types and amounts of wood products and potential contaminants in a waste stream include: the type and extent of wood product industries in operation; the level of construction, demolition, or shipping activities in a region; and climatic characteristics that affect the choice of building materials such as the increased use of pressure-treated wood in humid climates.

Composition of Waste Wood

The study identified specific types of waste wood materials that are treated in some way and which are commonly found in solid-waste streams including:

- Wood products manufactured with glues, binders, or resins, such as structural and non-structural panels (e.g. plywood, particleboard, masonite, waferboard, and wood laminates);
- Wood products treated with paints, stains, or coatings; and
- Wood products impregnated with preservatives such as creosote, pentachlorophenol, or CCA (e.g. railroad ties, utility poles, and exterior grade lumber).

Information and product-specific data were obtained from industry reports, sales representatives, research chemists, state and federal government research scientists, and others. A summary of common wood products and the level and types of non-wood contaminants is provided in Table 4-7.

Major issues affecting the use of waste wood (especially treated wood) for fuel are the types and amounts of potential contaminants contained in the material; and the physical, chemical, and environmental characteristics of the contaminant. Overall, the study determined that:

- Adhesives used in wood products manufacturing are primarily interior grade urea resins (61 percent) and, to a lesser extent, phenolic and resorcinol resins (37 percent) and isocyanate resin (2 percent). However, 96 percent of plywood and strandboard products manufactured in the U.S. in 1991 use phenolic resins. The proportion of adhesive ranges from 2 to 15 percent by weight depending on the product.

- Many different types of waste wood are treated with surface coatings. However, surface-coated wood contains the lowest percentage of non-wood contaminants compared to other types of treated wood. Surface-coated wood usually contains less than 0.1 percent of non-wood contaminants based on weight. Of common paint formulations, approximately 50 percent are made up of binder resins and fillers; primary and secondary pigments make up the remaining 50 percent. Paints are increasingly water-based due to restrictions on VOC emissions. A common primary pigment is titanium dioxide, while secondary pigments may contain other metals. Secondary pigments are typically less than 5 percent of the overall paint mixture. Old painted wood, particularly from buildings constructed before 1950, may contain significant quantities of lead-based paint, up to 20,000 parts per million (ppm).
- Impregnated wood consists primarily of oil-borne preservatives, such as creosote and pentachlorophenol, and water-borne preservatives, such as CCA. Overall, 75 percent of all wood preservatives used for impregnating wood are water-borne formulations of CCA.

Waste-Wood Processing Facilities

The study investigated facilities that collect, sort, and process waste wood for fuel. Site visits to six processing facilities in the U.S. and Canada were conducted. In addition, processing equipment manufacturers, solid-waste regulators, and facility owners and operators that were not visited were interviewed.

Research focussed on investigating regulatory and economic issues that affect the ability of processors to use wood from the waste stream; determining the types and sizes of facilities that process waste wood in the study area; and identifying the major types and capabilities of equipment and systems used to process wood for fuel.

The study determined that operation of a waste-wood processing facility is contingent on many factors including the economic and regulatory climate that affects the types of waste wood available to processing facilities; way(s) in which recycling and solid-waste management authorities permit a processing facility; and the size and specifications of markets that use processed waste wood for fuel or other uses.

Waste-wood processing methodologies, equipment, and systems are evolving to meet the requirements of various end-use markets. Facility operators are becoming more specific about the types of wood accepted for processing. The level of inspection and enforcement of unacceptable materials prior to processing is an important step in achieving and maintaining the quality and specifications required for fuel and other end-use products.

Waste-wood processing methodologies, equipment, and systems vary among facilities. In general, there are four major types of waste wood processors:

- Mobile waste wood processors - that often consist of portable hogs, hammermills or tub grinders. Commercial- or

industrial-scale machines may also have the capacity to sort or screen for non-wood contaminants.

- Stationary wood-only processors - that frequently have one primary processing line. They may have two "finishing lines," depending on the availability of markets, such as fuel, compost, or landscaping.
- Stationary multi-waste processors - that collect, sort, and process a range of materials, such as source-separated or mixed construction and demolition (C/D) debris. Waste wood is only a portion of the material accepted and processed.
- On-site processors at combustion facilities - a growing number of utility-scale waste-wood combustion facilities maintain wood-processing systems to ensure the availability and proper preparation of wood fuel used in the combustion unit. This represents a significant increase in capital and operating expenses, and results in additional permitting requirements, especially if the facility handles treated waste wood.

Waste-Wood Combustion Facilities

Combustion facilities that burn, or intend to burn, processed waste wood for fuel were researched and identified in the study area. Data on the capacity of the facility, type of fuel handling, combustion, and pollution control equipment used, and stack emissions and ash characteristics were collected. Research techniques included surveying commercial and industrial wood energy facilities; conducting site visits to two combustion facilities in the U.S. and Canada; completing telephone interviews with plant engineers, equipment manufacturers, and air-quality regulators; and reviewing published research about the performance of various wood-combustion systems.

The study identified key issues concerning fuel specifications and procurement, fuel delivery and feeding equipment, and furnace and boiler designs for combustion facilities that use processed wood for all or part of their feedstock. The study focussed on utility-scale power plants that burn processed wood exclusively for electrical generation, and industrial facilities that burn processed wood to produce thermal and/or electrical energy. In particular, the project team investigated which issues affect the decision to procure and burn processed waste wood.

The decision to use processed waste wood for fuel, especially treated wood, is primarily affected by the fuel requirements of the combustion system; availability of fuel from untreated waste wood; local air quality conditions and local environmental regulations and standards; and the familiarity of state, provincial, or local regulatory authorities with waste-wood combustion technologies and facilities. From the perspective of combustion facility operators, three aspects of wood combustion using processed waste wood, especially treated waste wood, are unique.

- First, fuel specifications are likely to be more specialized for facilities that rely on multiple sources of processed fuel generated off-site to maintain permit standards and minimize wear on fuel handling and combustion equipment.

- Second, due to current testing and regulatory steps, most facilities that use significant amounts of processed waste wood, including treated wood, are utility- or industrial-scale independent power plants or cogeneration facilities that are larger than 100 MMBtu/hr. (An exception may be secondary wood products industries that burn treated waste wood that is primarily generated on-site. Many of these facilities operate under environmental permits that are currently "grandfathered.")
- Third, when burning processed waste wood, most facility operators believe they can meet air standards through a combination of adjustments in combustion unit parameters and careful monitoring of fuel quality, rather than by making fundamental equipment changes in their overall system.

Two major types of combustion systems are used for processed waste wood, thin- or thick-bed grate-fired systems, and bubbling or circulating fluidized bed systems. Each system has certain advantages and disadvantages based on the type of fuel used, location, and operating experience. Similar to processing facilities, the diversity in combustion equipment allows project developers to match fuel and combustion system characteristics. For a variety of reasons, processed waste wood is rarely used as the only fuel source. The primary exception is small- and medium-size wood products manufacturing boilers that use one or more sources of mill residue generated on-site. Processed waste wood at large facilities is typically co-fired with "clean" harvested wood, mill residue, coal, or MSW.

Chemical and Physical Properties of Waste Wood and its Ashes

The chemical and physical properties of waste woods and the ash produced from their combustion were evaluated. There is limited information available in the technical literature. There is some information on "clean" wood but it is also extremely limited and not completely applicable to waste-wood combustion. Since there is an increased interest in using waste wood to produce energy, it is important to understand its properties to predict the environmental impact from its burning.

The type of information gathered for this study is needed to evaluate the emission of trace metals due to combustion of waste wood and to understand the metal contaminants in the ash. The waste wood data collected can be used by developers, regulators and others:

- to evaluate combustion and pollution control alternatives;
- to predict air pollution emissions and ash properties from the combustion of waste woods and;
- to evaluate the environmental impacts from the combustion of waste woods.

This study used random sampling techniques to obtain waste wood and ash samples from six waste-wood processing and two combustion facilities that employed various processing and combustion methods. Samples gathered at these facilities were then finely ground, blended and analyzed to obtain information on their chemical and physical properties. Ash samples were obtained from combustion facilities and

also by laboratory ashing the collected waste wood samples. The data collected include:

- Chemical and physical properties of waste woods, their variance and ranges;
- Statistical significance of the analytical data;
- Values for specifying a waste-wood combustion system and its emissions; and
- Recommendations on limiting variability of waste-wood properties.

Waste-wood samples were collected from various types of wood-processing facilities. By reviewing the descriptions of the processors and evaluating the data collected at each individual facility the reader can make conclusions based on the types of waste woods processed and the processing methods used. This information will be helpful in designing future waste-wood processing systems and in understanding the quality of waste wood fuel which could be produced.

As part of this study homogeneous waste wood samples were collected and analyzed. Some of these samples were collected from facilities also burning these homogeneous materials. In those instances ash samples were also collected and studied. The following types of homogeneous waste woods were collected and analyzed:

- plywood;
- CCA pressure-treated wood;
- particle board;
- creosote-treated wood;
- furniture scraps; and
- laminated woods.

Major findings from this study include:

- Data about energy values, chemical and mineral analyses and concentration of metal contaminants in "clean" and "treated" wood and their ashes;
- Data about energy values, chemical and minerals analyses and concentration of metal contaminants in homogeneous wood types and their ashes;
- The variability of the preceding physical and chemical parameters in the waste-wood fuel stream at each specific test site and among the various sites tested. These parameters and their variability are important factors in the design of waste-wood processors and combustion facilities; and
- Suggested values of the physical and chemical parameters for specifying a waste-wood combustion system's environmental emissions.

Environmental Impacts of Waste-wood Combustion - Air

Emissions of heavy metals, sulfur, and chloride from the combustion of waste wood in boilers can be approximated using wood and ash

concentration data developed for this study. These data, and conservative observations about partitioning these compounds between bottom and fly ash, can be used to estimate air emissions. Worst case assumptions about the partitioning; e.g., 100 percent of metals are contained in the fly ash, can be used for overestimates of emission rates; however, emissions of organic compounds can not be estimated from wood and ash composition data.

Actual emissions data from testing existing wood boilers has been compiled to supplement the wood and ash concentration data gathered for this study. While emissions data for criteria pollutants such as particulate matter, nitrogen oxides, carbon monoxide, sulfur dioxide and total hydrocarbons were obtained, this study focused on non-criteria pollutants such as metals and various organic compounds that are regulated as hazardous air pollutants (HAPs) by most state agencies.

In the absence of HAP emissions data for wood boilers, regulators have used test data from residential wood combustion appliances to quantify emissions. Although these data may be useful in identifying the types of pollutants that may be products of wood combustion, the emission rates from industrial wood-fired boilers are significantly lower due to the differences in combustor design, combustion efficiencies and operating conditions. The overall objective of compiling emissions data for this project, therefore, was to summarize available HAP emissions data that are more applicable to commercial or industrial wood boiler facilities. The objectives of this study were:

- To identify pollutants that could be emitted from combustion of various waste woods;
- To compile available test data on emissions from different wood boiler designs firing different types of waste-wood fuels;
- To summarize test data using consistent units of measure and reference;
- To identify and evaluate operating variables that affect the levels of pollutants formed and emitted;
- To compare emissions from commercial/industrial wood boilers to those from residential wood-combustion appliances; and
- To evaluate the capability of different boiler designs and waste-wood fuels to meet regulatory standards.

Key findings developed during this study include:

- Criteria and non-criteria pollutant emissions data from more than 100 wood combustors are summarized into consistent units. The data should be useful when characterizing emissions from wood combustors. However, the statistical summaries should be used with caution due to the wide variation in boiler designs, sizes, fuel sources and combustion controls represented by the many data sources.
- Few sources of emissions data were available on combustion of C/D, railroad ties, telephone poles or other "treated" wood. Comparing these data with data from "clean" wood combustion at the same sources indicates that organic

emissions are generally not increased from combustion of "treated" wood. While metals emission data from these sources were very limited, they indicate only slightly higher levels for "treated" wood combustion.

- Organic compounds regulated as hazardous air pollutants that have been measured in detectable amounts in wood-combustor flue gas include aldehydes, benzene, phenol, and polynuclear aromatic hydrocarbons (PAH). These compounds are products of incomplete combustion and a function of wood composition or source, but are apparently correlated to emissions of carbon monoxide and total hydrocarbons, which also indicate combustion efficiency. "Good" combustion conditions apparently minimize organic emissions.
- Metals usually found in wood combustor particulate include arsenic, chromium, copper, lead, zinc, aluminum, titanium, iron, and manganese. Emissions estimated from wood and ash composition data summarized in Chapter 7 indicate that C/D wood samples obtained for this research probably contained higher concentration of metals than wood fuel combusted at facilities for which emissions data were available.
- Particulate emissions vary according to the type of particulate control device. Electrostatic precipitators and baghouses perform the best, followed by wet scrubbers and mechanical cyclones.
- Metals-control efficiency is apparently roughly equivalent to total particulate control efficiency with the exception of mercury.
- Chlorinated organic compounds such as dioxins, furans, polychlorinated biphenyls, chlorinated phenols and chlor-benzenes are usually measured at extremely low concentrations or were reported at less than minimum detection limits.
- Combustion of wood fuel with high levels of C/D or "treated" wood, particularly CCA wood, may exceed state guideline concentrations. Exceedances of arsenic and chromium guidelines may mean that the amount of CCA-treated wood in a fuel stream may need to be reduced by good processing practices to insure compliance with state air toxics guidelines.

ACKNOWLEDGEMENTS

This study was conducted as a joint venture by Environmental Risk Limited (ERL) in Bloomfield, Connecticut and C.T. Donovan Associates Inc. (CTD) in Burlington, Vermont.

The Principal Investigator for Environmental Risk Limited was Dr. Richard Atkins, PhD, P.E. He was assisted by Michael I. Holzman, Senior Associate; Steve Dwelly, Environmental Engineer; Michael Weinmayr, Environmental Engineer; and Administrative Assistants Sherry Butch, Barbara Martin, Beth Merk, and Kristine Mothersele.

The Principal Investigator for C.T. Donovan Associates Inc. was Christine T. Donovan, President. She was assisted by Eric S. Palola,

Regulatory Analyst; Jeffrey Fehrs, P.E., Solid Waste and Recycling Analyst; and Dona Loso, Publications Assistant and Business Manager.

An Advisory Board provided valuable guidance throughout the project: Russell O'Connell and Philip Lusk of the CONEG Policy Research Center, Inc.; Steven Morgan of Citizens Conservation Corporation; Jennifer Snead of the Virginia Department of Mines, Minerals and Energy; Phillip Badger and David Stephenson of the Tennessee Valley Authority; Robert McCrillis, Brendan MacMillian and Cathy Zoi of the U.S. Environmental Protection Agency; Andrew Baker of the U.S.D.A. Forest Products Laboratory; Leonard Theran of G&S Mills, Inc.; Joseph Robert and Donna Clarke of the Canadian Department of Energy, Mines and Resources; Michael Charles of the American Wood Preservers Institute; and, Michael Hoag of the National Particleboard Association.

1.0 INTRODUCTION

Waste wood represents an alternative to the combustion of fossil fuels for many regions of the country. Environmental regulators and the general public, however, are concerned that waste wood "contaminated" with paints, resins, or preservatives may generate unacceptable environmental impacts during combustion. Given the difficulty of separating some non-wood materials from waste wood and the possible size of the resource, it is important to investigate solutions to the problems associated with combusting this material. This project, completed in mid-1992, was designed to:

- Identify the types and amounts of waste wood available in selected states and provinces.
- Review current and proposed environmental regulations that do (or may) apply to waste-wood processing and combustion facilities.
- Visit several representative processing and combustion facilities to review and characterize equipment and techniques used to gather, sort, process, and combust waste wood for fuel.
- Obtain and test representative samples of waste wood fuel and ash, and analyze the physical and chemical properties of the material.
- Evaluate air emissions and ash-disposal issues associated with the preparation and combustion of waste wood for fuel.
- Collect air emissions data from wood-combustion facilities to evaluate the effect of boiler combustion factors on air emissions.

1.1 The Defining of "Clean" and "Treated" Wood

This study emphasizes facilities that burn wood that is separated from the waste stream and processed into fuel. The wood is derived from municipal, commercial, industrial, agricultural, construction, and demolition sources, and is commonly referred to as "urban," "recycled," "treated," "dirty," and/or "demolition" wood.

In most states included in the study, the source and type of wood fuel affects the environmental permitting of facilities. Each state or province has either developed definitions for different wood fuels, or classifies combustion facilities according to the type of wood fuel burned. For this study and the final report, wood fuel types are divided into "clean" and "treated" with the following definitions.

- "Clean" wood is untreated and uncontaminated natural wood. It is a by-product of harvesting activities conducted for forest management, commercial logging, and site conversion. Harvested wood may be in the form of chips or stumps. Clean wood is generated by primary wood products industries and some secondary wood products industries. The resulting mill residue may consist of bark, chips, edgings, sawdust, shavings, or slabs. Clean wood is generated by municipal, commercial, industrial, agricultural, construction, and demolition activities. This wood often ends up

in the solid-waste stream, and consists of used pallets, dimensional lumber, and other untreated wood.

- "Treated" wood includes wood that has been treated, adulterated, or chemically changed in some way. Treated wood includes material treated with glues, binders, or resins, such as plywood, particleboard, and wood laminates. Treated wood also includes material treated with paints, stains, or coatings, such as painted wood, stained wood, and plastic laminates. Treated wood also includes material impregnated with preservatives, such as creosote, pentachlorophenol, and CCA. Examples are railroad ties, marine pilings, utility poles, and exterior-grade plywood. Both construction and demolition waste can potentially contain treated wood.

In this report, wood is referred to as "waste wood" when it is in its preprocessed form, and as "processed wood" when it has been prepared for fuel. Until the 1980's, most facilities that used wood for fuel burned primarily clean wood. An exception was secondary wood-products industries that burned treated wood for fuel that was primarily generated on-site. During the past decade, however, interest has grown in both the public and private sectors in finding new uses for wood in the solid-waste stream. This has stimulated development of wood-fired power plants and industrial wood-energy systems that burn, or would like to burn, wood separated from the waste stream and processed into fuel. This wood may contain treated materials.

The types and amounts of clean and treated wood used at a wood-fired facility will depend on the extent of forest harvesting, wood products industry, agricultural, construction, demolition, and other activities that generate waste wood in the area where the facility is located.

The report is based on a one-year study that included research on technical, public policy, and regulatory issues that affect the processing and combustion of waste wood for fuel. Types of waste wood included in the study were:

- Pallets;
- Construction and demolition waste;
- Wood treated with paints or stains;
- Wood containing glues, binders, or resins (including plywood, veneer, laminated wood, particleboard, and wood composites);
- Wood containing plastics or vinyl (including formica);
- Wood treated with preservatives (including chromium copper arsenate (CCA), pentachlorophenol or pressure-treated wood);
- Wood treated with creosote (including new or used railroad ties, telephone poles or marine pilings); and
- Wood treated with pesticides or fungicides (such as some orchard trimmings and agricultural waste).

1.2 Research Methodology

The project's purpose was to provide environmental regulators, project developers, and others with the necessary data to make decisions on using waste wood materials as a combustion resource. Potential environmental problems from the combustion of waste wood were identified and potential solutions were addressed.

This study included a variety of research methodologies and activities. The project team evaluated the specific types and quantities of waste wood generated in the study area. The availability of wood from municipal, commercial, industrial, agricultural, construction, and demolition sources was estimated. Potential non-wood materials, or contaminants, in various types of waste wood were identified. Existing or proposed environmental regulations for facilities that process and/or burn waste wood were reviewed.

The project team obtained, characterized, evaluated, and documented equipment and material flows at waste-wood processing and combustion facilities. A variety of technical, operational, environmental, and management factors that affect air emissions and ash characteristics from burning waste wood were identified. Six waste-wood processing and two waste-wood combustion facilities were visited, and samples of their feedstock and/or their ash were obtained.

A sampling, laboratory testing, and analytical program for waste-wood feedstock and ash was completed, and key characteristics of waste-wood fuel and ash that potentially affect wood energy facilities were identified. The sampling, testing, and analytical program included wood from various processing and combustion facilities, as well as homogeneous samples of specific types of waste wood treated with resins, glues, and binders; paint or stain; and preservatives.

The laboratory data were used to estimate air emissions and ash characteristics from the combustion of waste-wood fuel. Combustion systems and pollution-control equipment were evaluated for their abilities to reduce emissions and control ash composition to within environmentally acceptable limits. Waste wood components of environmental concern and specifications for future wood fuel use were identified. A specific result of this project was identification of combustion system operation parameters and air pollution control technologies that can minimize the emissions of identified air contaminants from the combustion of waste wood.

1.3 Study Area

The geographic area included California, Connecticut, New York, North Carolina, Vermont, Virginia, Washington, Wisconsin, and New Brunswick, Canada. The study was co-funded by the: New York State Energy Research and Development Authority; United States Environmental Protection Agency; Canadian Department of Energy, Mines, and Resources; United States Department of Energy's Regional Biomass Program; and the Virginia Department of Mines, Minerals, and Energy.

1.4 Organization of the Final Report

The report is organized into eight chapters and eight appendices; the first chapter is the introduction.

Chapter 2 discusses key federal, state, and provincial air, solid waste, and energy policies and regulations affecting the processing and use of waste wood for energy.

Chapter 3 describes the types and amounts of harvested wood and waste wood potentially available for fuel in the states and province studied. The purpose of the chapter is to determine how much wood currently generated in each state and province may contain non-wood material that could affect its use as fuel.

Chapter 4 describes the composition of harvested wood and waste wood that could potentially be processed and used for fuel. The purpose of the chapter is to identify the contents of harvested wood as well as waste wood derived from wood products that were processed or treated in some way. The focus of the chapter is on the presence of non-wood material in common wood products, and on the composition of the non-wood materials. The chapter is intended to assist solid waste and energy planners, wood-fired facility developers, and regulatory officials in understanding characteristics of wastewood that may affect its use as fuel.

Chapter 5 describes facilities that collect, sort, and process waste wood for fuel. Key steps used during processing and the sequence in a processing line are explained. Information is provided on the design, operation, and capabilities of specific types of equipment commonly used by waste-wood processors.

Chapter 6 describes combustion facilities that burn waste wood for fuel, emphasizing facilities that use wood that is separated from the waste stream and processed into fuel as at least part of their feedstock. Key issues concerning fuel specifications and procurement, fuel delivery and feeding equipment, furnace and boiler designs, and pollution control equipment are explained. The discussion applies to power plants that burn, or intend to burn, processed wood for electrical generation, and industrial facilities that burn, or intend to burn, processed wood to produce thermal and/or electrical energy.

Chapter 7 describes the development, implementation and results of the sampling program conducted to obtain quantitative data on the physical and chemical properties of waste wood and the ash that is produced from its combustion. The program entailed the collection and analysis of wood and ash samples from various waste wood sources and combustors within the US and Canada. Wood samples collected include a variety of mixed stream waste wood as well as several pure wood product samples such as CCA-treated and creosote-treated woods. Ash samples from waste wood processors and from pure wood products were obtained by laboratory ashing methods, whereas ash samples from combustors were collected from these facilities' particulate control devices. The information is used to evaluate the environmental impacts of waste wood combustion from the emissions of trace metals and the disposal of combustor ash.

Chapter 8 presents the results and evaluation of a comprehensive survey of emissions data from more than 100 operating wood-fired boilers. Statistical summaries of the data are provided to evaluate the operating and design variables that affect the levels of pollutants formed and emitted. Although the majority of facilities represented by the emissions data purportedly burn "clean" wood, limited data were found on several facilities that had conducted test burns with C/D wood, railroad ties and other "treated" wood. Using the organic emissions from the data survey and metals emissions estimated from the wood and ash

analyses presented in Chapter 7, two hypothetical cases representing "good" combustion of C/D wood with high efficiency particulate controls were modeled to estimate worst case ambient impacts. Ambient impacts were then compared to state guidelines for hazardous air pollutants to assess compliance potential.

Appendix A includes a description of key environmental policies and air emissions regulations for each state and province in the study area.

Appendix B includes a description of key environmental policies and regulations concerning solid waste management for each state and province in the study area. Solid waste regulations can affect the waste-wood feedstock and the management of ash combustion facilities produce.

Appendix C includes more detailed information on the estimates of waste-wood generation and reuse in each state and province presented in Chapter 3.

Appendices D and E include specifications used for waste wood accepted for processing into fuel.

Appendix F presents details on the statistical methods used to evaluate data in the test program.

Appendix G includes details on how samples were collected and reduced at each of the six processing and two combustion facilities.

Appendix H includes more detailed information about laboratory tests done for this study.

2.0 ENVIRONMENTAL REGULATIONS

2.1 Introduction

This section discusses current environmental regulations and trends in the permitting and operation of waste wood-fired facilities in the following eight states and one Canadian province: California, Connecticut, New York, North Carolina, Vermont, Virginia, Washington, Wisconsin and the Province of New Brunswick; Canada.

Agencies in the study area with direct knowledge of waste wood-fired facilities were contacted for the following information:

- Air and solid waste permitting requirements;
- Regulatory concerns;
- Public acceptance;
- Compliance methods and procedures;
- Ash handling and disposal methods;
- Published policy documents;
- Emission testing results; and
- Fuel and ash analysis data.

Environmental regulations and the regulatory climate are constantly changing. The research phase, including interviews of regulatory agency personnel and review of regulations and permits was conducted in the summer of 1991.

The timing of this research is particularly important since the 1990 Clean Air Act amendments passed on November 15, 1990. This legislation mandated numerous regulations, some of which were proposed and/or implemented after the research phase of this project, but before publishing this document. Whenever possible, information was updated (to late 1992) and references were made to impending changes in the regulations.

The reader should consider this information as highlighting major requirements and issues. For permitting and compliance issues the reader should obtain the current regulations for the particular location and not rely solely on the data presented here.

When the research was completed, the information was analyzed and summarized by state and province. The following subsections of this chapter analyze federal, state and provincial:

- Air Regulations;
- Solid and Hazardous Waste Regulations; and
- Energy Policies.

Summaries of the regulations of the states and province in the study area are given in appendices:

- Appendix A -- Air Regulations; and
- Appendix B -- Solid Waste Regulations.

2.1.1 Key Issues In Federal Air Quality Regulations

- Which federal air quality regulations are potentially applicable to a waste wood combustion facility?
- What are the implications of the 1990 Clean Air Act Amendments on new and existing wood combustion facilities?

2.1.1.1 Key Findings

- Most federal (USEPA) air quality programs establish a framework of regulation; states either adopted these regulations without modification or make them more stringent. These programs include Prevention of Significant Deterioration (PSD), National Emission Standards for Hazardous Air Pollutants (NESHAPS), and non-attainment provisions. Each of these programs is potentially applicable to new wood-fired boiler facilities depending on the site and quantity of emissions.
- New Source Performance Standards (NSPS) potentially applicable to wood-fired boilers (depending on size) include 40 CFR Part 60, subparts Db and Dc. Emission standards for sulfur dioxide and particulate matter included within these subparts apply to new facilities and are less stringent than those usually required in recent state permits.
- Hazardous Air Pollutant regulations are currently being written by EPA pursuant to Title III of the 1990 Clean Air Act Amendments. Based on discussions with EPA, wood-fired boilers are in a subcategory of sources for which Maximum Achievable Control Technology (MACT) standards will be established by November, 2000. Other relevant provisions of the 1990 Clean Air Act Amendments including Title I (attainment and maintenance of National Ambient Air Quality Standards (NAAQS)) and Title V (Permits), will be administered by State programs.

2.1.2 Key Issues In State Air Quality Regulations

- What are the state regulatory implications for permitting a "treated" versus a "clean" wood combustion facility?
- What level of control and control equipment is currently considered Best Available Control Technology (BACT)?
- What are the implications of the 1990 Clean Air Act Amendments on new and existing wood combustion facilities.

2.1.2.1 Key Findings

- Each state's air pollution regulatory agency has either developed definitions for different wood fuels or classifies facilities according to the type of wood fuel burned. In general, permit review procedures are more difficult and permit requirements more stringent for facilities burning "treated" wood (e.g. lower emission limits, additional controls, additional testing and record keeping requirements) than for facilities burning "clean" wood.
- All wood-fired facilities in California are classified as resource recovery facilities, along with municipal solid waste incinerators, tire burners or sludge incinerators. This classification subjects wood combustion facilities to a similar level of agency review and public scrutiny as solid waste incinerators.
- With the exception of California, "clean" wood-fired energy recovery facilities are classified as wood boilers or combustion equipment compared to solid waste combustors or incinerators. The classifications differ in some states about burning "treated" wood, even when energy recovery is included.

- Best Available Control Technology (BACT) is required in most states regardless of whether PSD applies. BACT-derived emission limits are typically much more stringent than federal NSPS and state emission standards. Typical add-on control requirements for new facilities include ESPs or baghouses for particulate control and selective non-catalytic reduction (SNCR) for nitrogen oxides (NO_x) control. Good combustion design, including selection of the combustor type, is usually required for carbon monoxide (CO) and volatile organic compounds (VOC) control.
- As of this writing (mid-1992), the non-attainment provisions of the 1990 Clean Air Act Amendments are not in effect. However, by November 15, 1992, new wood-fired combustors planning to locate in areas not meeting NAAQS for ozone will likely require some combination of additional controls and emission offsets for VOC and/or NO_x emissions. The requirement for and/or degree of controls and offsets are functions of the classification (severity) of non-attainment in the area, the quantity of VOC and NO_x emissions from the facility and the area's mix of ambient NO_x and VOC concentrations.
- All states in the study area have hazardous air pollutant regulatory programs that are more comprehensive than current Federal NESHAPS. Pollutants usually associated with wood-fired facilities that are regulated include benzene, formaldehyde, acetaldehyde, and trace metals. Polynuclear aromatic hydrocarbon, dioxins and furans are also regulated, although available data (see Chapter 8) indicate that these compounds are usually not detected in significant amounts. Each state has developed acceptable ambient concentrations for hazardous air pollutants based on occupational exposure limits or toxicity studies. New Brunswick currently has draft guidelines for limiting stack emissions of formaldehyde and hydrogen chloride from wood-fired facilities.
- Connecticut has passed a law specifically excluding "treated" wood as an acceptable fuel source for a wood-fired combustor. The number of existing facilities permitted to burn "treated" wood in the study area is extremely limited.
- The majority of states in the study area require permits to construct and/or operate, regardless of facility size or emissions. Some states, such as Connecticut, Washington, Vermont and Wisconsin have permit trigger levels based on heat input or emissions rates.

2.1.3 Key Federal Solid Waste Issues

- What aspects of a waste wood combustion facility could be affected by federal solid waste regulations?
- If a wood fuel feedstock or combustion ash is defined as solid waste, are hazardous waste rules and procedures applicable?

2.1.3.1 Key Findings

- Solid waste regulations may affect a waste wood combustion facility in two ways. First, the waste wood feedstock used as fuel is usually defined as a solid waste. Second, the ash produced by a facility is usually defined as a solid waste.
- Currently, waste wood ash is not categorically defined as a hazardous waste by EPA. However, waste characterization of the ash may be

required by federal or state authorities to determine if the material is hazardous.

- TCLP testing for potentially toxic characteristics of ash may be required, particularly for fuel feedstock, that may contain chemical compounds, heavy metals, or inorganic substances regulated by RCRA.
- Provisions of the current RCRA statute categorically exclude certain types of waste wood or waste wood ash as being defined as a hazardous waste including waste wood or waste wood ash derived from "household sources," such as wood from municipal solid waste.
- Existing ash classifications for certain types of solid waste may change during pending reauthorization of RCRA that may in turn affect the classification of ash from treated wood combustion. RCRA reauthorization is underway and may be completed in 1992.

2.1.4 Key Issues in State Solid Waste Regulations

- Are there regulatory definitions under solid waste rules that distinguish "clean," untreated waste wood from "treated" waste wood? If there are no definitions, it may be unclear how to review and permit a waste wood processing or combustion facility.
- Are there regulations or policies specifically for the management and disposal of construction and demolition waste? Is wood specified in the state definition of C/D waste? C/D waste is often regulated less stringently than other types of solid wastes. However, some types of treated waste wood may not be included in the definition of waste which is to be managed as C/D debris.
- Is waste wood processed for fuel defined as a recycling activity under state recycling policies? Do state recycling targets and definitions for recyclable materials encourage or prevent the processing and use of waste wood for fuel?
- How do state solid waste programs evaluate waste wood combustion ash? Do state standards differ from the federal RCRA program for the management of solid and/or hazardous wastes?

2.1.4.1 Key Findings

- Definitions of waste wood, particularly those that distinguish "clean," untreated wood from treated waste wood vary in the study area. In several states, there are no definitions.
- Depending on the approach of state solid waste management programs, disposal of waste wood may be managed under several classes of landfill or combustion facilities including C/D disposal facilities, "inert debris," landfills, and solid waste landfills. Combustion facilities that burn waste wood may be permitted as a wood residue, resource recovery, or solid waste incineration facility.
- There are significant differences in combustion performance of facilities that burn MSW for fuel (often referred to as waste-to-energy plants) compared to utility and industrial scale facilities that burn "clean" and/or "treated" waste wood for fuel. The differences are not always recognized by permitting and regulatory agencies. The lack of distinction between these two types of combustion facilities often poses

problems in siting, permitting, and public perception about using waste wood for fuel.

- In the study area, with the exception of New Brunswick, the reuse of waste wood for fuel is not a recycling activity. Source separation of wood from the waste stream, however, is encouraged under state recycling policies. All state solid waste programs in the study area discourage combustion for energy recovery as an end use of recycled material. However, some states are beginning to distinguish energy and environmental preferences for certain types of combustion, such as those that are primarily for energy recovery, not disposal, or those that have low net environmental impact compared to other energy sources.
- Ash from waste wood combustion is typically regulated as a non-hazardous material following the same waste characterization procedures used under RCRA. Treated wood fuel sources may require hazardous waste characterization for both fuel and ash as part of air and solid waste permitting. Solid waste regulators are usually concerned with metals concentrations and potentially high pH values in the ash.

2.1.5 Key Energy Policy Issues

- Which major federal energy statutes affect the siting and construction of waste wood power plants or industrial facilities? Do federal statutes distinguish between clean and treated waste wood combustion?
- Do state energy policies cover waste wood combustion? Is there a distinction between "clean" and "treated" waste wood combustion?

2.1.5.1 Key Findings

- The major federal energy statute affecting wood energy projects is the 1978 Public Utilities Regulatory Policy Act (PURPA) which governs how power is sold to utilities. PURPA applies to wood energy projects that are designated as "qualifying facilities" for small power production. Industrial and commercial facilities are not affected by PURPA unless they sell power off-site.
- State public utility commissions (PUCs) determine rates paid to wood energy projects based on avoided cost calculations required under PURPA and other state statutes. Until recently, the rates were based on issues only concerning the cost, availability, and duration of the power provided. Historically, rate-setting by PUCs has not distinguished between the source of fuel, type of fuel, or environmental impacts.
- State energy policies and rate determinations by PUCs are increasingly viewing some small power facilities as more desirable than others. Projects that rely on renewable fuels, such as harvested wood and waste wood, or which have low net environmental impacts compared to other fuel sources, may receive tax credits, production incentives, or rate subsidies that enhance the competitiveness of wood energy in utility bidding.

2.2 Federal Air Pollution Regulations

2.2.1 USEPA

EPA air pollution regulations potentially applicable to new or modified wood-fired facilities are New Source Performance Standards (NSPS), National Emission Standards for Hazardous Air Pollutants (NESHAPS) and Prevention of

Significant Deterioration (PSD) regulations. New source review and nonattainment regulations are implemented at the state or local level under permit programs approved by EPA that are at least as stringent as the federal requirements.

2.2.1.1 New Source Performance Standards

Depending on the heat input capacity, a waste wood-fired steam generating facility may be subject to Standards of Performance for New Stationary Sources (40 CFR Part 60) for steam generating units. New steam generating units with more than 100 MMBtu/hr heat input capacity are subject to Subpart Db - Standards of Performance for Industrial-Commercial-Institutional Steam Generating Units. Facilities rated between 10 and 100 MMBtu/hr are subject to Subpart Dc - Standards of Performance for Small Industrial-Commercial-Institutional Steam Generating Units. Wood-fired electric generating facilities are not subject to Subpart Da (Standards of Performance of Electric Utility Steam Generating Units for which construction commenced after September 18, 1978) as long as fossil fuel heat input (e.g. coal, oil or natural gas co-fired with wood) does not exceed 250 MMBtu/hr. Subpart E - Standards of Performance for Incinerators or Subpart Ea - Standards of Performance for Municipal Waste Combustors are not applicable because waste wood fuel does not meet the Federal definitions of solid waste or MSW in these subparts. In fact, according to the definition given in subpart Ea "construction/ demolition waste is not considered MSW".

The following standards (in mid-1992) apply to steam generating units subject to Subpart Db (> 100 MMBtu/hr):

- Sulfur dioxide (SO₂) 0.50 lb/MMBtu, if the facility co-fires with oil and has an annual capacity factor of 30 percent or less for oil.
- Particulate matter (PM) 0.1 lb/MMBtu, if the facility has an annual capacity factor greater than 30 percent for wood. 0.2 lb/MMBtu if less than 30 percent capacity factor for wood.
- Nitrogen oxides (NO_x) No standard is given for a wood-fired boiler or one that simultaneously combusts gas or oil with wood if the annual capacity factor is less than 10 percent for gas or oil.

The following standards apply to steam generating units subject to Subpart Dc (10 - 100 MMBtu/hr):

- Sulfur dioxide (SO₂) 0.50 lb/MMBtu or 0.5 weight percent sulfur for any oil fired in the boiler.
- Particulate matter (PM) 0.10 lb/MMBtu for facility with > 30 percent annual capacity factor for wood. 0.20 lb/MMBtu if annual wood capacity factor < 30 percent.
- Nitrogen oxides (NO_x) No NO_x emission standard applicable to Subpart Dc.

It should be noted that NSPS are merely the starting point for establishing emission limits for new wood-fired boilers. New sources undergoing state permit review are usually restricted to more stringent emission limits based upon a Best Available Control Technology evaluation (see Section 2.3).

2.2.1.2 National Emission Standards for Hazardous Air Pollutants (NESHAPS)

NESHAPS have been developed by EPA (40 CFR Part 61) to regulate emissions of eight specific pollutants in fourteen categories of sources (Subparts B through W). Only one of the NESHAPS (Subpart C) may be interpreted as being applicable to waste wood-fired facilities. Subpart C applies to emissions of beryllium from incinerators, among other sources. According to the definition of incinerator given in this NESHAP, "any furnace used in the process of burning waste for the primary purpose of reducing the volume of the waste by removing combustible matter", a waste wood-fired facility that is not used for energy or steam generation would be subject to this regulation. Regardless, no data has been found to indicate that beryllium would be emitted from a waste wood-fired facility.

2.2.1.3 Maximum Achievable Control Technology (MACT) Standards

Due to the perceived ineffectiveness of the NESHAPS regulations, EPA will be developing standards for specific source categories under the 1990 Clean Air Act Amendments (CAAA) to regulate emissions of 189 hazardous air pollutants. (It should be noted, however, that NESHAPS will generally remain applicable until they are reviewed and revised pursuant to the 1990 CAAA). In writing the 1990 CAAA, congress established an initial list of 189 hazardous air pollutants. EPA was subsequently responsible for developing a list (by November, 1991) of source categories that emit these pollutants and would be subject to meeting emission standards. Industrial external combustion boilers, a source category that includes wood-fired boilers, are currently on EPA's list of potential sources to be regulated. According to EPA (Svendsguard, 1992) emission standards for this source category will be promulgated by November, 2000.

The emission standards, called Maximum Achievable Control Technology (MACT) standards will be established for new and existing sources. The level of control may vary depending on the size, type and subcategory of source and whether it is new or existing. For example, MACT standards for new major sources will not be less stringent than the maximum degree of emission control that is achieved in practice by similar sources. The standard will take into consideration the cost of achieving such emission reduction and any environmental, health and energy impact. MACT standards for existing sources may be less stringent and dependent on the number of sources within a category or subcategory. For category or subcategories with 30 or more sources, MACT may be established based on the average emission limitation achieved by the best 12 percent of existing sources.

The wood sampling and analysis portion of this study focuses on the trace metal contaminants in waste wood and their resulting air emission potential (see Chapter 7.0). Organic emissions have also been characterized by compiling stack emissions data obtained from existing wood-fired facilities throughout the world. Chapter 8.0 summarizes these data and discusses the variables affecting the levels of emissions. Metal and organic emissions will likely be subject to MACT emission standards.

2.2.1.4 Prevention of Significant Deterioration (PSD) Regulations

PSD regulations apply to the construction or modification of major sources located in areas that are attaining ambient air quality standards or are unclassifiable for at least one criteria pollutant. Most states have been delegated authority by EPA to enforce the PSD regulations. Some of the states have developed more stringent interpretations; for example, lowering the emission rate threshold that defines a major stationary source subject to the regulation. A summary of EPA definitions and requirements follows.

Since a waste wood-fired facility is not one of the 28 specific source categories listed in the PSD regulations, a major stationary source is defined as one that has the potential to emit 250 tons per year or more of any pollutant regulated under the Clean Air Act. The more stringent definition used in some states (e.g. Connecticut) is that any source emitting 100 tons per year or more of an attainment pollutant is considered a major stationary source subject to PSD review. When a new source is subject to PSD regulations for one pollutant, a pollutant applicability determination must be made for emissions of other pollutants. To determine which pollutants are subject to PSD requirements, facility emission rates are compared to specific numerical cutoffs. Table 2-1 lists the significant emissions increases for each of the regulated pollutants. For each regulated pollutant emitted in significant quantities, a Best Available Control Technology (BACT) analysis, air quality impact analysis and additional impact analyses (e.g. soils, visibility and vegetation) must be performed.

Table 2-1. U.S. EPA prevention of significant deterioration (PSD) emission rates.

Pollutant	Emission Rate, tons per year (TPY)
Carbon monoxide	100
Nitrogen oxides	40
Particulates	25
Sulfur dioxide	40
Ozone ¹	40
Lead	0.6
Mercury	0.0004
Flourides	3.0
Sulfuric acid mist	7.0

1 Volatile organic compounds as methane.

EPA's definition of BACT is .."an emissions limitation...based on the maximum degree of reduction for each pollutant subject to regulation under the Clean Air Act which would be emitted from any proposed major stationary source or major modification which the Administrator, on a case-by-case basis, taking into account energy, environmental, and economic impacts and other costs, determines is achievable for such source or modification...". In practice, BACT requirements are imposed by most states even for non-major sources not subject to PSD review. In fact, some states require application of BACT for any source requiring a permit. Moreover, air pollution control agencies are increasingly making BACT determinations that put less emphasis on cost and energy impacts and more on whether a type of control or emission limitation is feasible in practice. By requiring new sources to test for emissions, the BACT determination process has been effective in increasing the stringency of emission limits. In order to allow some safety factor in meeting emission limits, equipment vendors continue to over design control equipment. This, in

turn, further lowers tested emission levels, and causes reductions in BACT levels.

The requirements for the air quality impact analysis for PSD sources are more stringent than for non-PSD sources (i.e. non-major sources). Whereas maximum ambient impacts from all sources of air pollution must comply with National Ambient Air Quality Standards (NAAQS), PSD sources must go beyond demonstration of compliance. PSD sources must demonstrate that emissions from the proposed facility in conjunction with other nearby sources will not violate the NAAQS and more stringent PSD increments. A comparison of NAAQS to PSD increments is presented in Table 2-2. An applicant for a PSD permit must also assess the source's impact on soils and vegetation, analyze the air quality impacts associated with direct growth created by the new source, and assess the source's impact on visibility.

2.2.2 Canadian Air Regulations

Federal Canadian regulations have limited authority compared to USEPA. Regulations are developed and enforced on a provincial basis. Based on discussions with Environmental New Brunswick, the Canadian Council of Ministers of the Environment (CCME) have published Operating and Emission Guidelines for Municipal Solid Waste Incinerators that would serve as a benchmark in evaluating "treated" wood combustion.

In addition, Environment Canada is developing a priority substance list for 44 specific sources of air pollution. From discussion with regulators in the Province of New Brunswick, PAH emissions from wood burners will be one of the substances regulated by Environment Canada.

2.3 Comparison of Regulatory Air Emission Requirements Within the Study Area

2.3.1 State and Provincial Air Regulations

This section discusses similarities and differences in the permitting requirements and regulatory climate for waste wood-fired facilities in the study area. A summary for each state and province included in the study area is presented in Appendix A. The comparative discussion is organized in the same manner as the information included in the summaries.

2.3.2 Applicable Regulations

The Clean Air Act requires each state to submit to the EPA a State Implementation Plan (SIP) for implementation, maintenance, and enforcement of NAAQS in each air quality control region (AQCR). EPA also requires nonattainment areas (areas not meeting NAAQS) to revise SIPs to reflect amended federal criteria (see Table 2-2) The SIP establishes the control strategies, emission limitations, and timetables for compliance and is the regulatory framework for evaluating new sources for consistency with air quality goals.

Because individual states are required to develop SIPs to meet national goals, the state regulations have similar components. The basic components common to all state regulations include new source review procedures, emission limitations for criteria pollutants, and nonattainment regulations. As discussed in Section 2.1, some states have been delegated authority by EPA to enforce PSD, NSPS, and NESHAP regulations. In addition, most states (all states in the study area) have developed hazardous air pollutant regulations applicable to a much larger group of compounds than the eight regulated by NESHAPs. A comparison of hazardous air pollutant regulations among the states in the study area is provided in Section 2.3.8.

The majority of the states in the study area require permits to operate all new wood-fired facilities, regardless of size (heat input capacity) or emissions. All new sources (regardless of size or emission rate) in California, New York, North Carolina, Virginia and Washington require permits or certificates prior to construction or operation. Connecticut, Washington and Vermont, however, have permit trigger levels based on heat input and/or annual emission rates. Connecticut requires permits to operate for all new wood-fired facilities with greater than 5 MMBtu/hr heat input or that emit

Table 2-2. Summary of National Ambient Air Quality Standards (NAAQS) and PSD increments as of mid-1992.

Pollutant	Averaging time	NAAQS ¹ ($\mu\text{g}/\text{m}^3$) ²		PSD increments ($\mu\text{g}/\text{m}^3$) ³		
		Primary	Secondary	Class I	Class II	Class III
Carbon monoxide	8-hour	10,000	Same as primary	None	None	None
	1-hour	40,000				
Lead	Calendar Quarter	1.5	Same as primary	None	None	None
Nitrogen Dioxide	Annual	100	Same as primary	2.5	25	50
Ozone ⁴	1-hour	235	Same as primary	None	None	None
PM10 ⁵	Annual	50	Same as primary	4	17	34
	24-hour	150		8	30	60
Sulfur dioxide	Annual	80	None	2	20	40
	24-hour	365	None	5	91	182
	3-hour	None	1300	25	512	700

- 1 National standards, other than those based on calendar quarter or annual averages, are not to be exceeded more than once a year (except where noted). Primary standards are set at levels designed to protect public health. Secondary standards are set at levels to protect public welfare. (Source: U.S. Code of Federal Regulations, 40 CFR 50.4-50.12.)
- 2 $\mu\text{g}/\text{m}^3$ = concentration of air pollutants in ambient air in mass per volume basis; millionths of a gram per cubic meter of air.
- 3 Class I areas include specified national parks and wilderness areas. All other areas are currently classified as Class II areas.
- 4 The ozone standard is attained when the expected number of days per calendar year in which the maximum hourly average

more than five TPY of any pollutant. Washington requires permits for all wood-fired facilities with more than 5 MMBtu/hr input. Vermont has a 90 H.P. (approximately 10 MMBtu/hr) permit trigger level. A comparison of permit trigger level among states in the study area is summarized in Table 2-3.

With the exception of New York State and North Carolina, all of the states in the study area have been delegated authority to enforce PSD regulations. Virginia, Washington and Wisconsin use the same definition of "major stationary source" as EPA for wood-fired facilities, that is, any source with greater than 250 TPY of an attainment pollutant are subject to PSD review. Connecticut uses a 100 TPY PSD trigger level and Vermont uses a 50 TPY trigger level. In California, the trigger level for PSD or "major" sources varies by district. The South Coast Air Quality Management District, for example, uses a 40 TPY trigger level. PSD trigger levels for states in the study area are summarized in Table 2-3. It should be noted that permit and PSD trigger levels may be revised pursuant to the 1990 Clean Air Act Amendments.

Table 2-3. Comparison of permit and PSD trigger levels in selected states.

State	Permit trigger level	PSD trigger level
California	varies by district in SCAQMD any source >0	varies by district in SCAQMD >40 tpy
Connecticut	>5MMBtu/hr >5 tpy emissions	100 tpy
New Brunswick	>0 (all sources) ¹	not applicable
New York	>0 (all sources)	>250 tpy (EPA)
North Carolina	>0 (all sources)	>250 tpy (EPA)
Vermont	wood-fired equipment >90 hp output (approx. 10 MMBtu/hr)	>50 tpy
Virginia	>0 (all sources)	>250 tpy
Washington	>0 (all sources)	>250 tpy
Wisconsin	wood burners > 5 MMBtu/hr	>250 tpy

1 Discretionary. Small sources may be exempt.

Compared to state regulations in the U.S., the Province of New Brunswick (N.B.) has less comprehensive air regulations. The regulations only contain requirements regarding certificates of approval, smoke density standards and performance testing and maximum permissible ground level concentrations. Standards applicable to wood-fired boilers have been established for carbon monoxide, nitrogen dioxide, sulphur dioxide, and total suspended particulate. Based on conversations with N.B. regulators, small dedicated wood boilers at paper mills are exempt from regulation.

2.3.3 Wood Source Considerations

In most states studied for this task, the source of wood fuel has implications affecting the environmental permitting of facilities. Each state has either

developed definitions for different wood fuels or classifies facilities according to the type of wood fuel burned.

Table 2-4 summarizes how the states in the study area define wood or classify facilities according to the two general definitions presented in Chapter 1: "clean" wood and "treated" wood. Most states make a distinction between "clean" and "treated" waste wood in order to impose different permit requirements. In general, permit review procedures are more difficult and permit requirements more stringent for facilities burning "treated" wood than for those burning "clean" wood. For example, permits for facilities burning "treated" wood may require more stringent emission limits, additional (or more effective) control equipment, and testing requirements for both fuel quality and hazardous air pollutant emissions. Only one state, Connecticut, has prohibited by law (Public Act 90-264) the burning of "treated" wood until the environmental impacts have been further studied. Most of the other states in the study area have not permitted such facilities, although there is no law prohibiting it.

California defines waste wood-fired facilities either as "biomass" or "urban wood waste" resource recovery facilities. These facilities are therefore usually subject to a similar level of scrutiny as MSW waste incinerators. The definitions of both "biomass" and "urban wood waste" generally fit within the definition of "clean" waste wood in this report. Burning wood treated with paint, resins, glue, etc. has not been permitted to date; however, based upon evaluation of data in Chapter 7 as well as observations during the sampling program, "treated" waste wood is being burned in facilities permitted to burn "urban waste wood" from demolition activities.

With the exception of California, all the states in the study area classify "clean" wood-fired energy recovery facilities (for steam and/or electricity generation) as wood boilers or combustion equipment. In this case, a facility would be classified as an incinerator only if it was used for volume reduction. However, the classifications differ in some states where burning of "treated" wood is concerned, even when energy recovery is included. For example, New York State classifies waste wood-fired facilities as incinerators of discreet waste streams if "treated" wood is included. Washington considers "treated" wood-fired facilities as solid waste incinerators, as does Virginia, if the facility receives waste wood from off-site sources. In Vermont, there is no precedent for permitting "treated" waste wood facilities and an applicant would need to request a declaratory ruling. Wisconsin is the only state in the study area that does not have a different classification for "clean" or "treated" waste wood-fired facilities. It is important to note that the classification of a facility as an incinerator typically has significant implications in terms of public concern and regulatory scrutiny.

In New Brunswick, there is no large scale burning of "treated" waste wood of which regulators are aware. However, small quantities of "treated" waste wood may be mixed with clean hogged fuel and co-fired in wood boilers at pulp mills. In general, landfilling "treated" waste wood is the preferred option at present with only "clean" wood burning encouraged.

2.3.4 Criteria Pollutant Emission Standards

State emission standards for criteria pollutants are applicable to existing and new sources. They are not used to set permit limits for new wood-fired facilities, although they may be used for permitting very small sources not subject to BACT review. The emission standards are summarized in Table 2-5.

Table 2-4. Classification of wood-fired facility by fuel type.

State	"Clean" waste wood	"Treated" waste wood
California	"Biomass" or "urban waste wood" resource recovery facility	"Urban wood waste" resource recovery facility
Connecticut	"Acceptable wood fuel" fired boiler	Not currently allowed by law (under study)
New York	Stationary combustion installation	Incineration of discreet waste stream
North Carolina	Clean "unadulterated" wood boiler	"Adulterated" wood boiler (incinerator for volume reduction only i.e. no energy recovery)
Vermont	"Natural" wood fired equipment	No precedent - proposed source should apply for declaratory ruling (incineration for volume reduction only)
Virginia	Wood fuel burning equipment	Not currently allowed (test burns planned) burning of waste wood from off-site sources classified as incineration
Washington	Clean wood boiler (biomass energy facility)	Solid waste incinerator
Wisconsin	Wood residue boiler	Wood residue boiler (same permit requirements as clean wood)
New Brunswick	Wood-fired boiler	No precedent - treated wood typically landfilled

With the exception of California and New Brunswick, standards applicable to wood-fired facilities have been established only for particulate matter (PM) and sulfur dioxide (SO₂) emissions. Except for very small facilities in some states, new facilities would be subject to much more stringent permit limitations as discussed in Section 2.3.5 (BACT). The emission limits listed in Table 2-5 for California are guidelines (as opposed to regulatory standards) that have been specifically established for wood-fired facilities based on operating test data in that state. These guidelines are more typical of BACT levels. The draft guidelines listed in Table 2-5 for New Brunswick appear to be extremely stringent compared to recent BACT levels from permitted facilities in the States, especially for carbon monoxide (CO) and nitrogen dioxide (NO_x).

Table 2-5. Comparison of state emissions standards (lb/MMBtu)

State	PM	SO ₂	NO _x	CO	HC
California ¹	0.02	0.0025- 0.025	0.14	0.05- 0.1	0.0006- .006
Connecticut	0.1	1.0	----	-----	-----
New Brunswick ²	0.2	0.1	0.02	0.1	0.1
New York	0.1-0.6	0.2- 2.5	----	-----	-----
North Carolina	0.15- 0.7	2.3	----	-----	-----
Vermont	0.2-0.4	-----	----	-----	-----
Virginia	0.1-0.6	1.52- 2.64	----	-----	-----
Washington	0.4	1000ppm	----	-----	-----
Wisconsin	0.1-0.5	-----	----	-----	-----

Blanks indicate no promulgated standards. Federal standards and/or BACT determined emission limits apply. 1 lb/MMBtu = 429.5 μg/KJ

- 1 Guidelines, not regulatory standards.
- 2 Draft guidelines for compliance, air quality regulation 83-208, New Brunswick Clean Air Act. Also includes stack gas emission limits for HCl (0.075) and formaldehyde (0.1).

2.3.5 Best Available Control Technology (BACT)

Table 2-6 summarizes BACT trigger levels, limits and controls for the study area. This information was obtained from draft permits or the most recently issued final permits obtained from the regulatory agencies. The requirement to perform BACT determinations varies among the states (and districts in California). In some districts in California and in New York State, Virginia and Washington, all sources of air pollution are subject to BACT review. BACT is required for any pollutant emitted more than 5 TPY in Connecticut and more than 50 TPY in Vermont. Vermont uses the terminology "most stringent emission rate". In North Carolina and Wisconsin, BACT is required only for PSD sources.

Emission limits and controls for particulate matter (PM) are fairly consistent in the study area for sources subject to BACT. BACT levels typically range from 0.005 grains/dscf (corrected to 12 percent CO₂) to 0.02 gr/dscf¹. The most stringent PM permit limits were found in Connecticut and Vermont (0.005

¹ 1 pound = 7000 grains

and 0.007 gr/dscf, respectively). The least stringent permit levels for PM were found in recent permits for sources in North Carolina and New York State (0.02 gr/dscf). Multicyclones followed by high efficiency particulate controls, electrostatic precipitators (ESPs) or baghouses, are universally accepted as BACT in the study area. However, interviews with state agencies indicate that some regulators have personal preferences either for baghouses or ESPs. Baghouses are believed by some regulators to have better control of submicron particulate, while other regulators are concerned with the greater potential for baghouse fires.

Most agencies regard selective non-catalytic reduction (SNCR) as BACT for NO_x emissions from wood-fired facilities. The permit limits, however, vary widely. This seems to be largely a function of boiler type and operating experience in a particular state. For example, in California, which has the most operating experience with SNCR, NO_x permit levels range from 0.06 to 0.1 lb/MMBtu on recent installations. Most recent wood- or biomass-fired facilities in California also use fluidized bed combustors, which inherently have slightly lower uncontrolled NO_x levels than other combustor designs. The other states, which have less or no experience with SNCR on wood-fired facilities have higher permit limits, ranging from 0.15 to 0.25 lb/MMBtu. A recent Vermont permit requires a phased tightening of the emission limit as operating experience increases. The only states that have not required SNCR on recent large wood-fired facilities are New York State, North Carolina, and Wisconsin. Regulators from these states said that they would be seriously evaluating SNCR on future applications.

With the exception of California, none of the states in the study area is requiring add-on controls for sulfur oxides (SO_x) emissions. Limiting the allowable sources of wood fuel and the realization that wood has an inherently low sulfur content are the primary justifications for no controls. In addition, test data has shown that at least 90 percent of sulfur in wood fuel remains in the bottom ash due to high alkalinity also in the wood. (Oglesby and Blosser, 1980). In California, recent permits for fluid bed boilers have required limestone injection for additional SO_x control. Test data from these facilities have indicated extremely low SO_x emission, even without limestone injection.

No add-on controls have been required for carbon monoxide (CO) or unburned hydrocarbon (HC) emissions from wood-fired facilities. Based on discussions with regulators, add-on controls such as oxidation catalysts do not appear to be technically feasible, cost effective, or warranted at this time. In most states, permit limits for CO range from 0.3 to 0.6 lb/MMBtu (approximately 250 to 500 ppmvd) and "good" combustion design or control is specified as BACT. The exception again is in California, where most of the recent wood or biomass facilities have required fluidized bed combustors. Although these boiler designs typically emit comparatively low levels of CO and HC (less than 10 ppmv for both CO and HC and often less than 1 ppmv), operating experience has shown much lower availability and higher maintenance requirements and installed costs than more conventional wood-fired boilers such as spreader stokers. In Wisconsin, permits typically do not contain limits for NO_x, CO and HC emissions. Instead, "good combustion technology" is specified. The minimum requirements include a 1250°F boiler exit temperature, 1 second residence time, and maximum 500 ppmv CO concentration.

The Province of New Brunswick does not have formal BACT requirements similar to EPA or state requirements. Instead, emission controls are reviewed on a case-by-case basis. Until recently, installations of industrial-sized wood boilers usually only required controls on PM. Typical controls include multicyclones and ESPs with relatively high emissions limits (0.1 gr/dscf). However, in September, 1991, Environment New Brunswick issued draft Guidelines

for compliance under the Air Quality Regulation 83-208 (Clean Environment Act) for wood-waste boilers in the 3 to 10 mw size range. The draft guidelines recommend stack emission limits for all criteria pollutants in addition to hydrogen chloride and formaldehyde. The guidelines are especially stringent for CO and NO_x compared to recent state BACT determinations.

2.3.6 Nonattainment Review

While the nonattainment provisions of the 1990 Clean Air Act Amendments (1990 CAAA) are not yet in effect, even the largest wood-fired facilities (from 3 to 50 MW depending on combustor design) in most states do not typically trigger review under nonattainment regulations of the old Clean Air Act. Ozone, for which HC emissions are considered the major precursors under the old Clean Air Act, is the pollutant that most often is nonattainment. Wood-fired facilities are typically not "major" emitters of HC emissions by the various states' definitions (usually 50 to 100 TPY), and therefore, do not trigger nonattainment requirements for lowest achievable emission rates (LAER) and emission offsets. Again, California is the exception, by requiring LAER and offsets for any emission increases of ozone precursors in some districts and relatively minor emission increases in others.

A significant consideration for wood-fired facilities in the future, when regulations are promulgated under the 1990 CAAA (by November, 1992), is that LAER and emission offset requirements will be mandatory in many other areas including California. The trigger levels for nonattainment requirements will vary depending on the severity of nonattainment in a particular region. The definition of a "major" source of nonattainment pollutants will vary from 10 TPY (in areas such as southern California) to 25-50 TPY (for the northeast). Moreover, regulation of ozone precursors will be expanded to include both NO_x and HC.

California currently has an emission offset program that allows emissions from biomass resource recovery facilities to be offset based on the emission benefits that occur when biomass that would have normally been disposed of by open burning is used as fuel in an incinerator equipped with emission controls. The applicability of this program may be unique to California, which has a huge agricultural valley and associated biomass generation rate.

There are no non-attainment provisions in the regulations for the Province of New Brunswick.

2.3.7 Hazardous Air Pollutants

Hazardous air pollutants (HAPs) usually associated with wood-fired facilities include benzene, formaldehyde, acetaldehyde, trace metals, and with less probability (based on available test data), polynuclear aromatic hydrocarbons, chlorinated dioxins, and furans. All of these compounds are regulated in each of the states in the study area. Draft guidelines have been issued to regulate stack emissions of formaldehyde from wood boilers in New Brunswick, Canada. Table 2-7 compares the requirements for HAP emissions in the study area. The similarity in state requirements and the fact that all states go well beyond the federal NESHAPS regulations are evident from this comparison. Each state has established acceptable ambient air concentrations that are, for the majority of chemicals, based on occupational exposure limits with health-protective factors applied. These safety factors and the names assigned to the ambient concentrations vary among the states. In addition, California and New York use compound-specific toxicity studies and other sources in addition to occupational exposure limits to develop some of the acceptable ambient concentrations. The other major similarity in the HAP requirements is that all states require some level of dispersion modeling or dispersion-based

Table 2-6. Typical BACT levels based on recent permits (mid-1992).

state	BACT trigger level	PM			NO _x			SO ₂			CO			HC		
		limits, gr/dscf	controls	limits (lb/MMBtu)	controls	limits (lb/MMBtu)	controls	limits (lb/MMBtu)	controls	limits (lb/MMBtu)	controls	limits (lb/MMBtu)	controls	limits (lb/MMBtu)	controls	
California	0-250 lb/day	0.01	multiclones & ESP or baghouse	0.06-0.1	SNCR ³	0.0004-0.04	fuel control, limestone injection	0.021-0.15	fluid bed combustion design	0.001-0.03	fluid bed combustion design					
Connecticut	5 TPY or NSPS	0.005	multiclones & ESP or baghouse	0.175	SNCR	0.044	fuel control	0.29	combustion design	0.05	combustion design					
New Brunswick	No BACT requirement draft guidelines	0.1	cyclone + ESP	0.02	combustion control	0.1	fuel control	0.1	combustion design	0.1	combustion design					
New York	all sources (part 212)	0.02	multiclones & ESP or baghouse	0.23	combustion control	0.03	fuel control	0.35	combustion design	0.1	combustion design					
North Carolina	>250 TPY	0.02	multiclones + ESP	0.35	combustion control	---	---	0.66	combustion design	0.07	combustion design					
Vermont	>50 TPY (MSER)	0.007	multiclones + ESP	0.15-0.25	SNCR	0.07% S content	fuel control	0.3	combustion design	---	---					
Virginia	all sources (large boiler) (small boiler)	0.01 0.1	multiclones + ESP multiclones	0.13 0.2-0.4	SNCR combustion control	0.02 0.02	fuel control fuel control	0.5 0.5	combustion design combustion design	0.2 0.2	combustion design combustion design					
Washington ²	all sources	0.01	multiclones & ESP or baghouse	---	SNCR	---	fuel control	---	combustion design	---	combustion design					
Wisconsin	>250 TPY	0.01	multiclones & baghouse	---	*good combustion control ⁴	---	---	---	*good combustion control ⁴	---	*good combustion control ⁴					

Footnotes:

1. corrected to 12% CO₂; 1 gr/dscf ~ 2.2 lb/MMBtu.
2. no recent permits.
3. SNCR = selective non-catalytic reduction.
4. means >1250° F exit temperature, >1 second residence time, <550 ppm CO.

calculation procedure to evaluate compliance with the regulations. Dispersion modeling (screening level or refined analyses) are required in all states in the study area except Connecticut and Vermont. In Vermont, modeling is optional and up to the discretion of the agency. In Connecticut, the dispersion equation has been solved for an assumed set of conservative meteorological inputs and a maximum allowable stack concentration is back-calculated for compliance demonstration purposes. The calculation procedure is a function of stack height, gas volume rate, and distance from stack to property line.

Application of BACT or LAER is mandatory only in Vermont, Virginia and Wisconsin if HAPs are emitted at rates above compound-specific action levels. In all other states in the study area, BACT would be required only if compliance with acceptable ambient concentrations could not be demonstrated with dispersion modeling.

Table 2-7. Comparison of requirements for hazardous air pollutants.

state/provence	mandatory health risk assessment for carcinogens	Acceptable ambient concentrations (ACC) based on occupational exposure limits	dispersion modeling to evaluate compliance with ACC	BACT or LAER
California	Yes	Yes	Yes	Yes ¹
Connecticut	No	Yes	Yes ²	Yes ¹
New York	No	Yes	Yes	Yes ¹
North Carolina	No	Yes	Yes	Yes ¹
Vermont	No	Yes	Yes ³	Yes ⁴
Virginia	No	Yes	Yes	Yes ⁴
Washington	Yes ⁵	Yes	Yes	Yes ¹
Wisconsin	No	Yes	Yes	Yes ⁴
New Brunswick ⁶	No	No	No	No

Footnotes:

1. Only if required to demonstrate compliance.
2. Back calculation of maximum allowable stack concentration based on ACC.
3. At discretion of agency.
4. Mandatory if action levels (ACCs) exceeded.
5. If required to meet ACCs.
6. Regulates stack emissions instead of ambient concentrations.

Guidelines for preparing health risk assessments for carcinogens have been published only in California. Although there is no automatic requirement to prepare a cancer risk assessment, wood-fired facilities in California are classified as resource recovery facilities with the connotation of incinerators. Large facilities being permitted in the state typically require risk assessments as part of the review process under the California Environmental Quality Act.

In Connecticut, the potential for cancer and acute non-cancer risks became an issue in recent public hearings for a "clean" waste wood-fired boiler. The state agency maintained that its HAP program was sufficiently health

protective and that no further analyses were necessary if the applicant was able to comply with the program. However, the state Attorney General's office, acting in the interest of the public, requested that a targeted health risk analysis be performed for the proposed facility. The analyses demonstrated that the state agency's HAP program was sufficiently health protective.

Air toxics are not formally regulated in the Province of New Brunswick, although draft guidelines recommending stack emission limits have recently been issued for hydrochloric acid and formaldehyde emissions from wood boilers. In addition, Environment Canada is developing lists of priority substances and source categories. Regulation of hazardous air pollutants is imminent in the provinces. The likely pollutants of concern from wood burners are formaldehyde and PAH.

2.3.8 Regulatory Climate/Additional Requirements

To evaluate the regulatory climate for obtaining permits for "clean" and "treated" waste wood-fired facilities, regulatory agencies were contacted to answer the following questions:

- How many facilities are operating/permitted in the state?
- How many recent permits have been issued?
- Do any burn or plan to burn "treated" wood waste?
- What has been the public acceptance of "clean"/"treated" waste wood-fired facilities?
- Has there been much public intervention or hearings?
- To what extent do new facility permits require stack emissions testing (for criteria and noncriteria pollutants), fuel testing, ash testing, and continuous emission monitoring (CEM) equipment?

Table 2-8 summarizes answers to these questions. Several of the states, including California, North Carolina, Virginia, Washington and Wisconsin have many small "clean" wood-fired facilities operating at sawmills, paper mills, and furniture manufacturers. Most of these facilities have with small antiquated boilers. California has approximately 70 "biomass" and/or "urban wood waste" fired resource recovery facilities generating electricity for sale to local utilities. These facilities have typically been encouraged in California as a means to provide incentives to minimize open burning of agricultural (biomass) waste. Other states, including New York, North Carolina, Virginia, Washington, Vermont and Connecticut have fewer facilities operating, under construction or in the permitting stage. Connecticut is the only state in the study group that does not currently have a wood-fired electric generating plant. Two facilities have been in the permitting stage for more than four years and were recently bought out by the power utility for eighteen million dollars to prevent their construction. New Brunswick, Canada has approximately 12 wood boilers operating at pulp and saw mills.

The only states in the study area that have permitted facilities to burn "treated" wood are Virginia and Wisconsin. The Koppers facility in Roanoke, Virginia does not strictly burn "treated" wood. Rather, it has been permitted to burn a mixture of "clean" wood with a waste creosote/coal tar sludge from a railroad tie manufacturing plant. The facility has been tested and has demonstrated compliance with its 99.9 percent creosote destruction and PM emission limits. An older Northern State Power plant in Wisconsin is the only

other facility located in the study area that is permitted to burn "treated" waste wood (railroad ties). Another Koppers facility outside the study area (in Pennsylvania) was identified as a railroad tie burner.

Although "treated" wood combustion has been permitted in Virginia and Wisconsin, it may not be appropriate to characterize other small manufacturing boilers as "clean" wood-fired facilities. Many of these facilities burn treated mill residue such as plywood, OSB or particleboard trim as a substantial portion of their feedstock. The concern is magnified by the fact that many of these are antiquated boilers that may have little if any combustion or stack controls.

There is also an important regulatory issue brewing in several states such as Wisconsin, Virginia and North Carolina that have many small wood manufacturing boilers. These state agencies are attempting to find out how "clean" these manufacturing boilers are and, if necessary, upgrade permit requirements and stack controls for previously grandfathered or exempt systems. A statewide testing program in Wisconsin of small boilers is an example.

There has been interest for wood-fired facilities to burn scraps of plywood and particle board. Wood makes up from 85 percent to 95 percent of these products and the urea formaldehyde and phenol formaldehyde adhesives, which make up the remainder, are composed entirely of molecules of carbon, hydrogen, oxygen, and nitrogen atoms. Nevertheless, burning plywood and particle board scraps has been specifically excluded from these facilities' allowable fuel sources. One facility in Virginia has as a permit condition the provision to conduct a test burn of plywood scraps. Based on the results of emission tests conducted during this test burn, the facility may conditionally be allowed to burn plywood scraps.

With the exception of Connecticut, "clean" wood-fired facilities have been able to gain public acceptance. In Connecticut, two "clean" wood facilities, that originally proposed to burn "treated" wood, have been mired in the permit review process for more than four years. Due to public scrutiny, a law was passed to prevent "treated" and demolition wood as an acceptable fuel source and permit conditions that were originally written for burning "treated" wood have remained in the draft permits even for "clean" wood. These permit conditions include extensive stack testing of noncriteria pollutants in addition to all criteria pollutants. Stack testing will be required for fifteen trace metals and more than ten organics, including benzene, aldehydes, PAHs, dioxins and others that are not expected to be present in detectable concentrations. Public hearings for one of these facilities set a record in the state for number of days. In most other states in the study area, public opposition is expected to be heightened for facilities proposing to burn "treated" waste wood.

All states in the study area require stack compliance testing for most of the criteria pollutants. For larger facilities subject to federal NSPS requirements, compliance testing is mandatory for PM, SO_x, NO_x and CO. California and Connecticut also require stack testing for HC emissions. Other states require testing of fewer criteria pollutants for smaller facilities. All states and New Brunswick have required at least PM testing on all facilities. Of the states in the study area, testing of noncriteria pollutants has only been required in California, Connecticut and to a lesser extent in Wisconsin. The most extensive requirements, as mentioned previously, have been for the proposed plants in Connecticut. California is the only state in the study area for which extensive testing has been performed to date. The California Air Resources Board (CARB) has tested at least four "biomass" and one "urban waste wood" facilities for metals, PAHs and other aromatics, benzene, chlorinated phenols and aromatics, PCBs,

Table 2-8. Comparison of regulatory climate/additional requirements.

state/ province	estimate number of permitted or operating facilities ¹	number of recent permits ²	number of permits for "treated" wood	public acceptance	public hearings	emission testing required		fuel testing	ash testing	CEMs
						criteria	non-criteria			
California	70	10	0	good	Yes	PM, HC, NO _x , CO, SO ₂	representative group tested for metals, benzene, PAH, dioxins, etc.	Yes	Yes	Opacity, CO, NO _x
Connecticut	5	2 draft permits	0	very low even for "clean" wood	Yes	PM, HC, NO _x , CO, SO ₂	for "clean" wood: 29 HAPs including metals, PAH, dioxins, benzene, aldehydes, chlorinated HC.	Yes for "clean" wood - metals	Yes for "clean" wood - metals	Opacity, CO, NO _x
New Brunswick	12	3	0	good	No	PM, HC, NO _x , CO, SO ₂	HCl, formaldehyde	No	No	Opacity
New York	5	1	0	good	No (optional)	PM, HC, NO _x , CO, SO ₂ if >100 MMBtu/hr, PM if <30 MM	Yes for "treated" wood	Yes for "treated" wood	Yes for "treated" wood	Opacity, CO, NO _x
North Carolina	2	1	?	opposition expected for "treated" wood	optional	PM	Yes for "treated" wood	Yes for "treated" wood	Yes for "treated" wood	Opacity
Vermont	2	2	0	opposition expected for "treated" wood	Yes, mandatory for >50 TPI	PM, CO, NO _x	Yes for "treated" wood	Yes for "treated" wood	Yes for "treated" wood	Opacity, CO, NO _x
Virginia	3	4	1	opposition for "treated" wood. State law: Facilities will not be reviewed without local support.	Yes (for major sources, optional for others)	PM, NO _x	Yes for phenols and formaldehyde	Yes	Yes	Opacity
Washington	3 (>50MW) 150 small "clean" wood boilers	0	0	good	No (optional)	PM, CO, HC, NO _x (annually)	Yes for "treated" wood	maybe for "treated" wood	maybe for "treated" wood	Opacity, CO
Wisconsin	2	?	1	good	No (optional)	PM, CO, NO _x	formaldehyde, metals (annually)	maybe for "treated" wood	maybe for "treated" wood	Opacity, CO

Footnotes:

1. All waste wood burning facilities, "clean" and "treated" wood.
2. Last 3 years.

Dioxins, and furans. The Timber Association of California has also pooled its resources in response to an HAP testing requirement to test a representative sample of wood boilers. These data are summarized in Chapter 8.0 in addition to data from other reports of noncriteria emission tests. According to draft guidelines applicable to wood boilers, additional facilities in New Brunswick will require testing for criteria pollutant emissions, hydrochloric acid and formaldehyde.

The only state in the study area that requires both fuel and ash sampling for "clean" wood-fired facilities is Connecticut. As discussed previously, this requirement is on draft permits that carried over conditions that were originally part of a proposal to burn "treated" wood. Based on telephone interviews, regulators from New York and Wisconsin indicated that fuel and ash testing may be required for "treated" waste wood-fired facilities.

Continuous emission monitoring (CEM) requirements for all states are at a minimum, in conformance with NSPS requirements. NSPS require opacity, CO, and NO_x CEMs depending on the size of the facility. Connecticut will also require SO₂ monitoring and may require a CEM for hydrogen chloride. New Brunswick only requires CEMs for opacity.

2.4 Federal Solid Waste Regulations

This section provides an overview of federal solid waste regulations that potentially affect facilities that combust waste wood for fuel. Information on current regulations and policies in each state and province in the study area is presented in Appendix B.

Federal solid waste regulations that potentially apply to new and modified waste wood combustion facilities are contained in the Resource Conservation and Recovery Act (RCRA) of 1976 (42 USC 6901 et seq.) and the Hazardous and Solid Waste Amendments of 1984. The 1984 legislation amended the original RCRA statute in several key areas.

Similar to air pollution regulations, the Environmental Protection Agency delegates authority to states for administering provisions of RCRA where state programs meet or exceed federal standards. In addition the state program must be implemented in accordance with guidelines set by EPA in order to keep its administration of the program. Each state in the study area has complied with, or exceeded RCRA regulations that were initiated in 1980. Therefore, regulatory activity concerning solid waste management and disposal occurs primarily at the state or local level.

2.4.1 USEPA Definitions of Solid and Hazardous Waste

According to RCRA, a solid waste is "...any discarded material... which is...abandoned,...recycled,...and inherently wastelike..." regardless of whether the material is accumulated, stored, reused, reclaimed, recycled, burned or incinerated, or disposed of. The definition of solid waste applies to "garbage, refuse, or sludge; solid, liquid, semi-solid or contained gaseous material" including by-products from manufacturing industries.

Also according to RCRA, a solid waste is a hazardous waste if it exhibits characteristics of hazardous waste identified in Subpart C and Subpart D of the Act, and if it is not purposefully exempted from regulation as a hazardous waste under one or more "exclusions" as defined in Subpart A.

If there is uncertainty about the composition of the feedstock used or ash produced by a facility, a waste characterization and testing process is required to determine whether the material exceeds concentrations for key

inorganic and complex organic constituents. The characterization process for determining whether a material should be managed as a solid or hazardous waste is described in Title 40, Code of Federal Regulations under:

- Subpart A, Section 261.2, Definition of a Solid Waste;
- Subpart A, Section 261.3, Definition of a Hazardous Waste;
- Subpart A, Section 261.4, Exclusions; and
- Subpart C, Section 261.22 and 261.24 that describes Characteristics of Hazardous Waste.

Subpart C evaluates waste based on characteristics of ignitability, corrosivity, reactivity, and toxicity. If waste wood feedstock is determined to be hazardous, then it must be handled in a designated hazardous waste facility and is beyond the scope of this study. Only corrosivity and toxicity characteristics are relevant to waste wood ash, since the material is neither ignitable nor explosive. Corrosivity is determined by measuring the pH value of material.

The RCRA standard for corrosivity is whether the material is "...aqueous and has a pH value less than or equal to 2 or greater than or equal to 12.5..." In most states, only the corrosivity of aqueous ash leachate is measured. However, one state, Washington, has adopted a 12.5 pH corrosivity standard that is used for ash in its solid form, as well. Ash from the combustion of clean wood and treated wood has typical pH values from 8 to 13 (Campbell, 1990).

Two tests have been developed to simulate the leaching characteristics of ash or any material containing hazardous contaminants. The Extraction Procedure Toxicity Characteristic Test, the EP Tox Test, is the older test method, and has been criticized for lack of reliability and consistency. In 1990, EPA adopted a more expansive extraction test, the Toxic Characteristic Leaching Procedure (TCLP) test, now the test method that must be used for regulatory purposes. TCLP is more stringent than the EP Tox Test due to the increased number of organic constituents (such as pentachlorophenol and cresols) requiring testing, and to the sensitivity of the test method used. However, TCLP has also been criticized for its cost and inconsistent sampling procedure (Rogoff, 1991).

The toxicity test in section 261.24 of RCRA establishes the TCLP test methods and concentration levels for potential hazardous wastes.

Selected levels for toxicity characterizations that may affect the classification of ash from waste wood combustion are listed in Table 2-9.

2.4.2 Exclusions under RCRA

Subpart A, Section 261.4 of RCRA contains key "exclusions" or exemptions for wastes that might otherwise be designated as hazardous. There are two exclusions among a list of ten that potentially apply to waste wood combustion facilities. These exemptions prevent facilities that combust certain types of waste wood from being categorically defined as facilities that combust feedstock or produce hazardous ash.

The first pertains to the "household exclusion" for MSW facilities. This provision states that "...A resource recovery facility managing municipal solid waste shall not be deemed to be treating, storing, disposing of, or otherwise managing hazardous wastes for the purposes of regulation [under

Table 2-9. Selected threshold concentrations for toxicity characteristics under RCRA¹

Contaminant	Regulatory level, mg/l
Arsenic	5.0
Barium	100.0
Cadmium	1.0
Chromium	5.0
Cresol	200.0
Lead	5.0
Lindane	0.4
Mercury	0.2
Pentachlorophenol	100.0
Selenium	1.0
Silver	5.0

Footnotes:

1. Excerpted from "Table 1. Maximum concentration of contaminants for the toxicity characteristics" in 40 CFR, Section 261.24. This standard is applicable to any waste containing potentially toxic characteristics.
2. mg/l = milligrams per liter.

federal hazardous waste rules]..." provided that the facility receives and burns only:

- "household waste";
- "solid waste from commercial or industrial sources that does not contain hazardous waste"; and
- that facility operators establish "...contractual requirements or other appropriate notification or inspection procedures to assure that hazardous wastes are not burned in such facility."

This section of RCRA has generated considerable controversy, particularly amendments to the 1990 Clean Air Act. Some claim that ash residue from municipal solid waste facilities should not be exempt from federal hazardous waste rules. The 1990 Clean Air bill avoids a position on this question and defers to RCRA reauthorization legislation that is expected to be acted on in 1992. This could affect the federal and state environmental review and permitting of waste wood combustion facilities.

The second exclusion applicable to potential waste wood combustion facilities pertains to certain types of treated waste wood. Under RCRA, a solid waste is also defined as non-hazardous if the waste "...consists of wood or wood products which fails the test for the Toxicity Characteristic solely for arsenic and which is not a hazardous waste for any other reason or reasons, if

the waste is generated by persons who utilize the arsenical-treated wood and wood products for these materials' intended use."

Some states, such as New York, have accepted both these federal exclusions as part of their solid waste program. New York emphasizes, however, that regulators will closely review wood fuel agreements between fuel suppliers and combustion facilities for guarantees that the facility will not accept or burn hazardous waste. If contractual guarantees on fuel quality cannot be verified, then New York reserves the right to require fuel and/or ash characterization and testing.

2.4.3. Ash Disposal Regulations

The primary solid waste management concern with respect to waste wood combustion facilities is ash characterization and disposal. Ash management is the focus of the solid waste regulatory discussion in the overview of state solid waste regulations in Section 2.5 and in each of the state descriptions included in Appendix B.

Approximately 20 to 25 percent of the total weight of waste burned in mixed-waste MSW facilities is produced as ash residue (Hauser, 1991). Approximately 1 to 3 percent of the total weight of wood burned in waste wood combustion facilities is produced as ash residue (Campbell, 1990). Therefore, smaller quantities of metal contaminants in wood than in municipal solid waste could result in much higher metals concentrations in the wood ash than in municipal solid waste ash due to the lower level of dilution resulting in wood ash than solid waste ash. The overriding concerns about disposal of any ash is the potential for the material to leach heavy metals and other contaminants, and the potential for contaminants in the leachate to enter ground or surface waters.

It is important to note that tests done to date of ash from full-scale operating facilities burning "clean" waste wood and ash from "treated" waste wood combustion do not demonstrate a clear tendency to exceed federal toxicity or corrosivity standards. However, test methods and standards in some states are more stringent than federal standards for some ash characteristics.

2.4.4 USEPA Solid Waste Regulatory Trends

There are several solid waste regulatory issues at the federal level that may affect the permitting of facilities that combust waste wood in the future such as the anticipated reauthorization and amendment of RCRA in 1992, and recent EPA proposed rulemakings on land disposal of contaminated debris. The issues noted below were discussed in 1990 and 1991 during initial RCRA reauthorization hearings and EPA rulemaking efforts.

An important question expected to be addressed at the federal level is if ash from MSW combustion is categorically defined as a hazardous waste, and this is not likely to occur, then it could prompt federal and state regulators to define ash from certain types of waste wood combustion as hazardous. If this occurs, it would significantly change the regulatory review, characterization, testing, and permitting procedure for most wood-fired facilities, particularly those that currently burn or intend to burn "treated" waste wood. It is likely to increase the length of time and expense involved in permitting and operating a facility. However, waste characterization and testing procedures are currently required for all MSW ash and, to a lesser extent, ash from wood-burning facilities.

A second issue likely to be raised in RCRA reauthorization is establishment of a national recycling goal of 25 percent (or some other target recycling

rate) as a prerequisite for permitting MSW combustion facilities. The 25 percent goal was proposed during rulemaking in 1990 and subsequently rescinded by EPA (Fields, 1991). The establishment of a target recycling rate for MSW combustion facilities will in turn result in a discussion and listing of which materials are recyclable; whether burning waste wood for fuel counts towards recycling goals; and whether MSW facilities that burn waste wood will have to dedicate a portion of the available feedstock to alternative end uses to meet recycling quotas.

A third issue concerns the effect of a new rule proposed by EPA in May, 1991 under 40 CFR, Part 268. The rule may enhance the recoverability of waste wood for energy. Among other issues, the rule addresses development of a Best Demonstrated Available Technology (BDAT) standard for certain types of "contaminated debris." EPA has proposed "eight preliminary subcategories of debris that may pose different problems in treatment." One of the categories is wood. Other categories include brick, concrete, rubber, and plastic. The significance of the rule to waste wood combustion is that EPA, in explaining a rationale for a potential BDAT standard for contaminated debris, has emphasized that certain materials such as "contaminated" wood, may best be handled through combustion technologies:

"...The treatability of debris is also affected by the physical and chemical characteristics of the chemical contaminants on the debris, and their respective concentrations. For example, it may be reasonable to incinerate a debris material contaminated with high concentrations of toxic organics and low concentrations of metals..." (Federal Register, May 30, 1991, Vol. 56, No 104, p. 24457).

2.4.5 Federal Solid Waste Guidelines in Canada

The Canadian federal government does not publish solid waste regulations specific for the combustion of waste wood or other forms of solid waste. Regulatory jurisdiction is left primarily to the provinces. Guidelines for the operation of municipal waste incineration have been published, however, by an interprovincial task force under the Canadian Council of Resource and Environmental Ministers (CCREM). The province of New Brunswick has published site and design requirements for landfills but does not require, for example, a hazardous waste characterization of waste wood ash or feedstock. Environmental standards for combustion systems in New Brunswick and other provinces are addressed primarily through air regulatory controls. The province of Ontario has proposed air quality rules specific to waste wood combustion that include requirements for ash testing under a leachate extraction procedure test. The test is detailed in the provincial Environmental Protection Act, Schedule 4; however, these rules have not been adopted to date.

While the CCREM guidelines may end up as a reference for how ash disposal from "treated" waste wood combustion is reviewed in New Brunswick in the future, they may not be appropriate for ash from waste wood combustion facilities. In a section on ash management, the CCREM guidelines recommend (generally) that ash should be tested for physical and chemical characteristics, be quenched to prevent fugitive emissions, and that bottom ash should be treated and disposed of separately.

With respect to hazardous waste determinations, the Canadian government has established a law entitled "Transportation of Dangerous Goods Regulation" under its federal transportation authority, that pertains to the transport of hazardous materials. The law does not have direct regulatory authority for

ash management from combustion; however, some provincial officials use this law as guidance when making determinations about proper disposal for substances believed to have toxic characteristics (Godin, 1991). Most threshold toxicity concentrations under this law are similar to standards in the U.S. EPA's TCLP procedure and are noted in the discussion of state and provincial solid waste regulations in Section 2.5.

2.5 State/Provincial Solid Waste Regulations

This section discussed state or provincial solid waste management, permitting, and regulatory issues affecting waste wood facilities in the study area. This discussion addresses both waste wood processing and combustion facilities.

As noted in Section 2.4, solid waste regulations in each state in the study area have met or exceeded standards required by the Federal Resource Conservation and Recovery Act. Therefore, the waste management, permitting, and enforcement responsibilities have been delegated to the states. In Canada, solid waste management is essentially under provincial jurisdiction, although guidelines have been developed at the federal level for MSW combustion. The Province of New Brunswick relies on landfills for waste disposal; their solid waste strategy is based on landfill design and management standards.

In addition, six states in the study area have developed hazardous waste regulations in addition to federal rules. The states include California, Connecticut, North Carolina, Virginia, Vermont, and Washington. With the exception of California, the rules tend to be only slight modification to the overall approach established in RCRA. The Province of New Brunswick had not established specific hazardous waste regulations and relies, instead, on consultation with and guidelines promulgated by the federal government in Canada, which governs the transportation of hazardous substances.

A variety of state and provincial solid waste management, permitting, and regulatory issues affect the regulatory review and permitting of waste wood processing and combustion facilities. Key issues and their significance are summarized below. A summary of solid waste regulatory strategies in the study area is presented in Table 2-10.

2.5.1 Regulatory Definitions of "Clean" and "Treated" Waste Wood

The first issue is whether there are regulatory definitions under solid waste rules that distinguish "clean" waste wood from "treated" waste wood, and what the definitions are. If there are no definitions, it may be unclear how to review and permit a waste wood processing or combustion facility.

In the study area, there are definitions for "clean" waste wood in all states, except California and New Brunswick. Specific language and definitions used to describe "clean" waste wood as defined in this report vary widely. For example, the terms harvested, virgin, yard, or untreated waste wood may be used to define and describe "clean" waste wood. Some states indirectly define "clean" waste wood by specifically defining what is not clean, such as wood from demolition activities. One state, California, uses a broad definition of wood waste that includes wood generated from the manufacturing, harvesting, processing, or storage of wood materials, or construction and demolition sources. Overall, however, the states tend to consider harvested wood, yard waste, some or all pallets, and mill residue burned on-site for fuel as "clean" wood fuel.

Currently, four states, Connecticut, New York, Vermont, and Washington, have specific regulatory definitions for "treated" waste wood as defined in this

Table 2-10. Summary of solid waste management strategies in the study area affecting waste wood combustion and ash disposal¹.

Solid Waste Regulatory Policy	CA	CT	NC	NY	VT	VA	WA	WI	NB (CAN)
a. Regulatory definition for "clean" waste wood.		Y	Y	Y	Y	Y	Y	Y	
b. Regulatory definition for "treated" waste wood.		Y		Y	Y		Y		
c. Regulatory definition of construction or demolition debris that includes waste wood.	Y	Y	Y	Y	Y	Y	Y	Y	
d. Energy recovery of treated wood specifically defined to not be a "recycling" activity ² .	Y	Y	Y	Y	Y	Y	Y	Y	
e. State has recycling targets that discourage waste wood from being landfilled ³ .	Y		Y	Y	Y	Y	?	?	
f. Solid waste regulators classify "clean" waste wood combustion for energy as ⁴ :									
Incineration									
Energy/resource recovery	Y	Y	Y	Y	Y	Y	Y	Y	Y
Wood residue combustion							Y	Y	Y
g. Solid waste regulators classify "treated" waste wood combustion for energy as ⁴ :									
Incineration		Y		Y	Y		Y	Y	?
Energy/resource recovery	Y		Y			Y			
Wood residue combustion									
h. Waste characterization of feedstock required for "treated" waste wood combustion ⁵ .		Y	?	Y	Y	Y	?	Y	
i. Ash from waste wood combustion classified as ⁶ :									
Solid waste			Y	Y	Y	Y	Y	Y	Y
Special waste	Y								
Other waste residue		Y							
j. Ash management plan required.	?	Y	Y	Y			Y	Y	
k. Waste characterization of ash from "treated" waste wood combustion required ⁷ .	Y	Y	Y	Y	Y	Y	Y	Y	?
l. Non-hazardous "treated" wood combustion ash to be disposed of in:									
Lined landfill	Y			Y	Y	Y		Y	
Unlined landfill			Y						
Lined monofill or monocell	Y	Y		Y	Y		Y		Y
On-site monofill at the facility	Y		Y			Y		Y	Y
m. Alternative utilization standards for ash disposal ⁸ .	Y		Y	Y	Y		Y	Y	

Footnotes:

1 A "Y" indicates this regulatory strategy is in effect at the state or

Table 2-10 concluded.

province noted. A blank indicates the strategy is not in effect. A "?" indicates that the state/province strategy is uncertain, based on a review of written documents and telephone interviews with regulatory officials.

- 2 Although most states do not view energy recovery of waste wood as consistent with state recycling goals, conversations with state regulators indicate interest in further defining certain combustion activities as compatible with "reuse" goals and as preferable to mixed MSW incineration.
- 3 Several states are in the process of restricting the land disposal of waste wood as part of their efforts to meet statewide recycling targets. Some states, such as Virginia, note that "clean" wood is a recyclable material while "treated" wood is not. In other states, such as California, all waste wood types are included. Overall, the trend points to an increasing need for additional reuse, recycling, or disposal options for waste wood.
- 4 Solid waste regulatory definitions about facility classifications vary among states/provinces. In California, for example, any combustion facility, whether burning for volume reduction or energy recovery, is termed a "transformation" facility. Similarly, in Vermont, combustion facilities are termed "treatment facilities." This table shows the general regulatory approach taken by each state/province although the exact classification may differ.
- 5 In many states, feedstock characterization will be required under both solid waste and air quality regulations while other states, such as California, rely on fuel testing as part of the air quality review only.
- 6 In some states, such as Connecticut and New York, fly ash may be managed differently from bottom ash for disposal. Fly ash typically contains higher concentrations of metals and organics than either bottom or combined ash.
- 7 States do not specify "treated" wood combustion as being subject to toxicity waste characterization in their rules. States typically have authority, however, to require ash testing under state law or RCRA, if ash contents are uncertain or if data are unavailable on ash or fuel contents.
- 8 In many states, there is a regulatory procedure for demonstrating that ash or other wastes have alternative "beneficial uses" versus landfilling (such as landspreading, soil amendment or additive to concrete). This process may require ash testing and a petition for a variance to landfilling.

report. The definitions distinguish between "clean" and "treated" waste wood; however, the specific language varies. For example, the terms adulterated, urban, and demolition waste wood may be used to describe "treated" wood. The states generally tend to consider painted or stained wood, wood containing glues or resins, wood from demolition sources, and wood treated with preservatives or other materials as "treated", and therefore, potentially subject to regulatory scrutiny.

2.5.2 Regulations or Policies on C/D Waste Wood

A second issue is whether there are regulations or policies for the management and disposal of construction and demolition waste, and whether wood is specified. If there are C/D regulations or policies and they specifically

address wood, this can affect the review and permitting of processing and combustion facilities that receive C/D waste wood.

Presently, all of the study area, except New Brunswick, has regulations or policies that define C/D waste. Most of the regulations specifically mention wood as a type of C/D waste. For example, New York and Virginia have a specific definition for C/D waste that includes wood. Other states, such as North Carolina and Washington, refer to wood as an acceptable waste in design standards for the disposal of C/D waste materials in "C/D landfills" or "inert debris" landfills.

2.5.3 Is Waste Wood for Fuel Considered Recycling?

Many states have specific recycling goals due to comprehensive waste management in response to decreasing landfill capacity; public interest in recycling; delayed or canceled new MSW combustion facilities; increased siting and permitting costs; and escalation of tipping fees. Several states in the study area including California, Connecticut, New York, North Carolina, and Vermont have adopted recycling goals of 25 to 50 percent within several years.

If the processing and use of waste wood for fuel does not contribute to recycling goals, there may be greater regulatory or political barriers. In addition, there may be less incentive for solid waste managers and regulatory staff to review and permit waste wood facilities. No states in the study area currently define processing and using waste wood for fuel as recycling. In New Brunswick, this issue has not been decided either way.

2.5.4 Definitions of Waste Wood Combustion Facilities

One of the most important regulatory issues affecting a waste wood combustion facility is whether it is subject to the same environmental review and permitting process as a facility that burns MSW. Definitions, regulations, and policies vary among states and provinces, and sometimes depend on the specific types of wood burned at a specific facility. In addition, the relevant regulations are developed and implemented by different divisions of a state or provincial environmental regulatory agency, depending on the state or province. In some states and provinces, the air permitting division of the environmental agency has jurisdiction over the regulatory classification of waste wood combustion facilities. In others, the solid waste permitting division has jurisdiction, or jurisdiction is unclear, or untested.

Table 2-10 summarizes how state and provincial solid waste agencies in the study area define a combustion facility that burns "clean" waste wood compared to how a facility is defined if it burns "treated" waste wood. A waste wood combustion facility generally is defined as one of three types of facilities including an incinerator; energy or resource recovery facility; or wood residue boiler. The actual solid waste permitting process used for a facility varies, depending mostly on whether regulators view the waste wood as combusted primarily for disposal or energy recovery.

- In some states, a facility is defined as an "incinerator" if it only burns waste to reduce volume, whereas an "energy recovery facility" is defined as an energy producer first and a waste combustion unit second. Some states in the study area classify "treated" waste wood combustion as "incineration," even if the facility is developed as a power plant. Facilities burning "clean" wood, however, are classified as "energy (or resource) recovery" or "wood residue" facilities because the "clean" wood is assumed to be collected for use as a fuel only and not for waste disposal purposes. This regulatory approach is in effect in Connecticut, New York, Washington, and Wisconsin.

- In other states, the terms "incineration" or "energy recovery" are subsumed under broader facility definitions such as a "treatment facility" in Vermont; "transformation facility" in California; "energy recovery and incineration facility" in Virginia; or "resource recovery facility" in North Carolina. In these states, the regulatory procedure is similar to the approach previously described. In both Vermont and North Carolina, for example, regulators indicate that they regard "treated" waste wood combustion as incineration, although state policy is not explicit due to anticipated fuel and ash properties and related disposal needs.

Overall, interviews with state and provincial solid waste regulators in the study area indicate mixed opinions about whether facilities that burn "treated" waste wood for energy should be regulated as incinerators, energy/resource recovery facilities, or wood residue boilers. In many cases, no regulatory precedent exists for "treated" wood combustion, except perhaps from the on-site burning of mill residue produced by primary and secondary wood products industries. (In the study area, this is true in Connecticut, Vermont, Virginia, and New Brunswick). Seven of the nine states/provinces make a regulatory distinction, however, between the definition of "clean" waste wood and "treated" waste wood. In most instances, state or provincial solid waste rules consider "clean" waste wood combustion facilities to be energy recovery facilities, while the combustion of "treated" waste wood is defined as the combustion of mixed municipal solid waste and is therefore incineration.

The determination of how waste wood combustion facilities are defined by solid waste regulators can have a direct effect on the review and permitting process. First, in many states, solid waste policies actively discourage siting and construction of new combustion facilities that are construed to incinerate solid waste. Yet, the source separation of wood from the waste stream to meet recycling goals, avoid landfilling, or prevent illegal disposal is frequently encouraged. One state, North Carolina, has a solid waste policy that favors "incineration for energy production" compared to "incineration for volume reduction."

Second, positions taken by solid waste regulators may be inconsistent with air regulators in the same state or province. For example, in Washington during review and permitting by air regulators, a "treated" waste wood combustion facility will be viewed as an energy recovery facility. Yet, solid waste regulators will regard the same facility as a type of incinerator. How these issues are addressed, coordinated, and reconciled has a large impact on the way solid waste rules and policies affect the energy recovery of waste wood.

2.5.5 Definitions of Waste Wood Processing Facilities

Several states in the study area have specific regulations for recycling facilities that process waste wood into fuel. Regulatory definitions of the facilities vary among states. The definitions depend on the types of materials in addition to wood that are processed. Definitions also depend on whether a processing facility is part of an integrated materials recovery program, or whether it is a private supplier of fuel for power. For example, in California, a waste wood processing facility is permitted as a "materials recovery facility." In Connecticut, it is permitted as a "solid waste volume reduction facility." In New York, it is permitted as a "solid waste management facility." In Virginia, it is permitted as a "resource recovery system."

2.5.6 Ash Disposal Regulations

Each state in the study area has established solid waste regulations that apply to the characterization, testing, and disposal of ash from wood-fired facilities. New Brunswick regulates the design of landfills, but does not specifically regulate wood ash disposal.

The type of characterization, testing, and disposal required for wood ash varies among states. The regulatory determination of which is required depends on the type of wood fuel burned, the known or expected characteristics of the ash, and the historical (permitted) disposal method used by an ash generator. Table 2-10 gives a summary of the type(s) of disposal allowed for wood ash in the study area.

Some states have established specific regulations and policies or experimental programs concerning the reuse of wood ash for other purposes. Examples include the reuse of wood ash as a soil amendment on agricultural lands, in the chemical extraction of heavy metals ("forced leaching"), as a stabilizer in cement mixtures, in vitrification with glass, and in reducing metal solubility through chemical stabilization.

Interviews with solid waste regulators in the study area reveal the following overall trends regarding the disposal or reuse of ash from waste wood combustion facilities:

- Most solid waste regulators have received minimal, if any, data on the characteristics of ash from waste wood combustion. The primary exception is California and other northeast states not in the study that are familiar with land-spreading wood ash, such as Maine. This is especially true for "treated" waste wood. Therefore, a facility intending to combust significant quantities of "treated" waste wood will be asked to provide test data on ash characteristics. Issues of particular interest are ash toxicity, corrosivity and specific metals concentration.
- In many states, ash from the combustion of "clean" waste wood (e.g. harvested wood, some mill residue, and perhaps pallets) is assumed to have non-hazardous characteristics. Regulators expect to invoke authority to require ash testing, however, for "treated" waste wood. The extent of testing will depend on how much of the fuel will be "treated" waste wood, the variability of waste wood used for fuel, and the known characteristics of the fuel. Testing may be required not only for a hazardous waste determination. It may also be required for petitions seeking to reuse the ash for other purposes, or to assess the risk of leaching from ash to determine appropriate land disposal options.
- The process for determining ash characteristics in most states is the same as waste characterization procedures outlined in Subpart C of RCRA (described in Section 2.4.1. of this report).
- Table 2-11 lists state threshold limits for selected toxicity characteristics. In most cases, the thresholds are identical to federal RCRA standards with the exception of California, North Carolina, and New Brunswick. The Toxicity Characteristic Leaching Procedure is the generally acceptable test, although some states use a more stringent leaching procedure. For example, in California, a waste extraction test must be performed if any waste exceeds a Soluble Threshold Limit Concentration for toxicity.
- Solid waste regulators tend to be most concerned with high pH values (greater than 12.5) in waste wood ash as well as the presence of inorganics and heavy metals in the ash.

- In the study area, ash from "clean" waste wood and "treated" waste wood is usually required to be disposed of in lined landfills, or dedicated monofills within lined landfills. Most states have a process, however, whereby facility operators may petition a solid waste agency for a variance from landfill disposal requirements. Variances to landfilling or monofilling are granted based on "inert" qualities of the ash, or its potential "beneficial use" as a soil amendment, fill material, or aggregate in bonding applications. In some states not in the study area, such as Maine, Idaho, and New Hampshire, ash from "clean" waste wood is commonly spread on agricultural land.

Table 2-11. State threshold limits of selected inorganics for toxicity characterization (units are mg/l).

State	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Molybdenum	Nickel	Selenium	Silver	Zinc
CALIFORNIA (b)											
STLC (mg/l)	5.0	1.0	5.0	25.0	5.0	0.2	350.0	20.0	1.0	5.0	250.0
TTLc (mg/kg)	500.0	100.0	500.0	2500.0	1000.0	20.0	3500.0	2000.0	100.0	500.0	5000.0
CONNECTICUT (c)	5.0	1.0	5.0	ns	5.0	0.2	ns	ns	1.0	5.0	ns
NORTH CAROLINA (d)	0.5	0.1	0.5	ns	0.5	0.02	ns	ns	0.1	5.0	ns
NEW YORK (c)	5.0	1.0	5.0	ns	5.0	0.2	ns	ns	1.0	5.0	ns
VERMONT											
Toxicity limit	5.0	1.0	5.0	ns	5.0	0.2	ns	15.0	1.0	5.0	250.0
Soil Amendment Limit (mg/kg dry wgt basis)	ns	10.0	1000.0	1000.0	250.0	10.0					2500.0
VIRGINIA (c)	5.0	1.0	5.0	ns	5.0	0.2	ns	ns	1.0	5.0	ns
WASHINGTON											
"Dangerous Waste"	5.0	1.0	5.0	ns	5.0	0.2	ns	ns	1.0	5.0	ns
"Extremely Haz. Waste"	500.0	100.0	500.0		500.0	20.0			100.0	500.0	
WISCONSIN (c)	5.0	1.0	5.0	ns	5.0	0.2	ns	ns	1.0	5.0	ns
NEW BRUNSWICK (e)	5.0	0.5	5.0	ns	5.0	0.1	ns	ns	1.0	5.0	ns

(a) All values are in mg/l unless otherwise noted. The symbol "ns" means no adopted standard.

(b) STLC refers to the Soluble Threshold Limit Concentration; TTLc refers to the Total Threshold Limit Concentration as calculated on a wet-weight basis. Both STLC and TTLc are calculated on the basis of individual elements, not compounds.

(c) These states generally follow federal standards for toxicity characteristics in RCRA, Subpart c, Section 261.

(d) North Carolina uses standards that are 1/10 of the EPA in order to minimize risk from leachate in landfills. This fraction was chosen, according to state officials, not as a result of a risk analysis but rather as a safety factor since most landfills in the state are currently unlined.

(e) These are Canadian federal standards that are promulgated under a "Transportation of Dangerous Goods Regulation." They only affect the transportation of materials and are used as guidelines for the disposal of hazardous wastes.

2.6 Energy Policies in the Study Area

This section describes energy policies in the study area that affect the siting and construction of new waste wood combustion facilities and the conversion of existing facilities. The emphasis is on federal and state energy policies that affect development of wood combustion facilities rather than environmental regulations and permitting standards. Energy policies are relevant because they can either encourage or constrain the development of wood-fired facilities.

2.6.1 Introduction

A variety of federal and state energy policies generally affect waste wood combustion and wood energy development. While energy policies do not usually distinguish between the different types of waste wood, they may be critical to successfully complete a new wood energy project or conversion.

For wood products manufacturers that use waste wood for on-site heat and steam needs, energy policies are relevant in several ways. State or federal tax credits for renewable energy or energy efficiency improvements may be available. Or, states may offer incentive grants for retrofitting furnace and boiler equipment to burn wood, provide job training in wood conversion technologies, or help fund wood energy demonstration projects (NCEPC, 1989; DNYSEP, 1991). These policies usually do not distinguish between the types of waste wood used.

They may, however, be critical to the economic viability of a new wood energy project or industrial conversion. For wood-fired power plants, energy policies can have an important effect in several ways. Wood-fired power plants are developed by non-utility, independent power producers (IPP) that sell power to a local electric utility or regional utility power grid. To accomplish this, IPP's must negotiate with utilities to determine the amounts of power that will be provided to the utility, and the price the utility will pay for the power. These negotiations are influenced by state and federal government energy policies that affect all types of renewable energy development. Most energy policy issues affecting wood-fired power plants are not unique to waste wood combustion, but apply to the development of other renewable energy sources as well.

State energy policies and public utility commissions (PUCs) affect and may determine the terms of power sales contracts between IPP's and utilities, the permitted rates of return from power sales, and the role of energy efficiency programs (VCEP, 1990). Overall, state and local energy policies are responsive to the relative availability of power in a given region and the marginal cost of power from other sources. If, for example, power from waste wood combustion is more expensive than investments in energy efficiency or other renewable sources, PUCs are unlikely to sanction new power purchases from wood-fired combustion. On the other hand, if waste wood combustion is more economic or environmentally beneficial, the PUC could encourage its use.

A variety of incentives affect development of wood-fired power plants. Direct incentives include solicitations from public or private utilities seeking bids on power contracts by "qualified" renewable energy sources, or the availability of investment tax credits for certain types of power sources, for example, the early round of Standard Offer #2 and Standard Offer #4 contracts offered by Pacific, Gas, and Electric Company in California in the early 1980's. These offers stimulated wood-fired power plant development based on a fuel price forecast that anticipated high costs of fossil fuels in the future (Delaney and Zane, 1992). These offers have since been withdrawn as the price of oil and natural gas did not increase as expected.

Indirect incentives to wood-fired power production result from high avoided costs of alternative power sources and from public policies that value energy from renewable resources. In many states and provinces, the economic and environmental benefits attributed to renewable energy production, including wood, are just beginning to be reflected in power purchase rates offered to independent power producers (DNYSEP, 1991).

2.6.2 Federal Energy Policies

The passage of the Public Utilities Regulatory Policy Act (PURPA) in 1978 (Section 201) guarantees certain small power producers and cogeneration facilities the opportunity to produce and sell power to public and private utility companies. PURPA is administered by the Federal Energy Regulatory Commission (FERC) whose overall purpose is to assure that adequate supplies of energy are available for U.S. consumers that also provide sufficient rates of return to energy providers. FERC has promulgated rules to implement PURPA (CFR Title 18, Part 292) that determine the status of qualifying facilities eligible for PURPA benefits. Six criteria under PURPA that affect wood-fired power development are summarized below. Most wood-fired power plants meet these criteria.

1. Electric utilities are required to purchase excess power offered for sale by qualifying facilities (QF).
2. A QF is a generating project that:
 - Is owned by an individual or a corporation, and no more than 50 percent by a public utility;
 - Produces electrical energy primarily by the use of a renewable sources (including biomass) as long as 75 percent or more of the total energy input is from renewable sources; and
 - Has a power production capacity of 80 megawatts or less.
3. Electric utilities required to purchase a QF's excess energy include, state or federal agencies, and other entities that sell electricity.
4. The rate at which electric utilities are required to pay a QF has three parts:
 - They shall be just and reasonable;
 - Not discriminate against the QF; and
 - Not exceed the utilities' "avoided cost," the marginal or incremental cost to a utility of energy or capacity which, without supply from a QF, would have to be generated internally or obtained externally.
5. PURPA authorizes FERC to exempt QFs (up to 30 megawatts) from certain provisions of the Federal Power Act and Public Utility Holding Company Act, and financial and administrative regulations of electric utilities.
6. PURPA requires FERC to issue regulations defining QFs and setting standards for rates.

PURPA stimulated development of independent power plants and cogeneration facilities using wood fuel. Access to the power grid, the determination of rates, and conditions for the sale of power are typically regulated, however, by state level PUCs. PUCs focus on both the cost-effectiveness and reliability of power, and balance the interest of power producers to achieve reasonable rates of return over the life of a plant with the broad public interest of obtaining reliable and cost-competitive power.

Currently, many PUCs and energy policymakers are striving to enhance the role of "demand side" pricing in power consumption by encouraging major electric utilities to invest in and provide energy efficiency programs (VCEP, 1990; CEC, 1990; VA Energy Patterns and Trends, 1990). These efforts may forestall the development of major new power supplies in areas where energy supply is relatively abundant compared to demand.

2.6.3 Provincial Energy Policies in New Brunswick

Similar to the United States, most wood-fired power generation in New Brunswick is provided by non-utility producers. Examples include large pulp and paper mills that sell excess power to the grid, or small district heating systems such as the facility at the University of New Brunswick in Fredericton. As of mid-1992, the planning and development of two independent wood-fired facilities of 25 MW net power production is underway. The viability of small non-utility power generators is determined by "buy-back" rates (similar to PURPA in the U.S) based on an avoided cost calculation for alternative fuel sources. The willingness to invest in non-utility power production is a function of the buy-back rate offered by the major provincial utility (New Brunswick Power) and the imported costs of oil and coal. The province has a policy to encourage non-utility generation from wood and to encourage the provincial Public Utilities Board to promote non-utility generation during their review of buy-back rates (An Energy Policy for New Brunswick, 1990).

2.6.4 State Energy Policies

Most state energy planners and policymakers support, in concept, the increased use of waste wood for fuel. In general, they believe wood fuel and waste wood in particular can be an important part of an overall renewable energy supply strategy. State energy planners anticipate greater wood energy recovery opportunities in cogeneration and industrial conversion projects than in the construction of new power plants (NWPPC, 1991; NCEPC, 1989). In several states, this view can be attributed to either an excess supply of power and/or low avoided costs for qualifying facilities, both of which decrease the value of new investments in power production. In addition, in states and provinces with significant numbers of aging industrial boilers, conversions to new wood burning technologies may provide the best opportunities for gains in both energy efficiency and energy recovery from renewable sources. Table 2-12 compares energy policies and wood energy consumption in the study area.

Emerging state energy policies may enhance the role of waste wood combustion facilities in the future. State level policies increasingly emphasize efficiency and investment in renewable sources such as biomass, wind, and solar power sources. As a result, PUCs are beginning to include environmental and economic "externality" benefits and costs in ratemaking decisions for new sources of power. These efforts are underway in states such as California, Connecticut, New York, Vermont and in the province of New Brunswick. The evaluation of externalities may have a positive impact on the competitiveness of wood-fired power plants compared to conventional fossil fuel plants in time (Richard, 1992).

Despite the difficulty in allocating externality costs and benefits in ratemaking decisions, energy policies and planning documents already in place emphasize several economic and environmental benefits unique to biomass combustion. State energy policymakers generally believe such benefits should be reflected in ratemaking decisions or state economic incentive programs. The policy perspective of energy planners may not be the same, however, as solid waste planners and environmental regulators in the same state or province.

Policy statements that reflect the positions of state and provincial energy agencies are presented in the following section (2.6.5). The statements were obtained from the most recent energy planning documents in each state or province. Energy planners do not usually differentiate between "clean" and "treated" wood fuel sources for two reasons. First, the use of waste wood processed for fuel is fairly recent. In many states, energy planners are unfamiliar with either the fuel potential or combustion characteristics of processed wood fuel. Second, energy planners do not usually distinguish among different types of wood fuel because the overall contribution of all wood fuel combustion is usually small compared to oil, gas, nuclear, or coal sources. Greater attention to wood combustion, however, is occurring due to the presence of the wood energy industry in states such as California and Wisconsin, and in the province of New Brunswick. In addition, specific policies to secure more energy from wood combustion are being developed due to the advantage of wood compared to other energy sources, as in the province of New Brunswick.

2.6.5 Examples of State/Provincial Energy Policies Regarding Wood Combustion

- "The use of biomass as a fuel resource can often alleviate environmental problems associated with disposal or in-field burning" (California Energy Development Report, 1988).
- "The severity of the environmental effects of woodburning plants falls between gas and oil-fired generation, but wood is not as risky as these other fuels because it can help delay global warming" (Northwest Power Planning Council, 1991).
- "There are many advantages to expanding the use of wood biomass fuels in Vermont...to the extent that wood replaces non-renewable fossil fuels, there can be a significant reduction in Vermont's production of greenhouse gases." (Vermont Comprehensive Energy Plan, 1991).
- "...facilities awaiting approval from Connecticut DEP are expected to use [BACT] technologies for pollution abatement. This in combination with complete combustion which results from high temperatures, assure that this fuel is used in the least polluting manner. There is concern about emissions from demolition wood. Research is needed in this area. These plants provide an opportunity to reduce the landfill requirement which would otherwise be needed, and offer a much needed market for wood residues presently left in our forests" (Connecticut's Energy Future, 1991).
- "Biomass fuels, with the exception of municipal solid waste, are relatively clean burning. Their low sulfur and nitrogen content permit burning without the need for acid gas scrubbers. Their carbon dioxide emissions on an energy basis are comparable to coal but there is one important difference: the

Table 2-12. Summary of wood energy use and energy policy in the study area.

State energy policies	CA	CT	NC	NY	VT	VA	WA	WI	N.B.
1. Current percentage of total electrical generation from all types of wood. ^a	1.9%	<1%	<1%	<1%	2.3%	1.4%	<1%	0.6%	5%
2. Percentage of total state industrial energy consumption from all types of wood. ^b	<1%	na	na	14%	<1%	12%	32%	7.2%	40%
3. State policy specifically supports "clean" waste wood combustion.	X	X	X	X	X	X	X	X	X
4. State policy explicitly recognizes wood from the waste stream as a viable fuel source.	X	X		X		X		X	
5. State policy wants the combustion of wood to increase.	X	X	X	X	X	X	X	X	X
6. State-level financial incentives exist for using wood as a fuel. ^{c,d,e,f}		X	X	X				X	

Notes:

- a. These figures do not include other types of biomass utilization such as residential firewood use, or process steam or heat for internal manufacturing uses.
- b. States typically divide wood energy consumption between residential and industrial sectors. Some states, such as California, evaluate biomass energy potential among several categories including urban wood waste, mill residue, wood from forestry, and wood from agricultural operations.
- c. Financial incentives vary among states, but may include tax credits. CT offers several tax credits for renewable energy projects, including exemption from sales and use, and property taxes. In addition, alternative energy systems with gross yearly sales revenues of less than \$100 million are exempt from state corporate business tax.
- d. In NC, a 15% credit is available only for conversion of existing oil- or gas-fired industrial boilers to wood fuel.
- e. NY has conducted several risk sharing projects to encourage electrical generation from waste wood combustion and other uses of biomass. Commercial wood energy projects are also recommended for funding under the state Energy Investment Loan Program.
- f. WI is actively promoting the use of waste wood for fuel, particularly waste generated from wood products manufacturing, through a grant program entitled "Wood Waste Energy Incentive Program." This program awards grants to new and existing facilities based on a formula that evaluates energy output, cost, capacity factor, and moisture content of the fuel used.

biological growth of biomass fuels uses carbon dioxide...thus their net contribution to global warming is zero" (Washington State Energy Office, 1989).

- "The use of waste wood to generate heat and/or electricity holds the most potential, especially in the near term, for the State's businesses and industries. Generally considered to be a liability due to collection, transportation and disposal costs, waste wood can be used to produce energy on-site while reducing the amount of refuse deposited in landfills" (New York State Energy Plan, Draft 1991 Update).
- "The state investment in renewable [wood] energy was approximately \$1.00 per million Btu; about 25 percent of the average commercial cost of fossil fuels in Wisconsin. Energy expenditures that remain in-state as a result of these wood energy projects are over \$1 million per year" (Wisconsin Energy Bureau; summary of Wood Waste Energy Incentive Program, 1990).
- "In New Brunswick, biomass in the form of wood is our most significant alternative to fossil fuel...The potential remains for a substantial expansion in the use of wood for energy and is particularly attractive when used for industrial process heat and in cogeneration applications" (An Energy Policy for New Brunswick, 1990).
- Goal II of the Virginia Energy Plan indicates that state policy should "Advance Renewable and Alternative Energy Sources in Virginia." Under this general goal, Objective B directs state agencies to "...research the feasibility of burning waste wood to generate electricity..." and, "...to promote expanded use of wood as a supplemental or direct heat source by using environmentally sound wood burning technologies" (VA Energy Plan, 1991).

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3.0 HARVESTED WOOD AND WASTE WOOD AVAILABLE FOR FUEL

3.1 Introduction

This chapter describes the types and amounts of harvested wood and waste wood potentially available for fuel in the states and province studied for this report. The purpose of the chapter is to determine the quantity of wood currently generated in each state and province containing non-wood materials that could affect its use as fuel. In addition, the total amount of harvested wood and waste wood produced in each state and province is identified, as are the types and amounts of wood that may contain non-wood materials.

Section 3.2 begins by organizing the many different types of harvested wood and waste wood into eight categories. General information is provided on the types of activities that produce wood in each category. Categories of wood that may contain non-wood materials are identified.

In Section 3.3, estimates are provided of the types and amounts of waste wood generated in each state and province, as well as information on the types and amounts of wood currently reused for fuel. The section identifies the relative magnitudes of different types of wood potentially available for fuel.

Information on industry trends likely to affect the types and amounts of waste wood that contain non-wood materials in the future is presented in Section 3.4. Manufacturing rates for specific wood products, the geographic concentration of wood product manufacturing firms, and the geographic distribution of typical wood products are discussed. This information indicates the likely composition of waste wood streams in the future.

Overall, this chapter is intended to assist solid waste and energy planners, power plant developers, and regulatory officials in understanding the magnitude of the entire wood fuel resource, and the portion that may contain non-wood materials. More detailed information on the composition of waste wood that may contain non-wood materials is provided in Chapter 4.

3.1.1 Key Issues Regarding Types and Amounts of Waste Wood

- What are the major types of waste wood that may be available for fuel?
- Of the various types of waste wood available for fuel, what is the relative magnitude of fuel available from the waste wood stream that may contain treated material in the study area?
- For wood fuel obtained from the waste stream, what are the wood products types likely to be found in the waste stream? What economic, geographic, and demographic factors influence the presence of certain waste wood products in the waste stream?

3.1.2 Key Findings

- Three major wood waste types are identified as "urban" wood waste, mill residue, and harvested wood waste. "Urban" wood waste includes pallets, construction and demolition (C/D) wood and municipal solid waste wood. Mill residue includes primary and secondary wood product industry waste. Harvested wood waste includes site conversion, silvicultural, and agricultural wood wastes.

- Of the three major categories of wood waste, "urban" wood waste is most likely to contain "treated" wood products. To a lesser extent, treated waste wood may also be produced as secondary mill residue. The project team did not assess potential pesticide contamination of agricultural derived fuels.
- Within the eight-state, one-province study area it is estimated that "urban" waste wood and secondary mill residue (which potentially contains treated wood material) comprises approximately 19 percent of total waste wood generation prior to reuse, recycling, and disposal. It is important to note, however, that these estimates only represent a "snapshot" of current generation and reuse in the study area. The actual amounts generated will change over time due to economic, regulatory, and other factors.
- Of the total amount of waste wood estimated to be reused for fuel within the study area, 17 percent is derived from urban waste wood and secondary mill residues. The majority of waste wood used for fuel in the study area is derived from primary wood industries as mill residue and directly from harvesting operations.
- It is difficult to predict the exact types and amounts of specific wood products that may be present in a given waste stream. Key factors that assist in evaluating the likely types and levels of contaminants of waste wood include assessing:
 - The level and types of primary and secondary forest products industry in a region;
 - The extent of construction and demolition activities in a region;
 - Climatic factors that influence the choice of wood products used, such as the use of pressure-treated wood in moist climates;
 - The level and types of shipping, freighting, or hauling industries in a region that create waste wood dunnage; and,
 - Major trends in wood products industries that affect the types and composition of wood products produced. Examples are recent shifts in plywood manufacturing from the northwest to the southeast, or the increasing reliance of the wood preservation industry on waterborne preservatives such as CCA.

3.2 Types of Waste Wood

Waste wood generally refers to wood residue generated by a variety of forest harvesting, industrial, commercial, and residential activities. As shown in Table 3-1, eight major types of waste wood are potentially available for use as fuel in power plants and other industrial and commercial combustion systems. Each type can be grouped into one of three broad categories. "Urban" wood waste includes used pallets, wood from construction and demolition waste, and other wood found in the municipal solid waste stream. "Mill residue" includes waste wood generated by primary and secondary wood industries. "Harvested wood" includes site conversion waste wood, silvicultural waste wood, and agricultural residue (CTD, 1991). Types and categories of waste wood potentially available for fuel are described in Table 3-1.

3.2.1 "Urban Wood Waste"

In this report, the term "urban wood waste" refers to used pallets, construction and demolition wood, and wood that is commonly commingled with other municipal or commercial solid waste. Common features of wood in this group are the relatively low moisture content, usually from 7 to 20 percent and the likelihood that some of the wood contains non-wood materials or additives such as paints, preservatives, or glues.

Table 3-1. Categories of waste wood^a.

<p>Urban waste wood</p> <p><u>Pallet waste</u> - generated from disposal of used pallets that have served their useful life. Waste from pallet manufacturing and repair is accounted for in secondary mill residue.</p> <p><u>Construction and demolition (C/D) wood waste</u> - produced from the construction, renovation, and demolition of buildings, roads, and other structures.</p> <p><u>Municipal solid waste (MSW) wood</u> - produced by a variety of residential and commercial activities and typically commingled with municipal solid waste.</p>
<p>Mill residue</p> <p><u>Primary wood products industry waste</u> - generated by sawmills and other millwork companies.</p> <p><u>Secondary wood products industry waste</u> - produced by firms that manufacture or use products from wood materials milled by primary wood industries.</p>
<p>Harvested wood</p> <p><u>Site conversion waste wood</u> - harvested when forest land is converted for roads, houses, industries, business, or other development activities.</p> <p><u>Silviculture waste wood</u> - harvested during commercial harvesting, timber stand improvement, and other forest management activities conducted to improve the health and productivity of the forest.</p> <p><u>Agriculture residue</u> - including waste wood produced when agricultural land is cleared, thinned, or pruned as well as when citrus groves and other orchard trees die due to age, frost, or storm damage.</p>

Notes:

a. Source - C.T. Donovan Associates Inc., 1990, 1991.

"Urban wood waste" appears in quotes because the term has not been specifically defined by regulatory agencies or industry groups, yet it is widely used. "Urban wood" or "urban wood waste" is used as a collective reference for waste wood in municipal and commercial solid waste. However, the term is actually a misnomer since the types of wood attributed to "urban wood waste" are also found in suburban and rural locations.

Of the three urban wood waste categories evaluated in this report, the two categories of C/D wood and MSW wood are most likely to contain significant

portions of treated wood. Treated wood is defined to be non-harvested or manufactured waste wood that is treated with paint, stain, glue, adhesives, fire retardants, pesticides, preservatives, or other chemicals. Treated wood may also be wood that has been contaminated in some way by exposure or commingling with other waste, such as some types of demolition debris.

3.2.1.1 Pallet Waste

Pallet waste is generated from the disposal of pallets that have served their useful life. (Waste from manufacturing and repairing pallets is accounted for in mill residue produced by secondary wood industries.) The average weight of an individual pallet is 60 pounds. (Other wooden shipping containers with walls weigh 100 pounds or more.) Because pallets are bulky, they tend to present a significant disposal problem. Whenever possible, they are repaired and reused.

Some wood fuel users prefer pallet-derived fuel compared to other sources of "urban wood waste" because they believe pallets are a "cleaner" source of waste wood. Used pallets have a relatively low moisture content of 15 percent and can be, but are not necessarily, free of paints, stains, or other wood treatments.

Some pallets are treated with preservatives or water repellents, depending on the type and grade of pallet. Pallets intended to be used outdoors or for multiple shipping jobs may contain some chemical protection. According to industry representatives, about 60 percent of pallets are heavy duty and are reused as long as possible.

Pallets intended to be used indoors or for "one-way" shipping purposes tend to be free of non-wood additives. About 40 percent are "one-way" pallets that are used only once.

Used pallets can become available for fuel by having them delivered directly to a combustion facility, where they are hogged or chipped in some way. Or, waste haulers may deliver pallets to a waste wood recycling facility that processes and sells the pallets for fuel.

Nails or staples commonly used to fasten pallets can be removed using metal separation equipment.

3.2.1.2 Construction and Demolition Wood

Wood is a common component of construction and demolition (C/D) debris that is produced during the construction, renovation, and demolition of buildings, roads, and other structures. The amount of wood contained in C/D waste varies from as low as 15 percent (based on weight) to as high as 85 percent (CTD, 1990). The actual amount depends on the source of the waste and where in the solid waste stream the wood is measured. A recent study by the Greater Toronto Homebuilders Association found, for example, that 40 percent of construction waste in new residential housing consisted of wood and wood products (GTH, 1991).

Construction and demolition wood can contain both treated and untreated waste wood. Waste from residential or commercial construction and renovation contains wood scraps from laminates used for sheathing and flooring, laminated beams, moldings and casings, dimensional lumber, painted or stained trim, and siding. Demolition debris contains painted wood, painted sheathing, wood with plaster, wood with preservatives, wood containing nails, and wood attached to other bulky waste such as asphalt

shingles, tar paper, or insulation. The average moisture content of C/D wood is about 15 percent.

Wood from construction and demolition waste can become available for fuel in a variety of ways. Generators of C/D waste may source separate specific components of their waste wood. Incentives for doing this are lower fees charged by waste haulers for roll-off containers filled with the separated wood, or lower fees charged for picking up and hauling source separated wood.

Waste wood haulers may then deliver the source separated wood to a wood recycling facility. The wood is processed at the facility and sold for fuel or other purposes. Most waste wood recycling facilities do not accept loads of waste unless they contain at least 95 percent wood. In addition, many recyclers only accept specific types of wood. Material delivered to a recycler must usually meet wood specifications developed by the facility. The processing equipment may be as simple as a mobile, outdoor tub grinder. Or, a more complex system may be used including float tanks, metal detectors, air classification equipment, rotary drums, hammer mills, and dust control equipment.

Haulers may also deliver source separated wood directly to a combustion facility, for further sorting and processing as fuel. As with stand-alone recycling facilities, most combustion facilities that process waste wood into fuel do not accept loads of waste unless they contain at least 95 percent wood. In addition, they usually only accept specific types of wood. Typically, waste delivered to the combustion facility must meet wood specifications developed by the facility. As with recycling facilities, the types and amounts of equipment used for processing the wood varies.

Waste wood that has not been source separated and is commingled with other C/D waste may be delivered to a C/D waste recycling facility. C/D waste recycling facilities often have the capability to separate and process other portions of the waste, in addition to wood.

Examples include concrete, asphalt, rubble, brick, masonry stone, topsoil, metal, and plumbing fixtures. The processing equipment used varies, depending on which portions of C/D waste are accepted and sold to end-use markets. Wood fuel markets are usually only one of a variety of end use markets served.

Commingled C/D waste may also be hauled to a solid waste disposal facility, such as a landfill or refuse-to-energy facility. Once unloaded, wood can be sorted from other waste before actually being landfilled or burned. Specifications of available end use markets can be used as the basis for determining which portions of the waste to recover. Operators of disposal facilities may sort and process wood on site, in conjunction with other waste separation or recycling activities. The woodfuel may be sold through a contract with a combustion facility that specifies the types, amounts, and price of the wood. Or, the wood may be stockpiled on site and sold on the spot market.

3.2.1.3 Municipal Solid Waste (MSW) Wood

MSW wood includes all types of wood not specifically accounted for in pallet waste, C/D waste wood, primary wood industry mill residue, secondary wood industry mill residue, site conversion waste wood, silvicultural waste wood, and agricultural residue. This includes wood commonly found in municipal solid waste, such as wood produced by household and small

commercial generators that is usually handled by MSW haulers and disposal facilities.

Examples include household yard waste, household remodeling scrap, and wooden shipping containers (other than pallets) disposed of by retail and grocery stores.

MSW wood tends to be produced in relatively small amounts by many different sources, so the ability to cost-effectively separate and recover the material for fuel is usually lower than for other types of waste wood. This is changing, however, as the resource value of waste wood becomes better understood, and as solid waste policies encourage more separation and recycling of wood (CTD, March, 1991). The city of Toronto, Ontario, for example, recently proposed a ban on landfilling loads of waste containing more than 10 percent "recyclable" wood products (Kalin, 1991). The moisture contents of MSW wood varies depending on the specific type and source of wood. An average moisture content of 15 to 20 percent is commonly used in the solid waste and energy industries. However, if a substantial amount of yard waste is present, the moisture content will be higher.

The sorting of wood from other MSW may occur through "curbside" collection programs, or by sorting it at landfills, transfer stations or refuse-to-energy facilities. Since MSW wood is commingled with a wide variety of materials, such as plastics, putrescibles, or household hazardous waste, both an economic incentive and public commitment to waste separation is necessary to ensure that wood is successfully removed from other solid waste.

3.2.2 Mill Residue

Mill residue is a term commonly used in the lumber and wood products industry to refer to waste wood produced by sawmills and other wood manufacturing firms. Firms are commonly grouped and described as either a primary or secondary wood products industry. Mill residue is produced by both types of industries.

3.2.2.1 Primary Wood Products Industries

Primary wood products industries use whole logs to create primary wood products, such as dimensional lumber, beams, and pulp. Examples of primary wood products industries include sawmills, pulp and paper mills, plywood mills and other millwork companies.

Primary wood industries produce a variety of waste wood including bark, chips, edgings, sawdust, and slabs. Typically, the waste wood contains minimal, if any, preservatives, paints, stains, or other non-wood material. Sawmill and other millwork residue typically have a moisture content of 40 to 50 percent.

A high percentage of waste wood generated by primary wood industries is recoverable for fuel and is currently reused for fuel. In fact, many primary wood industries throughout the U.S. and Canada burn all, or a portion of their waste wood on site for space heating, low temperature steam, hot water, and/or power generation. Availability for new fuel users depends on the extent of current fuel use and prices paid by other end-use markets.

3.2.2.2 Secondary Wood Products Industries

Secondary wood products industries manufacture engineered wood products from pre-manufactured wood materials, sawed dimensional lumber, or primary mill residue. Secondary wood industries include companies that manufacture building products, such as particleboard, oriental strandboard, or fiberboard, and also include companies that use engineered building products and dimensional lumber to manufacture windows, doors, boats, cabinets, furniture, pallets, and flooring. (Since plywood is typically processed directly from logs, it is considered a primary wood product by the forest products industry.)

Secondary wood products industries produce a variety of waste wood including chips, ends, and sawdust. The waste may be treated with preservatives, paints, or stains, and also contain non-wood material such as glue, plastic, or fabric. The moisture content of secondary wood industry waste varies considerably because both green, harvested wood and kiln-dried wood are used in secondary manufacturing. An average moisture content of 45 percent is commonly used in the wood energy industry (CTD, 1990).

A significant percentage of waste wood generated by secondary wood products industries is recoverable for fuel. Similar to primary wood industries, many secondary wood industries throughout the U.S. and Canada burn all, or a portion of their waste wood for fuel on site. The wood is used for space heating, low temperature steam, hot water, and/or power generation. Availability for new fuel users depends on the extent of current use and prices paid by other end-use markets.

3.2.3 Harvested Wood

Harvested wood, a term commonly used in the forestry and energy industries, refers to wood harvested directly from the forest that is used without being treated or processed with any chemical additives.

In this report, harvested wood also refers to wood obtained from agricultural land. Depending on the source, wood from agricultural sources may contain pesticide residues.

3.2.3.1 Site Conversion Waste Wood

Site conversion waste wood consists of wood harvested when forestland is converted for roads, houses, industries, businesses, or other development activities. Site conversion waste wood has an average moisture content of 45 percent.

The availability of site development waste wood for fuel is a function of the level of development. It also depends on whether it is customary in a given geographic area to remove waste wood from a cleared site, and whether wood can be burned or buried on-site. When possible, landclearers prefer to leave wood at the harvesting site, unless the material has value as timber, pulp, landscaping mulch, fuel, or other uses.

However, site clearing contracts in urban and developed locations may require removal of wood from the site, whether or not the wood currently has a market value. This can result in waste wood hauling and disposal costs that decrease the profitability of site conversion. In such cases, landclearers are likely to seek alternatives to disposal, including reuse for fuel.

Site conversion waste wood is currently used as fuel by a variety of wood-fired facilities throughout the U.S. and Canada. Availability to new

fuel users depends on whether landclearers need to remove waste wood from the site, hauling costs, prices fuel users are willing to pay, and prices paid by other end-use markets.

3.2.3.2 Silvicultural Waste Wood

Silvicultural waste wood is produced during commercial harvesting, timber stand improvement, and other forest management practices conducted on forestland. Similar to site conversion wood, silvicultural waste wood has an average moisture content of 45 percent.

The availability of waste wood from silviculture is a function of many factors, such as the extent of commercial harvesting, forest management policy, landowner attitudes, incidence of blight or infestation that require harvesting, and forest management techniques used in a given geographic area. At most sites, silvicultural waste wood is left on site as slash, unless there are timber, pulp, or fuel markets within a cost-effective hauling distance.

Silvicultural waste wood is currently used as fuel by a variety of wood-fired facilities throughout the U.S. and Canada. Availability to new fuel users depends on hauling costs and prices fuel users are willing to pay.

3.2.3.3 Agricultural Residue

Agricultural residue consists of waste wood produced during the harvesting, thinning, and pruning of agricultural land, and also includes waste wood produced when citrus groves and other orchard trees die due to age, frost, or storm damage. Among the states and province studied for this report, substantial amounts of agricultural residue are generated and used for fuel in the western states due to the amount of fruit, wine, vegetable, and nut production. Examples of agricultural residue include prunings from orange, apple, walnut, olive, and almond trees and from vineyards. Similar to other harvested wood, agricultural residue has a moisture content of 40 to 50 percent.

Some agricultural waste wood may contain pesticide residue. The presence of pesticide residue in fuel derived from waste wood depends on the source of wood, types and rates of infestation common in the wood, potential volatilization of the pesticide residue during wood fuel storage, and the extent to which the residue leaches from the wood during exposure to rain before harvesting, processing, and/or combustion.

In many states and provinces, until recently most agricultural operations burned waste wood in open piles outdoors. In some states such as California, air quality regulations have since restricted open burning and have created incentives by offering "emission credits" to wood-fired facilities that burn agricultural waste in controlled combustion units.

The availability of agricultural residue for fuel depends on the location of agricultural lands, hauling costs to fuel users, the price of wood fuel, and the availability of emission reduction credits.

3.3 Wood Fuel Available in the Study Area

Table 3-2 is a summary of waste wood generated and reused in the study area. This table includes information on the types and amounts of "urban wood waste," mill residue, and harvested wood generated in the state, and also includes information on the types and amounts of waste wood currently

reused for fuel. Appendix C contains a listing by waste wood types for each State and Province in the study area.

Three general conclusions can be made based on the profile of waste wood generation and reuse presented in the tables for each state and province.

First, in almost all locations, the amount of waste wood generated in all categories of wood substantially exceeds the amount currently reused for fuel. The difference between generation and reuse is particularly large for "urban wood waste" and harvested wood. It is important to note,

Table 3-2. Summary of combined waste wood generation and reuse in the study area^{a,b,c,d}.

Type of waste wood	Amount generated (1000s)	Reused for fuel (1000s)
Urban waste wood		
Pallets	2,872	760
c/d wood	5,323	825
MSW wood	4,836	785
Subtotal	13,031	2,370
Mill residue		
Primary wood industry	31,649	20,047
Secondary wood industry	8,613	3,957
Subtotal	40,262	24,004
Harvested wood		
Site conversion	15,287	1,847
Silviculture	42,491	6,818
Agriculture	4,880	1,880
Subtotal	62,658	10,545
Total	115,951	36,919

Notes:

- a. Estimates reported in thousands of green tons per year for 1990.
- b. Figures for generation and reuse are the consultant's estimates based on available data and interviews with state forestry, solid waste, and energy officials. These numbers may vary over time due to economic trends, forest practices, energy prices, and other factors.
- c. Estimates of reuse only measure the amount of wood consumed for combustion at industrial and commercial facilities. They do not include residential consumption such as firewood.
- d. This table does not include the amount of silvicultural wood that is potentially available on a sustained yield basis from new growth and natural mortality of biomass in the forest.
- e. Urban wood waste, particularly the categories of C/D wood and MSW wood, are most likely to contain significant proportions of treated wood. In addition, secondary mill residue may contain tailings, trim scraps, or furniture ends that have been treated (i.e., coated).

however, that other end use markets exist for waste wood in addition to fuel including markets for waste wood used for landscaping mulch, pulp and paper, animal bedding, binding agent in MSW and sludge compost, and engineered building products, such as flakeboard, among others. Depending on the state or province, the availability of other end-use markets for waste wood may decrease the amount currently generated that could be available for fuel, particularly for mill residue and harvested wood, which are generally considered "clean" sources of waste wood.

Second, it is apparent from the tables that the proportion of urban wood waste, mill residue, and harvested wood generated varies dramatically among the states and province studied. For example, in California almost as much "urban wood waste" is generated as mill residue and harvested wood. This reflects, in part, the large population and urban density in the state, and the relatively large role commercial activity has in the state's economy. By contrast, in Vermont substantially less "urban wood waste" is produced compared to mill residue and harvested wood. This reflects, in part, the large forest resource in the state and the relatively large role of wood products industries in the state's economy.

Third, it is apparent that in some areas "urban wood waste" represents a significant biomass resource. In the future, solid waste, renewable energy, and air quality policies and regulations will affect the extent to which "urban wood waste" is available for use as fuel.

3.4 Industry Trends Affecting Waste Wood for Fuel

An important objective of this report is to identify the types of waste wood that contain non-wood materials that may affect the use of wood for fuel. Examples include waste wood derived from wood products that contain adhesives, chemical additives, laminates, or coatings.

Ideally, information would be provided on the specific amounts of waste wood containing treatments, preservatives, or non-wood materials generated in each state and province. However, such data are neither compiled in any systematic way nor available from federal and state solid waste and energy offices, or professional trade associations.

It is possible to identify the types of waste wood likely to contain non-wood materials, and to anticipate the extent to which they are likely to be present in the waste stream. Based on research conducted for this report, of eight types of waste wood investigated, three are typically "clean" sources of waste wood harvested directly from the forest. These include:

- Primary wood industry waste;
- Site conversion waste wood; and
- Silvicultural waste wood.

Two types of waste wood may contain non-wood materials such as some types of pallets and some types of agricultural residue. However, the percentage of non-wood material is low compared to other treated wood products including:

- plywood;
- particle board;

- laminated woods; and
- pressure-treated wood.

Three types of waste wood are likely to contain non-wood materials. The presence of non-wood materials in the waste wood may affect use of the wood for fuel, depending on the amount of material contained in the wood and on existing and future environmental regulations including:

- Some types of wood found in construction and demolition waste;
- Mill residue from certain types of secondary wood product industries; and
- Some types of wood found in municipal solid waste.

There are six common wood products that account for a large proportion of waste wood that contains non-wood material. These include certain types of pallets, plywood, painted wood, pentachlorophenol treated wood, pressure treated wood, and creosote treated wood. Presented below is information on industry trends for each of these wood products. This information is presented to assist in determining how to estimate the likelihood that wood fuel in each state and province will contain non-wood materials. More detailed information on the chemical composition of the products is provided in Chapter IV.

3.4.1 Pallet Waste

Pallet manufacturing is one of the major wood product industries in the U.S. and Canada due to the widespread use of pallets and other wooden shipping containers by businesses and industries. Pallet manufacturing is the largest use of domestic hardwood lumber and the second largest use of sawed wood. According to a 1991 study published by Southern Illinois University (SIU), an estimated 460 million pallets were produced in the U.S. in 1990, 70 percent of the total capacity of the pallet manufacturing industry.

Several aspects of the pallet industry affect the types and amounts of pallet waste available in the study area in the future as summarized below:

- The average distance within which pallet manufacturing firms sold most (85 percent) of their pallets in 1990 was a 92 mile radius from the manufacturing plant. The median distance, however, was 50 miles, due to the shipping by a few large firms that sell nationwide.
- Only 12 percent of pallets manufactured in the three-state pacific region and 3 percent of pallets manufactured in the eight-state western mountain region were made of hardwood.
- Michigan and Pennsylvania had the largest number of pallet producing firms in 1990, with more than 200 each. Presented in Table 3-3 is the number of pallet manufacturing firms in each state and province in the study area.
- The rate of pallet recycling was lowest in the five-state New England region, at an average of 35 percent. The highest pallet recycling rate was in the western mountain region, at 66 percent.
- Compared to 1980 and 1985 data, 1990 showed a significant increase in average daily pallet production (from 611 to 835 to 900,

respectively). There was also an increase in daily production capacity in 1990.

The outlook for pallet manufacturing through 1994 is estimated to be an annual growth rate of 2.5 percent. However, better production and design efficiencies are necessary to achieve this (Smith, 1991). One method for producing improved pallets is to extend their usable life by preserving the wood with chemical treatments. According to representatives of the National Wood Pallet and Container Association, an extensive testing program is now underway to create a pallet that is usable for up to six years compared to a one- to two-year lifespan for pallets today. The "Enhanced Wood" testing program treats pallets using several layers of epoxy, urethane, or polyurethane coatings. The coatings are applied in layers of up to six to eight mils to increase the ability of the pallets to repel water and resist wear.

3.4.2 Painted Wood

Due to the variations in paint types and formulation it is difficult to identify key trends in the paint industry. The industry consists of many different paint, stain, and varnishing products manufactured by many different firms. Certain trends in paint formulations are evident, however. For example, a federal ban on using lead in paint and the increasing use of water-based paint are two major industry trends that affect the types and amounts of paint present in waste wood.

Table 3-3. Characteristics of pallet manufacturing in the study area^a.

Location	Number of firms producing pallets	Percent of non-recyclable pallets ^b	Percent hardwood pallets ^b
United States			
California	143	45	12
Connecticut	35	65	68
New York	168	53	91
North Carolina	90	50	82
Vermont	18	65	68
Virginia	69	50	82
Washington	22	45	12
Wisconsin	115	64	75
Canada			
New Brunswick ^c	N/A	N/A	N/A
Total study area	660	55	61
Total U.S.	3,222	54	71

Notes:

- a U.S. data supplied by McCurdy & Phelps, Southern Illinois University, June 1991.
- b Based on regional percentages as determined by McCurdy & Phelps, June 1991.
- c Figures for New Brunswick not available.

In addition, geography and climate indicate the types of exterior grade paints likely to be used in a given region. Paints containing fungicides

or insecticides, for example, are prevalent in hot, humid climates. Paints containing protection against excessive ultraviolet rays that create blistering or color fading are used in arid climates. Oil-based paints which penetrate and help preserve the wood are used in extreme climates, such as the northwestern and northeastern areas of the U.S. and coastal and mountain areas of Canada (Nelson, 1991). Marine-grade paints are used in coastal areas and regions with water-based recreation and transportation.

Two issues affect characteristics of paint used on wood. One is the type of paint produced, either oil-based (sometimes called solvent based) or water-based. The other is the type of resin base used. The resin contains the primary film-forming ingredient of paint (Nelson, 1991). The trend in the paint industry to increased use of water-based paints is due largely to recent restrictions on emissions of volatile organics from oil-based paints. It is also due to the ease in applying and cleaning water-based paints. Of all paints produced, 80-85 percent of the interior paint market is water-based, while 60-65 percent of the exterior paints consumed are water-based. These figures refer to all paints, not only paints used on wood (Nelson, 1991).

According to the National Paint and Coating Association (NPCA), "architectural coatings" comprise just over 50 percent of the total surface coating market. Architectural coatings are paint products intended for residential and other wood construction applications. Of all architectural coatings, 25 percent are oil-based and 75 percent are water-based paints, primarily latex.

The dominant resin bases which can be used in either oil- or water-based paints include alkyd, acrylic, vinyl, and epoxy resins. Together, these resin bases account for 67 percent of resins used in paint manufacturing, according to 1989 data from the NPCA. Other resins consist of a variety of oils, urethanes, and specialty combinations. According to 1989 data, alkyd resins account for 23 percent of all resins used. Acrylic resins account for 19 percent of the total, vinyl resins account for 17 percent, and epoxy accounts for 8 percent.

3.4.3 Plywood and Other Wood Panels

Common building products, such as plywood and other wood panels, are likely components of construction and demolition waste and some sources of secondary wood industry mill residue. Plywood is one of a variety of wood products referred to in the lumber and construction industries as structural panels. The three basic grades of plywood are sanded, sheathing, and specialty grades. Other wood panels include a relatively newer group of products referred to as oriented strandboard (OSB). According to the American Plywood Association (APA), several changes have occurred in the wood panel industry during the last five years. These changes could affect the types and amounts of wood found in construction and demolition waste, and their physical and chemical composition.

The predominant type of domestically used plywood is sheathing plywood that is bonded with exterior grade phenol formaldehyde glues. Sheathing plywood represents more than 50 percent of all structural panels produced, however, several grades of sheathing may be used for interior applications with interior grade urea formaldehyde adhesives. In addition, many types of interior grade plywood and non-structural panel products such as sanded plywood, underlayment, OSB, or waferboard are bonded with exterior grade adhesives to improve strength, durability, and moisture resistance. Exterior adhesives are used in approximately 96 percent of plywood and oriented strandboard products (APA, 1991). The exact formulation, however,

varies based on the application. Marine-grade classes of plywood may contain a higher proportion of adhesive than residential wall sheathing. Table 3-4 shows the proportions of various types of plywood produced and distribution by region.

Table 3-4. Plywood production by class and region^a (thousands of square feet, 3/8 in. thick basis)

Class	Production by classes of plywood	
	Exterior grade ^b	Interior grade
Sheathing (rough finish)	12,208,289	258,478
Sanded (smooth finish)	2,240,980	250,360
Specialty (textured sidings)	1,350,453	184,213
Oriented strandboard	5,640,722	-
Total	21,440,444	693,051

Class	Production by region				
	Western	Inland	Southern	Total	Total %
Sheathing (rough finish)	2,302,000	1,982,000	8,182,000	12,466,000	53.2
Sanded (smooth finish)	1,570,000	33,000	888,000	2,491,000	10.6
Specialty (textured sidings)	676,000	3,000	856,000	1,535,000	6.5
Oriented strandboard ^c				5,640,000	24.1
Imported from Canada				1,304,000	5.6
Total				23,436,000	

Notes:

- a Based on data from the American Plywood association, Tacoma, WA, 1991.
 b Numbers for exterior grade classes include several types of panels designed for interior uses. These include certain types of oriented strandboard (OSB) and underlayment manufactured using exterior grade glues.
 c Regional U.S. production figures for OSB are unavailable. The U.S. is the primary export market for Canadian produced OSB.

Several trends affect both the types and amounts of plywood and other wood panels produced. The structural panel industry in the western region of

the U.S., for example, is adjusting to recent changes in federal timber harvesting policies on federal lands and timber supply constraints on private lands. The coastal region west of the Cascade Mountains in Oregon and Washington lost more than 13 percent of their market share in 1990, continuing a decline that began in 1987. The southern region of the country from Virginia to Texas now produces the largest amount of structural panels, 55 percent of the total. This region has gained the largest market share since 1987, at a growth rate of roughly two to five percent per year.

End uses for plywood and other structural panels are primarily for new residential construction (38 percent) and remodeling (18 percent). Within residential construction, single-family housing accounts for 84 percent of all remodeling uses. Non-residential construction uses, such as for commercial buildings or concrete forms, accounts for 15 percent. Industrial uses, such as for pallets, furniture manufacturing, and transporting equipment, account for 24 percent. Within this amount, pallets and crates account for 50 percent of all industrial uses. The balance is shared between international exports and other residential uses.

It is apparent that timber supply constraints in the western U.S. and production costs throughout the industry are encouraging continued substitution of oriented strandboard for plywood. Since OSB was first produced in 1980, production has increased steadily. OSB now makes up approximately 20 percent of all U.S. structural panel production. This is expected to rise to 24 percent by 1996. The APA assumes that all increases in production capacity in the near term will be in OSB manufacturing. In addition, the role of the Canadian oriented strandboard industry is important to OSB consumption in both the U.S. and Canada. Currently, Canada exports approximately 60 percent of its OSB production, with the majority going to the U.S. Overall the plywood industry expects that other "engineered" wood products will continue to enter the market during the next five to 10 years. These products include laminated veneer lumber, structural panel webbed "I" beams, and structural composite lumber products.

Statistics on manufacturing trends in wood preservation are prepared by the American Wood Preservers' Institute (AWPI). Standards for wood preservation formulas are prepared by the American Wood-Preservers' Association (AWPA) and are discussed in Chapter 4.

The most recent information on trends in wood preservation are from a 1989 nationwide survey and analysis of wood preserving facilities (Mickelwright, 1990). According to the survey, there are 544 wood treating facilities in the U.S. Of these, 113 plants are located in states included in the study area for this report. The distribution of wood treating facilities in the U.S. is shown in Table 3-5. Major industry trends identified from the survey are:

- 97 percent of wood preserving plants use pressure treatment as a preservation method. With the exception of Vermont and New Brunswick, wood treating plants operate in each state within the study area. Overall, there is a high concentration of wood treating facilities in the southeastern U.S. Thirteen states in the southeastern and southcentral part of the U.S. produce 56 percent of treated wood products. Production in North Carolina and Virginia, combined, account for 11 percent of all domestically treated wood.
- Volumes of treated wood break down into four groups. Creosote solutions make up 16 percent, or 90 million cubic feet of treated

wood. Pentachlorophenol accounts for 9 percent, or 49 million cubic feet of treated wood. Waterborne preservatives, such as CCA, make up 73 percent, or 407 million cubic feet of treated wood. Fire-retardant chemicals consist of 2 percent, or 11 million cubic feet of treated wood.

Table 3-5. Production reported by 462 wood treating plants, by region, for 1989 (Micklewright, 1989).

Volume treated with ^a	Northeast	North Central	Southeast	South Central	Rocky Mountain	Pacific Coast	Total
No. of plants	49	77	150	121	26	39	462 ^d
All chemicals	56,608	69,258	154,006	135,803	13,011	43,122	471,807
Creosote solutions ^b	11,419	18,540	11,415	32,453	1,699	6,651	82,177
Pentachlorophenol	183	5,339	7,909	18,321	2,571	7,851	42,174
Waterborne preservatives ^c	43,641	44,793	131,731	82,975	8,470	26,917	338,528
Fire retardants	1,365	586	2,951	2,054	270	1,702	8,927

Notes:

- a Volume in thousands of cubic feet of lumber.
- b Creosote, creosote-coal tar, and creosote-petroleum.
- c includes CCA, ACZA, ACC, and CZC (333.7 million cubic feet treated with CCA).
- d Includes 453 pressure-treating plants and 9 nonpressure-treating plants.

Most wood preservatives are designed for products used in exterior, agricultural, and industrial applications. According to 1989 data from AWPI, three major wood product groups account for 88 percent of the wood preservatives used. Southern pine accounts for 71 percent of all treated wood products. (An exception to this are crossties, switch ties, and bridge ties, of which 92 percent are manufactured using hardwood species.)

More detailed information on end uses for various wood preservatives is provided in Table 3-6. The three major wood products are:

- Lumber and timbers make up 63 percent of the total volume of wood treated with preservatives. They are treated primarily with waterborne preservatives (97 percent). Of the waterborne preservatives used, 98 percent consist of formulations of chromated copper arsenate (CCA).
- Crossties, switch ties, and bridge ties comprise 11 percent of the total volume. They are treated entirely with creosote solutions.
- Utility poles comprise 14 percent of the total volume of wood treated.

Table 3-6. Production of treated wood in the United States for 1989^a (Micklewright, 1989).

Volume treated with ^b	Cross-ties	Switch & bridge ties	Poles	Cross-arms	Pilings	Fence posts	Lumber	Timbers	Ply-wood	Other	All products	
											1988	1989
All chemicals, 1988	57,770	6,315	71,191	1,473	9,699	12,404	359,865	45,017	12,705	22,707	1988	1989
All chemicals, 1989	58,022	6,301	73,975	1,881	9,678	14,377	306,577	43,951	13,189	28,992	599,145	556,943
Creosote solutions ^c	58,022	13,522	13,522	34	3,895	2,320	2,364	2,097	---	1,315	90,481	89,870
Pentachlorophenol	---	---	44,959	1,768	4	709	445	1,107	---	394	47,896	49,386
Waterborne preservatives ^d	---	---	15,494	79	5,779	11,348	298,443	40,747	8,636	26,415	450,565	406,941
Fire retardants	---	---	---	---	---	---	5,325	---	4,553	868	10,230	10,746

Notes:

- a Based on reported production of 462 treating plants (Table 3-5) plus estimated production of 91 nonreporting plants.
- b Volume in thousands of cubic feet of wood.
- c Creosote, creosote-coal tar, and creosote-petroleum.
- d includes CCA, ACZA, ACC, and CZC (98+% CCA).

Approximately 60 percent of treated utility poles are preserved with pentachlorophenol. Another 20 percent are poles treated with creosote solutions. The remaining 20 percent are poles treated with waterborne preservatives.

According to a 1989 survey, 16 wood treating facilities that use pentachlorophenol are located in the study area for this report. Of these, the state of Washington has the highest concentration of facilities (nine), followed by North Carolina and California with three each, and Wisconsin with one. No treatment facilities using pentachlorophenol were reported in Connecticut, New York, Vermont, or New Brunswick.

Nationwide, out of a total of 70 operating plants, wood treating facilities that use pentachlorophenol are most heavily concentrated in Missouri (nine), Washington (nine), Montana (six), Idaho (six), Alabama (five) and Georgia (five) (Greenpeace, 1989).

3.5 Bibliography - Chapter 3

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4.0 THE COMPOSITION OF HARVESTED WOOD AND WASTE WOOD

4.1 Introduction

This chapter describes the composition of harvested wood and waste wood that could potentially be processed and used for fuel. The purpose of the chapter is to identify the contents of harvested wood as well as waste wood derived from wood products that were processed or treated in some way. The chapter focuses on the presence of non-wood material in common wood products, and on the composition of the non-wood materials. The chapter is intended to assist solid waste and energy planners, power plant developers, and regulatory officials in understanding characteristics of waste wood that may affect its use as fuel.

The chapter begins by organizing the many different types of waste wood that could potentially be processed for fuel into five wood product groups. The groups are developed, based on the type of process or treatment used for wood in the groups. This is done to identify common wood products that are processed and treated in similar ways. Methods of preparing and treating wood products in each group that result in adding non-wood material are described. The concentrations of different chemicals used during processing and treatment are discussed.

Section 4.3 summarizes the composition of harvested wood and of common treatments used on wood, and provides information on chemical elements contained in adhesives, chemical additives, laminates, and coatings applied to wood. It also provides information on various compounds used to bind and preserve wood products.

Adhesives used in wood products are described in Section 4.4. Information is provided on the chemical composition of various adhesives, way(s) in which adhesives are applied to wood, and the frequency and extent to which adhesives are used in wood products. Emphasis is on formaldehyde-based adhesives, isocyanate-based adhesives, bioresins, and other adhesives.

Preservatives used in wood products are described in Section 4.5. Information is provided on the chemical composition of various preservatives, way(s) in which wood is treated with preservatives, and the frequency and extent to which preservatives are used in wood products. Emphasis is on creosote based preservatives, oil borne preservatives such as pentachlorophenol and copper naphthenate, and water-borne preservatives such as chromated copper arsenate or CCA.

Materials used as surface coatings on wood are described in Section 4.6. Information is provided on the chemical composition of various coatings, way(s) in which coatings are applied to wood, and the frequency and extent to which different coatings are used on wood products. Emphasis is on metallic pigments and major wood coatings, including paints and stains, water-based coatings, lacquers, varnishes, enamels, and polyurethanes.

Finally, Section 4.7 identifies and describes the physical and chemical characteristics of harvested wood as well as six wood products commonly used throughout the U.S. and Canada. Because the wood products are commonly used, they are potential sources of waste wood that could potentially be processed for fuel. In addition to harvested wood, the wood products described include: pallets, painted wood, plywood, particleboard, pressure-treated wood, and creosote-treated wood.

4.1.1 Key Issues Regarding The Composition of Waste Wood

- What are the major wood product types that may contain contaminants of concern?
- What are the major types of adhesives, preservatives, and surface treatments (paints and stains) used in wood products manufacturing?
- What are the physical and chemical characteristics of wood product types most likely to be found in the waste stream?

4.1.2 Key Findings

- Major wood product groups that contain non-wood material include structural and non-structural panels (containing glues and adhesives); impregnated wood treated with oil-borne or water-borne preservatives; and, painted wood containing oil- or water-based coatings.
- Adhesives rely primarily on phenolic resins, and to a lesser extent, urea and resorcinol resins. Impregnated wood consists primarily of oil-borne preservatives such as creosote and pentachlorophenol, and water-borne preservatives such as CCA. Paints have the greatest product diversity, however, they comprise the lowest percentage by weight (usually less than 0.1 percent) of non-wood contaminants found in waste wood.
- Non-structural panels bonded with either interior or exterior grade adhesives tend to have higher percentages of non-wood material (5 to 15 percent) compared to structural panels due to their reliance on the adhesive for torsional strength.
- Three-quarters of all wood preservatives used for impregnating wood are water-borne formulations of CCA due to the product's wide applicability in commercial and residential uses, the absence of odor and vapors, and durability.
- Typical paint formulations contain about 35 percent binder and 35 percent filler which comprise the paint vehicle. The remaining 30 percent consists of a combination of primary and secondary pigments. Paint vehicles are increasingly water-based due to restrictions on volatile organic emissions from oil-based formulations. Primary pigments often consist of titanium dioxide, while secondary pigments (typically less than 5 percent of the overall formula) may contain metals.

4.2 Wood Product Groups Containing Non-Wood Material

There are many types of wood that can potentially be processed and used as fuel at power plants, industries, and businesses. Throughout the U.S. and Canada, interest is growing in separating wood from the waste stream and processing it for fuel. This is causing increasing interest in the physical and chemical characteristics of a wide variety of waste wood types.

The varieties of processed waste wood have been organized into the following groups:

- structural panels;
- non-structural panels;
- impregnated wood;
- surface coated wood; and
- wood containing physically separable items.

4.2.1 Structural Panels

Plywood, laminated beams and trusses, oriented strandboard, parquet floors, and wood products overlaid with decorative veneers are examples of common wood materials referred to in the lumber and construction industries as "structural panels." Structural panels are wood products that are designed and manufactured to obtain strength from alternating patterns of thin wood layers. The two basic types of structural panels include laminated wood products and oriented strandboard (OSB).

Laminated wood products, such as plywood, are the most common type of structural panels. As defined by the American Wood-Preservers' Association (AWPA), laminated wood consists of "layers of wood fastened together (usually glued) with their grain direction parallel to the longitudinal direction of assembly" (AWPA, 1990). Most laminated wood is produced by "pressing" the wood together using high temperatures (referred to as "heat pressing") and by using moisture-resistant phenolic resins as adhesive. The resin and other additives, usually paraffin wax, make up 2 to 5 percent of the dry weight of the laminated wood product. Uses for structural panels include sheathing for floors, roofs, and walls.

Oriented strandboard (OSB) products are a recently developed class of structural panels. The predecessor to OSB is known as "waferboard" or the common registered trade name of "Aspenite" (Lowood, 1991). The design and manufacturing of oriented strandboard combines techniques used in laminated wood and in non-laminated wood composites to produce a different type of structural panel. As with laminated wood, OSB consists of multiple layers of wood fastened together with the grain lined up parallel to the longitudinal direction of assembly. The major difference between OSB and laminated wood, such as plywood, is that smaller pieces of wood, instead of sheets or veneer, are used in oriented strandboard. As with laminated wood, OSB is produced by heat pressing the wood using moisture-resistant phenolic resins as adhesive. To date, OSB is the only type of wood composite considered as structural panels. Recent advances in wood composite and adhesion technology used to produce oriented strandboard allow some OSB products to be substituted for laminated wood in structural applications.

4.2.2 Non-Structural Panels

Hardboard, medium-density fiberboard (MDF), particleboard, chipboard, and registered trade names such as "Masonite" are examples of common wood products referred to in the forest product industries as "non-structural panels." This group of wood products also includes panels containing wood laminated to non-wood materials, such as plastic.

Unlike structural panels, the strength of non-structural panels depends primarily on adhesive and bonding systems used when manufacturing the wood products. The panels are shaped into rough "mats" before being heated, pressed, and trimmed to their final shape. Non-structural panels are manufactured using both phenol and urea formaldehyde resins. Non-wood materials account for 5 to 15 percent of the dry weight of non-structural panels. Typical uses for non-structural panels include interior applications as flooring, sheathing, cabinets, and furniture.

4.2.3 Impregnated Wood

Impregnated wood products are treated with a variety of chemicals to resist rot, decay, infestation, and moisture. Impregnated wood products are typically pressure treated with, or soaked in aromatic organic hydrocarbon solutions or inorganic arsenical based preservatives. Hydrocarbon solutions

contain either creosote, coal tar, chlorinated phenols, or a combination of creosote and oil. Inorganic solutions contain compounds of arsenic, chromium, copper, zinc, and ammonium.

Creosote-treated wood is a common impregnated wood product. Creosote solutions account for approximately 14 to 20 percent of the dry weight of the treated wood. More concentrated solutions are used in wood treated for marine applications. Creosote-treated wood is widely used in railroad crossties and landscaping walls in concentrations of 6 to 15 pounds per cubic foot. Marine pilings and docks are treated up to 20 pounds per cubic foot, depending on the exposure to salt or fresh water.

Wood treated with pentachlorophenol (also referred to as "penta") is another common impregnated wood product. Penta is used almost exclusively in the treatment of utility poles and pilings. Penta accounts for up to 1.5 percent of the dry weight of the wood, depending on the species of wood used (this is equivalent to 0.60 pounds per cubic foot). Penta applied to material used for decking and fencing is applied with retention rates of 0.40 to 0.50 pounds per cubic foot (AWPA, 1990).

Inorganic preservatives include chromated copper arsenate (CCA) and ammoniacal copper arsenate (ACA). CCA and ACA are used extensively in the treatment of southern pine and other softwoods (Brennan, SPTA). There are different grades of CCA and ACA, each containing varying fractions of arsenic, chromium, copper, and zinc. CCA- and ACA-treated wood is used in agricultural stockyards and fences, residential fences, decks, playgrounds, and other exterior applications. For CCA- and ACA- treated wood used in non-marine applications, CCA and ACA account for 1 to 3 percent of the dry weight of the wood. This is equivalent to the CCA and ACA being applied at retention rates of 0.25 to 0.40 pounds per cubic foot. Marine applications of CCA and ACA are specified in ranges of 0.60 to 2.5 pounds per cubic foot (AWPA, 1990). The amount used depends on the species of wood, and the level of exposure to salt water and marine borers such as *Limnoria Tripunctata*.

4.2.4 Surface-Coated Wood

Paints, stains, varnishes, lacquers, or fungicide sprays are examples of materials applied to the surface of wood products for a variety of decorative and protective purposes. Coatings can be applied to pallets, plywood, softwood siding, wood shingles, waferboard, pine trim, hardwood floors, furniture, decks, fences, and other wood products.

Compared to the previous three categories, painted or coated wood products contain a small fraction of non-wood material, usually less than 0.1 percent because most coatings are applied as a thin surface film or as a slight impregnation of the surface of the wood. Surface coatings usually consist of combinations of natural oils, volatile organics, plastic acrylic or alkyd resins, and pigments. Pigments used in paint may contain metal compounds of chromium, copper, lead, mercury, or zinc. However, pigments usually account for less than 5 percent of a paint solution. Houses and buildings built before 1940 may contain painted wood that contains lead. The paint may contain 30 to 50 percent lead.

4.2.5 Wood Containing Physically Separable Items

Waste wood produced by construction and demolition activities or commingled with municipal solid waste may contain a variety of non-wood materials that can be physically separated from the wood. Examples include pallets containing nails; wood sheathing attached to asphalt shingles or fiberglass insulation; wood framing with electrical wire or plumbing fixtures attached;

or wood cabinets or furniture attached to upholstery. Most of these items can be physically separated from the wood by source- separating the material at the site of generation, manually sorting the material at a wood waste processing facility, and/or using a variety of mechanical sorting devices.

Listed in Table 4-1 are examples of non-wood items that may be present in construction, demolition, and municipal solid waste that can be physically

Table 4-1. Physically separable items contained in waste wood^a

Construction Wastes

Fiberglass insulation
Metals
 Ferrous
 Nonferrous
PVC plastic
Gypsum drywall
Moisture barrier films (1.e., Tyvek®)
Asphalt shingles
Tarpaper
Foam rubber
Cardboard shipping containers

Demolition waste

Concrete
Dirt, rubble
Ceramic or porcelain tiles
Gypsum or plaster drywall
Vinyl linoleum
Metals
 Ferrous
 Nonferrous
Tarpaper
Electrical wire
Asbestos
Painted or stained wood
Asphalt shingles
Urea formaldehyde foam insulation

Municipal solid waste

Furniture scraps
Upholstery
Stereo and other electronic components
Home improvement waste (similar to C/D waste)

- a. This is a partial list that demonstrates the range of materials that can be physically separated from waste wood.

separated from waste wood. Information in the table represents a partial list, and is intended to demonstrate the wide range of material that can be physically separated from waste wood.

The potential use of woodfuel from waste wood containing physically separable non-wood material depends on the fuel specifications of a combustion facility and on the way the wood is processed into fuel. Techniques vary for physically removing non-wood material from waste wood while processing it for

fuel. Some processing facilities only accept wood that does not contain non-wood material. Other facilities accept wood containing non-wood materials, and then separate the material on-site by manually sorting and mechanically processing the waste wood.

4.3 Components of Harvested Wood and Common Wood Treatments

This section summarizes the composition of harvested wood and common treatments used on wood. The summary provides information on chemical elements that are contained in adhesives, chemical additives, laminates, and coatings applied to wood. It also provides information on various compounds used to bind and preserve wood products.

Table 4-2 presents a list of chemical elements and their functional groups that are contained in adhesives, chemical additives, laminates, and coatings applied to wood. Table 4-3 presents a listing by chemical function of the various chemical compounds used as wood adhesives, additives and coatings. The tables, prepared by the National Forest Products Association (NFPA), identify the primary chemicals and chemical functions that may be present in both harvested wood and waste wood. As shown in Table 4-2, the primary chemical components of trees include cellulose, hemicellulose, and lignin that occur in varying amounts, depending on the species of tree. Hardwoods generally contain more hemicellulose and less lignin than softwoods (Tillman, 1981). Cellulose and hemicellulose, collectively described as holocellulose, determine the total carbohydrate content of wood. Lignin is considered the "glue" in wood chemistry. Lignin helps form new proteins and accounts for the nitrogen when wood is combusted. Wood is slightly acidic, with pH levels typically ranging from 3 to 6 (Baker, 1987).

As shown in both tables, additional chemicals are present in wood if the wood has been processed or treated with adhesives, additives, laminates, coatings, or other compounds. This chapter also presents additional information on the chemical composition of common wood treatments. Further information on the presence of the chemicals in wood or ash produced from combusting waste wood is presented in Chapter 7. The air emissions from various types of waste wood are discussed in Chapter 8.

4.4 Adhesives Used in Wood Products

The most common adhesive system used in wood products is thermosetting resins that contain phenol formaldehyde and urea formaldehyde resins. Less common, more specialized, and more expensive resins consist of resorcinol and melamine formaldehyde resins. These resins use formaldehyde as a "cross-linking agent" to bond individual urea, phenol, and other molecules (Wardell, 1991). Less well-used adhesive systems include isocyanate (Methylene-diphenyl-diisocyanate (MDI)) and bioresins.

4.4.1 Formaldehyde Resins

Phenolic formaldehyde resins are waterproof and typically used in exterior use structural panels, such as softwood plywood and oriented strandboard where resistance to moisture damage is needed. Typically, resins account for 2 to 4 percent of the dry weight of phenolic-bonded structural panels. Less expensive urea formaldehyde resins are used in wood products designed for interior applications, such as hardwood plywood, medium density fiberboard, and particleboard. Typically, glues account for 4 to 8 percent of the dry weight of non-structural urea-bonded panels; however, some brands of medium density fiberboard may contain up to 10 percent resins.

Resorcinol and melamine formaldehyde resins are used primarily in laminated

Table 4-2. Chemical elements used in wood products^a.

Solid wood		
Name	Chemical elements	Functional groups
Cellulose	C, H, O	Glycoside, alcohol
Hemicellulose	C, H, O	Glycoside, alcohol
Lignin	C, H, O	Phenol
Extractives		
Terpenes	C, H, O	Olefin, alcohol, carbonyl
Fatty acids	C, H, O	Carboxylic acid
Phenolics	C, H, O	Phenol
Adhesives		
Urea formaldehyde	C, H, O, N	Polyamide
Melamine formaldehyde	C, H, O, N	Polyamide
Phenol formaldehyde	C, H, O	Phenol
Resorcinol formaldehyde	C, H, O	Phenol
Isocyanate	C, H, O, N	Polyurea
Epoxy	C, H, O	Aryl ether, epoxide
Polyvinyl acetate	C, H, O	Aliphatic ester
Casein	C, H, O, N	Amino acids
Hot melts	C, H, O, N	Esters/amides/aliphatics
Chemical additives		
Urea	C, H, O, N	Amide
Waxes	C, H, O	Ester
Ammonia	N, H	
Phosphates	N, H, P, O	Phosphate
Borates	H, B, O (Na)	Borate
Sulfates	N, H, S, O	Sulfate
Arsenates	Cr, Cu, Zn, N, H, O, As	Arsenate
Polyesters	C, H, O	Ester
Laminates		
Melamine/paper	C, H, O, N	Amide/cellulosic
Phenol/paper	C, H, O	Phenol/cellulosic
Polyvinyl chloride	C, H, Cl	Chlorinated aliphatic
Polyester	C, H, O	Ester
Phenol/melamine/paper	C, H, O, N	Phenol/amide/cellulose
Coatings		
Alkyd	C, H, O	Ester
Alkyd urea	C, H, O, N	Ester/amide
Acrylic	C, H, O, N	Acid, ester, amide, nitrile
Polyvinyl acetate	C, H, O	Ester
Polyurethane	C, H, O, N	Urethane
Polyester	C, H, O	Ester
Nitrocellulose	C, H, O, N	Nitro/cellulosic
Ethyl cellulose	C, H, O	Ether/cellulosic
Butyrate	C, H, O	Ester
PVA/PVC	C, H, O, Cl	Chlorinated ester
Epoxy	C, H, O	Aryl ether/epoxide
Melamine	C, H, O, N	Polyamide
Polystyrene	C, H	Aromatic polymer
Styrene/butadiene	C, H	aromatic polymer

a. From National Forest Products Association (June 1989)

beams, trusses, and other structural applications where high resistance to abrasion or chemical deterioration is necessary (Clauser, 1976; Emery, 1991).

4.4.2 Isocyanate, Bioresins, and Epoxy

Due to the expense of some resins, concerns about exposure to formaldehyde during manufacturing, and the "offgassing" of formaldehyde vapors after manufacturing, the wood panel industries are using and experimenting with other adhesive systems including isocyanate, "bioresins", and epoxy.

Table 4-3. Chemical compounds used in wood products^a.

Cellulosic compounds	Amino compounds	Phenolic compounds
Wood Paper Ethyl cellulose	Urea formaldehyde Melamine formaldehyde Urea Ammonia Urethane Casein Melamine Alkyd urea Isocyanate	Phenol formaldehyde Resorcinol formaldehyde
Aromatic Hydrocarbons	Halegenated hydrocarbons	Phosphorus compounds
Polystyrene Styrene/butadiene	Polyvinyl chloride PVA/PVC	Amino and ammonium phosphates
Boron compounds	Sulfur compounds	Arsenic compounds
Sodium borate Boric acid	Ammonium sulfate	Copper chromium arsenate Ammonical copper arsenate ammonical copper zinc arsenate
Ethers and esters	Nitro compounds	
Epoxy Waxes Alkyds Cellulose acetate butyrate Polyvinyl acetate Polyester	Nitrocellulose	

a. From National Forest Products Association (June 1989)

Methylene-diphenyl-diisocyanate (MDI) and other isocyanate derivatives are being used as bonding agents predominantly in oriented strandboard in conjunction with typical phenolic resins. The benefits of isocyanate compounds are the increased strength, greater moisture tolerance, rapid curing, and absence of formaldehyde emissions. Although most experience with isocyanates has been in particleboard bonding, future trends indicate increasing use of isocyanates in waferboard and oriented strandboard (Steiner, 1986).

Bioresins are produced by extracting the natural lignin in wood and processing it into adhesive using a steam hydrolization process that extracts lignin-resin compounds from wood (Shen, 1989). The extracted bioresins are then used to "re-bond" wood fibers or flakes in pressed mats, similar to the way non-structural composite wood products are manufactured. Current experimentation with the production and use of bioresins may eventually develop a new group of more environmentally acceptable adhesive systems.

Epoxy is an elastomeric adhesive that has advantages in structural and non-structural applications where strength and flexibility are necessary. Epoxy resins are reaction products of epichlorohydrin and polyhydric phenols that are mixed with a "cross-linking" agent for hardening. The use of epoxy is limited to wood-plastic composite products and as an additive to phenolic resins. (Hsu, 1988).

4.4.3 Other Adhesives

Other adhesives that are currently used in laminated wood and wood composites are polyvinyl acetate, casein, water based latex, and hot melts containing polyesters, polyamides, or ethylene vinyl acetate. Asphalt distilled from petroleum is also used in some products (NFPA, 1989). These adhesive systems are more specialized, and are used less frequently than phenol and urea formaldehyde resins.

4.5 The Composition of Wood Preservatives

Standards for wood preservation are specified each year by the American Wood-Preservers' Association (AWPA). Information on industry trends and manufacturing rates are available from the American Wood Preservers' Institute (AWPI).

The AWPA publishes a comprehensive guide on recommended wood preservation formulations and standards for chemicals used in wood treatments. Overall, the process of preserving wood is designed to treat both the surface and subsurface layers of wood. There are three general categories of preservatives: organic preservatives, including creosote based preservatives; organometallic preservatives, including oil-borne preservatives; and inorganic preservatives, including water-borne preservatives. Table 4-4 gives a list of major categories and formulations of wood preservatives, according to the AWPA.

Preservatives are applied either using a series of hot and cold vats or baths, or by pressure treating the preservative to the wood in pressurized cylinders. When using pressure-treating techniques, the wood is often incised with small holes to maximize coverage of the preservative beneath the Table 4-4 surface. Subsurface penetration is typically required from 1 to 2.5 inches (Clauser, 1976; AWPA, 1990). The selection of preservative and the method of treatment depends on the intended use of a wood product and climatic considerations. Wood products used in marine applications or other settings with high rates of moisture, infestation, or decay generally contain higher proportions of preservative.

According to the AWPI, three types of preservatives were used on approximately 98 percent of pressure treated wood produced in the U.S. in 1988. Creosote solutions were used in 15 percent; pentachlorophenol solutions were used in 8 percent, and waterborne inorganics (primarily CCA solutions) were used in 75 percent (Mickelwright, 1989; ERI, 1991). In 1990, the Environmental Research Institute (ERI) analyzed how much of each preservative was used in pressure-treated wood, drawing on the AWPI 1988 data. According to ERI, "upper bound" concentrations of preservatives used in pressure-treated wood indicate that an average volume of one gallon of creosote was used per cubic foot of creosote-based, pressure-treated wood. An estimated .45 pounds of pentachlorophenol were used per cubic foot of pentachlorophenol treated, pressure-treated wood. An estimated .35 pounds of inorganic salts from CCA were used per cubic foot of CCA-treated, pressure-treated wood (ERI, 1991).

4.5.1 Creosote Preservatives

Creosote preservatives are blended solutions of creosote and various petroleum-based oils or coal tars. Creosote is defined by the wood preserving industry as a "distillate of coal tar produced by high temperature carbonization of bituminous coal..." that includes, "...liquid and solid aromatic hydrocarbons that also contain some tar acids and tar bases" (AWPA, 1990).

Table 4-4. Major categories of wood preservatives^a.

Organic preservatives
creosote creosote for marine use Pentachlorophenol in volatile petroleum solvent (LPG) Pentachlorophenol in light hydrocarbon solvent Pentachlorophenol in chlorinated hydrocarbon solvent Pentachlorophenol in petroleum 80/20 creosote-coal tar solution 70/30 creosote-coal tar solution 60/40 creosote-coal tar solution 50/50 creosote-coal tar solution Creosote-coal tar solution for marine use 80/20 creosote-petroleum solution 70/30 creosote-petroleum solution 60/40 creosote-petroleum solution 50/50 creosote-petroleum solution
Organometallic preservatives
Copper naphthenate in creosote Copper naphthenate in petroleum Copper-8-quinolinolate Tributyltin oxide
Inorganic preservatives
Acid copper chromate (ACC) Ammoniacal copper arsenate (ACA) Chromated Copper arsenate (CCA Type A) Chromated zinc chloride (CZC) Copperized chromated zinc arsenate (CuCZA) Chromated copper arsenate (CCA Type B) Chromated copper arsenate (CCA Type C) Ammoniacal copper zinc arsenate (ACZA)

a. From the American Wood-Preservers' Association Standards, 1990.

AWPA standards specify a range of 50 to 80 percent creosote for solutions containing creosote-petroleum oil combinations. Such solutions are well suited for use in arid climates. Another common creosote solution mixes creosote with coal tar. This solution contains a 20 to 50 percent creosote to coal tar combination, and is often used to treat railroad ties, posts, and marine pilings (AWPA, 1990). A marine-grade creosote solution is specified by AWPA that may be either a coal tar creosote mixture, or a coal tar creosote chlorpyrifos mixture. The chlorpyrifos mixture contains at least 50 percent chlorpyrifos for use in resisting marine organisms that attack wood (AWPA, 1990).

Standards for the retention of creosote in wood are usually in the range of 8 to 10 pounds per cubic foot of treated wood. This is equivalent to about 14 to 20 percent of the dry weight of the wood (ERI, 1991; AWWA, 1990). Over time, however, creosote solutions used to treat wood leach and oxidize. Used railroad ties that are ten years old, or older, may contain only 4 to 6 pounds of solution per cubic foot of wood, or about 7 to 13 percent of the dry weight of the wood (Brennan, 1991). It is estimated that 20 to 50 percent of the preservative may leach or oxidize from creosote-treated wood over a 10 to 25 year period (Arsenault, 1973).

4.5.2 Oil-Borne Preservatives

Oil-borne preservatives are applied to wood in an oil-based solvent which serves as a carrier. Oil-borne preservatives consist primarily of pentachlorophenol (penta) or copper naphthenate. Oil borne preservatives may also include other metallic solutions, such as combinations of tin (tributyltin oxides), copper-nickel compounds (Copper-8-Quinolinolate), or alkyl ammonium compounds (AAC).

Penta is a crystalline aromatic compound containing, "...not less than 95 percent chlorinated phenols" (AWWA, 1990). Penta has a distinct odor which limits its use in many residential, commercial, and marine applications. The preservative solution typically contains 5 to 8 percent of penta by weight. AWWA standards require that 0.4-0.6 pounds of penta be retained in each cubic foot of penta treated wood, depending on the intended use of the wood. This is equivalent to the penta accounting for 1.4 percent of the dry weight of the treated wood (ERI, 1991).

A major concern about the use of penta as a preservative is potential chemical contamination by polychlorinated dibenzo dioxins (PCDD) and furans (PCDF). PCDD and PCDF are believed to be acute toxic substances and are suspected of being carcinogens. The U.S. Environmental Protection Agency restricted the use of penta effective in 1984 (ERI, 1991) that resulted in a decrease in its use in many treated wood products.

Copper naphthenate is a "stable chemical compound" that is dissolved in a petroleum solvent and is deemed to have a "high degree of permanence in wood" (AWWA, 1990). Copper naphthenate is generally used as a water repellent on pallets or exterior decks. According to the AWWA, the concentration of copper in the preservative solution is between 0.5-1.0 percent by weight for pressure treated wood, and 2.0 percent by weight for surface treatments.

4.5.3 Water-Borne Preservatives

Water-borne preservatives are solutions of water soluble compounds that usually contain compounds of ammonia, arsenic, chromium, and zinc. Chromated copper arsenate is an example of a water-borne preservative. There are three major grades of CCA, made up of differing fractions of chromium, copper, and arsenic. Standard formulas include 35 to 65 percent chromium, 15 to 45 percent arsenic, and a constant fraction of copper of approximately 20 percent (AWWA, 1990; ERI, 1991). Other water-borne preservatives include acid copper chromate (ACC), ammoniacal copper arsenate (ACA), ammoniacal copper zinc arsenate (ACZA), chromated zinc chloride (CZC), and inorganic boron or sodium borate (AWWA, 1990.) CCA is used in many residential and commercial applications. Its use is supported by a 1984 EPA survey of wood preservatives that emphasized, "...wood treated with inorganic arsenicals is suitable for most end-uses of lumber, timber and plywood. Inorganic arsenical-treated wood is clean, odorless, paintable, easy to handle, harmless to plants, and more durable than other treated wood." EPA also distinguishes between arsenical-based preservatives and hydrocarbon-based preservatives noting that,

"...pentachlorophenol and creosote treated lumber, timber, and plywood have limited uses due to odor, objectionable vapors, and oily, unpaintable surfaces," (EPA, 1984; ERI, 1991).

4.6 The Composition of Wood Coatings

A wide variety of coatings and paints may be present in waste wood. Of the three non-wood materials discussed, wood coatings make up the least proportion by weight, usually less than 0.1 percent of non-wood additives in waste wood (ERL, 1990). The thickness of coatings depends on the wood product and the intended use. Coatings range from less than one mil thick to ten mils thick. (A mil equals 1/1000th of an inch.) By definition, coatings that exceed 10 mils are usually referred to as linings or films (Clauser, 1976). An alternative measure of paint thickness is supplied by fire toxicity tests, where paint was applied at a rate of three grams per 100 centimeters. This application was intended to resemble two coats of paint (ADL, 1988).

The most common surface coatings are organic coatings including paints, enamels, stains, varnishes, and lacquers. Organic coatings always consist of a vehicle and a pigment. The vehicle provides dispersion and film-forming characteristics that affect texture, spreading, and hardness. The film forming component of the vehicle binds pigments and other non-volatile components of the paint (NPCA, 1989).

Vehicles can be divided into three groups, based on the type of solvent or carrier: oil-based vehicles, water-based vehicles, or varnishes. Oil-based vehicles consist of alkyd, vegetable, linseed, or tung oils combined with resin, fillers, and pigment. Water-based vehicles contain fine particles of resin, filler, oil, and pigment. Varnish-based vehicles combine various resins with either drying or non-drying oils and solvents. Resins used in oil, water, or varnish vehicles include acrylic, acetate, butyrates, and polyvinyls (Dagostino, 1983; Clauser, 1976). All vehicles dry or cure through either evaporation of water or solvents, or through polymerization and oxidation of oils and resins.

Pigments are chemical agents that are used as coloring, water repellents, fire retardants, preservatives, and rust inhibitors. Pigment systems consist of primary pigments, fillers, and secondary organic or inorganic pigments. The predominant primary pigment used in the paint industry is titanium dioxide. Fillers are usually talc or calcium carbonate (NPCA, 1989).

The two classes of secondary pigments are comprised of organic "earth colors" and inorganic "chemical colors." Earth colors are chemically stable and resistant to heat and weather. The more specialized chemical colors are formed under chemical reaction for specific purposes such as color and refractive properties.

Chemical colors include metallic-based pigments such as aluminum powder, lead, and zinc chromate (Clauser, 1976). Before 1940, lead could comprise as much as 50 percent by weight of dry paint film. In 1955, the American National Standards Institute adopted a voluntary standard of 1 percent lead content by weight for interior uses. This standard was codified in 1971 and then lowered to 0.06 percent in 1976 (ERI, 1991). Currently, paint containing significant amounts of lead is most likely present in older buildings or in demolition waste derived from older buildings.

Other metal-based pigments may contain mercury, titanium, and copper. These consist of pigments such as arsenic pentasulfide (yellow), copper acetate (blue-green), copper ferrocyanide (red-brown), lead chromate (green, yellow,

red), and lead and zinc chromate ("Molybdate Orange" and "Zinc Yellow") (ERL, 1990).

4.6.1 Major Wood Coating Product Groups

A description of major groups of coatings found in waste wood is provided below. The description is based both on commonly used product terms and on product uses. The product-oriented description is supplemented by a list of major chemical components of various paints presented in Table 4-5. This table identifies the major chemical components of typical wood coatings. These chemicals are found in various concentrations in the products discussed.

4.6.1.1 Paints and Stains

Paints and stains were originally defined as a dispersion of pigment in an oil-based vehicle. Currently, however, the term paint is often used to describe a wide variety of organic coatings including stains, varnishes, and lacquers. Paints and stains are available in a wide range of non-oil, plastic, alkyd, or acrylic resin bases. According to the NPCA, oil-based paints account for roughly 30 percent of all paint produced in the U.S.

4.6.1.2 Water-Based Coatings

Water-based coatings contain minute particles of plastic resin and pigment in a water-based carrier. There are three types of water-based coatings: emulsions, latexes, and water soluble solutions. Emulsion coatings are "suspensions in an oil phase in water." Latexes are "dispersions of resins in water" (Clauser, 1976). Water soluble coatings are clear, solvent-like finishes that, unlike latexes and emulsions, contain low molecular weight resins. Latexes typically contain either acrylic, vinyl, or polyvinyl resins (Dagostino, 1983). Water-based paints make up 70 percent of architectural finishes, according to the NPCA.

4.6.1.3 Lacquers

Lacquers are quick-drying paint coatings that use solvents in the vehicle. The simplest and oldest form of lacquer combined alcohol with lac resin, which is the basic component of shellac or spirit lacquer. Common synthetic lacquers now include solutions of cellulose acetate or acetate butyrate, ethyl or nitro-cellulose, and vinyl resins (Clauser, 1976).

4.6.1.4 Varnishes

Varnishes are paints consisting of "thermoplastic resins and either drying or non-drying oils" (Clauser, 1976). Varnishes are frequently combined to form enamels and other types of organic coatings. Varnishes contain either alkyd or urethane resins.

4.6.1.5 Enamels

Enamels are paints defined as an "intimate dispersion of pigments in a varnish or a resin vehicle or a combination of both" (Clauser 1976). This group uses urethane, epoxy, and alkyd resins. Enamels are known for their hard, scratch-resistant finish and strong coloration.

4.6.1.6 Polyurethanes

Polyurethanes are formulated from several different products to produce a clear, waterproof, and mar-resistant finish. A main component of polyurethane

is tolylene diisocyanate. Polyurethanes are used primarily on floors, cabinets, and boats.

4.6.2 Proportion of Materials in Paint

In a report completed for the National Paint and Coating Association, a statistically representative range of concentrations of various components of paint were selected for flammability and toxicity testing.

Presented in Table 4-5 are "...factor levels representative of typical paint products" (ADL, 1998). These factors are based on a database

Table 4-5. Wood coating characteristics.

Typical chemical compounds in paints and coatings ^a	
Alkyd	Polybasic acid + polyhydric alcohol + monobasic fatty acid
Alkyd urea	Oil modified polyester with UF crosslinking
Acrylic	Acrylic acid, methacrylic acid, ester derivatives, nitriles and amide derivatives.
Polyvinyl acetate	-CH ₂ -CHOAc-CH ₂ -CHOAc-
Polyurethane	Isocyanates + hydroxyl containing compounds
Polyesters	Polybasic acids + polyhydric alcohols
Nitrocellulose	cellulose + nitric acid
Ethylcellulose	Hydroxyl groups replaced by ethoxy groups in cellulose
Butyrate	Cellulose acetate butyrate
Vinyl	Vinyl acetate - vinyl chloride copolymer
Epoxy	Bisphenol A + epichlorohydrin + sodium hydroxide
Melamine	Melamine + formaldehyde
Polystyrene	(CH ₂ -CHC ₆ H ₅ -CH ₂ -)n
Styrene-butadiene	(CH ₂ -CH=CH-CH ₂ -CHC ₆ H ₅ -CH ₂ -)n
Typical properties of materials in paints and coatings	
Binder (resin)	30% mass for all binder/substrate combinations
Primary pigment	Low level: 0%
	High level: 30%
Filler	Low level: 0%
	High level: 20%
Inorganic secondary pigment	Low level: 0%
	High level: 5%
Organic secondary pigment	Low level: 0%
	High level: 5%

a. From National Forest Products Association, 1989.

b. From Arthur D. Little, 1988.

collected by Arthur D. Little, Inc. that reflects the range of major surface coating concentrations. These concentrations were used in flammability tests. Note that the table does not show the level of solvent in the formulation because the solvent evaporates during the curing and drying process.

It is clear from this table that resin content is a primary ingredient (up to 30 percent) in all paint formulations due to its role in the paint vehicle. Primary pigments, such as titanium dioxide, also comprise up to 30 percent of a paint solution. Secondary pigments, while useful in paint identification, are usually less than 5 percent in most paint formulations.

Resin content has been identified by the National Paint and Coating Association as the primary variable in toxicity emissions, due to its high percentage content in paint formulations. According to a report prepared for the NPCA, "...only the film-forming component (or resin) contributes to the fire toxicity of the product" (NPCA, 1989).

Using this criteria, the NPCA identified five classes of surface coatings based on resin type: acrylic, alkyd, epoxy, vinyl, and urethane. The chemical components of each of these classes are described in more detail in Table 4-6. It is important to note, however, that the five resin classes were developed for fire toxicity tests. Due to the high temperatures used in controlled combustion systems, toxicity from resin combustion may not be as important to air emissions or ash content as metals in paint pigments or other products of combustion. The table on resin classes is provided to detail chemical composition only and does not portray the effects of burning painted wood in wood-fired combustion units.

4.7 Physical and Chemical Contents of Harvested Wood and Six Common Wood Products

This section identifies and describes the physical and chemical characteristics of harvested wood as well as six wood products commonly used throughout the U.S. and Canada. Because the wood products are commonly used, they are potential sources of waste wood that could potentially be processed for fuel. In addition to harvested wood, the wood products described include: pallets, painted wood, plywood, particleboard, pressure-treated and creosote-treated wood. The six wood products were selected for this study based on a variety of factors including their relative frequency and quantity in the waste stream; their availability to existing and potential fuel markets; interest by combustion facilities to recover the energy potential of the wood products; and suspected differences in the combustion characteristics of the products. Table 4-7, summarizes the key characteristics of each treated wood product. Information in the text and the table can be used to estimate the physical and chemical contents of non-wood materials likely to be present in waste wood.

4.7.1 Harvested Wood

This section focuses on characteristics of harvested wood that are relevant to its properties when burned. Since harvested wood does not contain non-wood materials, this provides a context for understanding potential environmental impacts of burning harvested wood compared to other waste wood.

Moisture content is a key factor affecting the heating value of wood burned for fuel. Moisture content is usually measured and described on the basis of how much of the contents of the wood is water. For example, freshly cut, green harvested wood typically has a moisture content of 40 to 60 percent. Measured on a wet basis, this means that 40 to 60 percent of the wood is moisture, and that the remainder is wood. Harvested wood that has been dried by letting it "season," has a moisture content of approximately 20 percent, or less. Wood that has been kiln dried and then processed into wood products usually has a moisture content of less than 10 percent (GLRBEP, 1986).

The energy content of woodfuel is defined in terms of gross and net heating values. Gross heating value (GHV) is a measure of the energy available from a pound of wood, taking into account the wood material that is displaced by water. The net heating value (NHV) represents the usable energy available after expending energy to evaporate moisture contained in the wood. The typical gross heating value for freshly cut harvested wood (often referred to as "green" wood) is approximately 4,800 BTUs per pound. The gross heating

Table 4-6. Description of resin classes^a.

<p>Acrylic</p> <p>Acrylic resins are the film-forming component of this product class. Acrylic are polymers of acrylic acid, methacrylic acid, and their esters and amides. Styrene, vinyl toluene, and acrylonitrile are often used as copolymers in acrylic resins. Individual resin manufacturers may introduce various comonomers to impact specific properties, such as improve adhesion and crosslinking.</p>
<p>Alkyd</p> <p>Alkyd resins are the film-forming component of this product class. Alkyd resins are polymers of polybasic acids, polyhydric alcohols, and fatty acids. In a number of products, specific properties are imparted to the resin through the use of modifying agents. These include rosin, polymerized resin, phenolic resin, silicone resin, polymer, urethane, epoxy resins, polyimides, styrene, vinyl toluene, methacrylate ester, acrylate ester, or dicyclopentadiene.</p> <p>Alkyd resins are often characterized by the amount and type of fatty acids used in their manufacture; or by the modifier used to impact specific properties. For example, phenolic modified alkyd, silicon alkyd, styrenated alkyd, and urethane modified alkyd.</p>
<p>Epoxy</p> <p>Epoxy resins are the film-forming component of this product class. Epoxy resins are polymers containing an average of more than one epoxy (oxirane) group per molecule. The epoxy group is most often attached to the polymer as a glycidyl ether. Other epoxy resins are prepared by the oxidation of unsaturated materials or by the incorporation of an epoxy isomer (i.e., glycidyl methacrylate) into an acrylic copolymer.</p>
<p>Vinyl</p> <p>Vinyl acetate resins are the film-forming component of this product class. Vinyl acetate resins include the homopolymers and copolymers of vinyl acetate along with specialty polymers such as polyvinyl alcohol and polyvinylacetal. Vinyl acetate copolymers are formed by copolymerizing vinyl acetate with other copolymers including vinyl acrylics, alkyd maleates and fumarates, other vinyl esters, and ethylene. Other commonly used monomers include hydroxyalkyl acrylates or acrylic acid.</p>
<p>Urethane</p> <p>Polyurethane resins are the film-forming component of this product class. Polyurethane resins are formed through the reaction of isocyanate groups and with themselves or with compounds containing an active hydrogen such as water, mono or polyfunctional alcohols, amines, polyesters containing hydroxyl groups, polyethers, epoxies, or acrylic polymers. The two main categories of urethane products are: (1) nonreactive (oxidative or amine/formaldehyde condensation) crosslinking types, high molecular weight polymers, and blocked isocyanate polymers and (2) reactive (two-component) systems moisture cured.</p>

a. From National Paint and Coating Association, March 1989.

Table 4-7. Characteristics of common wood product groups.

Wood product group and types	Primary non-wood chemical contents	Amount of chemical(s) in wood product	Typical moisture content ^a	Primary uses of wood product	Comments
A. Pallets and wood containers					
1. Pallets (hard and softwood)	Low levels of pesticides and preservatives (penta, lindane dimethyl copper, or copper naphthenate)	<10 ppm	15-20%	Besides shipping and handling, pallets are chipped for fuel and animal bedding	Testing underway for new pallet products with trade names of "Enhanced Wood" which use layers of epoxy and/or urethane for washability, water, and wear resistance.
2. Skids	Quinolinolate, or copper naphthenate	2-4%	8-12%		
3. Plywood pallets	Phenolic resins in plywood	2-4%	8-12%		Hardwood pallets found mainly in the east, softwood and plywood mainly in the west.
4. Glued pallets	Elastomeric adhesives (epoxy)	2-4%			
B. Painted or coated wood					
1. Lead based paint (demolition wood)	Lead level depends highly on the age of the paint	1400-20,000ppm (before 1950)	15-20% exterior 6-12% interior		Before 1950, lead as much as 50% of paint film. 1955 ANSI standard reduced lead to 1.0% by weight. 1971 legislation: <1.0% by wt. 1978 legislation: <0.6% by wt.
2. acrylic based paint	acrylic acid, styrene, vinyl toluene, nitriles	<0.1%	15-20% exterior 6-12% interior		
3. metallic pigments	aluminum powder, copper acetate, phenol mercuric acetate, zinc chromate, titanium dioxide, copper ferrocyanide	<0.1%	15-20% exterior 6-12% interior		

(continued)

Table 4-7. Characteristics of common wood product groups (continued).

<p>C. Structural panels</p> <p>1. Plywood</p> <p>a. Interior grade</p> <p>b. Exterior grade</p> <p>2. Oriented strandboard</p> <p>3. Waferboard</p>	<p>urea formaldehyde (UF) resins</p> <p>Phenol formaldehyde (PF) resins</p> <p>Pf or PF/isocyanate resins</p> <p>UF or phenolic resins</p>	<p>2-4% dry wt.</p> <p>2-4% dry wt.</p> <p>2-4%</p> <p>5-15% UF, 2.5% PF, 2% wax</p>	<p>6%</p> <p>8-12%</p> <p>8-12%</p>	<p>Walls, floors, cabinets</p> <p>Wall and roof sheathing</p> <p>Replacement of plywood in roofs, walls, and floors</p> <p>Wall and roof sheathing, interior and exterior</p>	<p>May be surface coated with fire retardants, preservatives and insecticides, or pressure treated with CCA.</p>
<p>4. Specialty grades</p> <p>a. Medium and high density overlay panels</p> <p>b. Luan plywood and PVC laminate</p> <p>c. Fire resistant</p>	<p>PF resins</p> <p>UF resins, polyvinyl chloride (PVC)</p> <p>Salt solutions in core or borax surface treatment</p>	<p>4-8%</p> <p>2.5% UF, 10% PVC</p>		<p>Highway signs, exterior panels</p> <p>Underlayment for floors</p> <p>Where building codes require it.</p>	
<p>D. Nonstructural panels</p> <p>1. Particleboard (10 grades, 3 density ranges.</p> <p>With PVC laminate</p> <p>2. Medium density fiberboard</p> <p>3. Hardboard</p>	<p>UF resins</p> <p>UF resins with PVC</p> <p>UF resins</p> <p>Phenolic resins</p>	<p>5-15% UF</p> <p>4.5% UF, 10% PVC</p> <p>1.5%</p>	<p>8-12%</p> <p>8-12%</p> <p>8-12%</p>	<p>Interior uses</p> <p>Interior uses</p> <p>Interior uses</p> <p>Composit I-beams, underlayment</p>	<p>May be sealed with polyurethane</p> <p>Used for smooth finish and painting</p> <p>Very limited use.</p>

(continued)

Table 4-7. Characteristics of common wood product groups (continued).

E. Poles, ties, piling, docking, fencing, decks					
1. CCA solutions	CCA-three grades	1-3%	(a)		Dominant wood preservative
a. Pressure and surface treated					Exterior use; decking, fencing, posts
2. Pentachlorophenol solution	Chlorinated phenols	1.2-1.5%	(b)		Utility poles, laminated beams, fresh water piling, bridge timbers
3. Creosote solutions	Creosote containing 85% PAHs Creosote containing 85% PAHs	14% by weight 14% by weight	(a) (a)		Restricted use due to industry change and concern over dioxin linkage; not permitted for residential uses.
a. Creosote-petroleum					Losses after treatment estimated to be 20-50% over 10-25 years; not recommended for residential uses.
b. Creosote-coal tar					Railroad ties, utility poles, marine pilings
c. Creosote coal tar (marine grade)					Saltwater use only
d. Creosote (marine grade)	Creosote/chlorpyrifos	15-20% 15-20%	(a) (a)		Chlorpyrifos specified where certain marine borers accelerate wood decay

- a. Moisture content will vary depending on wood species, exposure, and decay. Dry, treated wood will typically stabilize at 19-25% wet basis, depending on climate. Kiln dried wood will be initially treated at lower levels (10-15%).
- b. Waterborne preservatives will typically induce swelling of the wood. Following evaporation, wood will stabilize at atmospheric equilibrium.
- c. There are several fire retardant formulations variously used with wood coating or preservative solutions. Retardants are used for a range of materials including dimension lumber, pressed panels, and laminated beams. Chemicals used include monoammonium phosphate, boric acid, ammonium sulfate, and various formulations of nitrogen, boron, and phosphorus.

value increases dramatically, as the amount of moisture is reduced by seasoning or kiln drying the wood. Proximate and ultimate analyses are two tests commonly used to determine basic combustion characteristics of woodfuel. A proximate analysis measures the volatile matter, fixed carbon, and ash content of wood when combusted. An ultimate analysis measures the amount of several common chemical elements in wood such as carbon, hydrogen, oxygen, nitrogen, and sulfur. Results of ultimate analyses are used to determine the amount of air needed for efficient combustion and to predict potential airborne pollutants from combustion (Tillman, 1981). Section 7.6 of this study discussed in great detail the results of conducting ultimate and proximate testing of various "clean" wood and waste wood streams.

4.7.2 Pallets

Approximately 2,300 firms in the U.S. produce various sizes and grades of pallets. Wood pallets and containers are widely used in food, chemical, manufacturing, and agricultural industries. Pallet manufacturing represents the second largest use of sawn lumber and the largest use of hardwood lumber in the U.S. (Smith, 1991). Western pallet manufacturers rely on softwood lumber; eastern manufacturers rely on hardwood. Plywood pallets may be used when dimensional stability is needed and in automated handling systems (NWWPA, 1980).

Plywood pallet specifications require the use of exterior grade structural plywood. This plywood usually contains phenol formaldehyde glues.

Pallets may also contain chemical treatments, such as water and insect repellents, that extend their useful life. A recent study of pallets showed trace levels of penta, lindane, and dimethyl phthalate (White & McLeod, 1989). Surface applied water repellents used in pallet manufacturing include oil borne solutions of copper-8-Quinolinolate (0.25 percent by weight) and copper naphthenate (0.5 percent metal). Other preservatives may include borates or sulfonates (McNally, 8/91; NWWPA, 1967).

A new type of pallet is currently being tested with the trademark name "Enhanced Wood." Pallets using Enhanced Wood are waterproof and are designed to last for six years. Enhanced Wood pallets contain elastic epoxy or polyurethane formulations that are surface applied in a 6 to 8 mil thick coat. Enhanced Wood has been approved by the U.S. Food and Drug Administration for direct contact with food (McNally, 1991).

4.7.3 Painted Wood

Characteristics of painted wood depend primarily on the intended use of the product and the type of paint or coating. Film-forming finishes include paint, lacquer, varnish, polyurethane, and solid stains.

Penetrating finishes, such as stains and varnishes, are used for protection against water, insects, and wood decay. Penetrating finishes usually rely on oil-based stains containing alkyd or acrylic resins.

Finishes include water repellents, wood preservatives, pigmented stains, and semi-transparent stains.

Film-forming finishes, either oil- or water-based, are used when strong coloration and/or water and weather resistance are necessary. Acrylic and urethane resins are used primarily when durability and color are needed.

Besides pigments and fillers, other paint additives may include product-specific needs such as for pressure-treated wood, wood subject to insect infestation, or excessive moisture. These additives include ethylene glycol, preservatives such as copper naphthenate, or fungicides such as lindane.

4.7.4 Plywood

Plywood is defined by the American Plywood Association as "...the original structural wood panel. It is composed of thin sheets of veneer, or plies, arranged in layers to form a panel. Plywood always has an odd number of layers, each one consisting of one or more plies, or veneers" (APA, 1990). Plywood manufacturing consists of laying veneers in specific patterns, applying glue and hot pressing the layers to form a bonded panel. Common plywood thicknesses are 5/16, 3/8, 1/2, and 3/4 inch.

Panels are "performance rated" based on their intended structural use. Exterior grades will be typically bonded with phenol formaldehyde glues. Interior grades will contain urea formaldehyde glues. Depending on the specific manufacturer, plywood contains 2 to 4 percent of either phenol or urea formaldehyde glue by dry weight. Some exterior grades of plywood may be treated with acrylic or urethane based paints as well as moisture and insect resistant preservatives. Interior grades may contain fire retardants. Typical uses for softwood plywood are for floors, sheathing on walls and roofs, and concrete forms. Hardwood plywood is used in furniture, cabinets, floors, and trim work.

4.7.5 Particleboard

Particleboard is a non-structural wood panel developed in the 1930's as a way to recover planer shavings. Ninety-eight percent of particleboard manufactured in the U.S. is urea-bonded. However, the American National Standards Institute (ANSI) also defines exterior grade particleboard as a product that is phenol-bonded (Wardell, 1991). Because particleboard is urea-bonded, it is sensitive to moisture. Therefore, particleboard is used in interior cabinets, shelves, stairs, furniture, paneling, or as underlayment for floors.

Particleboard contains 5 to 15 percent urea formaldehyde resins by weight. It is manufactured in ten grades and three density ranges (high, medium, and low). The most common grade found in lumber stores is medium density particleboard. Two special density grades are made for prefabricated homes and floor underlayments. Higher density grades of particleboard are stronger and heavier. Particleboard is manufactured from discrete wood particles. Other non-structural panels, such as fiberboard or hardboard, are manufactured using an additional processing step which breaks wood down into individual fibers and which results in products with a smoother finish.

4.7.6 Pressure-Treated Wood

The pressure treatment of wood is defined by the American Wood Preservers' Institute to be a process "...by which chemicals are forced deep into a wood's cells in a closed hermetically sealed cylinder, or retort under pressures of 100 pounds per square inch or more" (AWPI, 1988). Pressure-treated wood is used primarily outdoors in docks, fences, decks, bridges, mine shafts, railroad ties, and landscaping applications.

Pressure-treated wood may be treated with one of three major wood preservatives (listed below) in two major grades. One grade is for aboveground uses such as sill plates, decks, or fences. The other grade is for ground contact with soil or fresh water (AWPI, 1988). Standards for both

grades as well as for specialty grades, such as salt water exposure, are specified by the American Wood-Preservers' Association.

Wood pressure treated with creosote is used primarily for railroad ties, utility poles, highway bridges, and marine uses. It is not recommended for interior uses. A specialty creosote- treated product intended for marine uses may contain an insecticide (such as chlopyrifos) used to repel specific marine borers that are found in semi-tropic coastal waters.

Wood pressure treated with pentachlorophenol is widely used to manufacture poles and pilings. Due to the difficulty of pressure treating very long poles, penta is frequently applied by soaking in thermal baths. Before the development of inorganic arsenicals, penta was used extensively in exterior preservation. However, two major corporations recently stopped manufacturing penta. The remaining manufacturers of penta sell almost exclusively to utility pole manufacturers. Glue- laminated beams in commercial structures, such as sports arenas or shopping centers, may also contain penta. However, penta is not recommended for interior uses. Wood pressure treated with inorganic arsenicals, such as CCA, is widely used for treating exterior dimensional lumber because CCA is chemically more stable and permanent than hydrocarbon preservatives, and CCA does not emit fumes. CCA-treated wood is used in decks, fences, landscaping, and playgrounds. It is also used for interior applications where exposure to moisture, potential infestation, or decay may be a problem (AWPI, 1988).

4.7.7 Creosote-Treated Wood

Creosote treatment may take place either through pressure treatment or by a process known as thermal treatment. Under thermal treatment "...the material to be treated is heated for several hours in an open tank of pentachlorophenol or creosote preservative, then quickly submerged in a cold solution for several hours...the thermal process resembles a vacuum process in principle..." (AWPI, 1988). Standards for creosote formulas and retention in wood are specified by the AWWA. Creosote- treated wood or logs are used in residential interiors, log homes, outdoor furniture, and animal pens. Prior to 1960, most utility poles were treated with creosote solutions. Since then, the primary treatment method has used pentachlorophenol independently or with other creosote solutions (Brennan, 1991). Due to vapors, creosote-treated wood may be sealed with coal tar pitch, urethane, epoxy, or shellac (AWPI, 1988).

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5.0 WASTE WOOD PROCESSING FACILITIES

5.1 Introduction

This chapter describes facilities that collect, sort, and process waste wood for fuel. Key steps and their sequence used during processing are explained. Information is provided on the design, operation, and capabilities of specific types of equipment commonly used by processors. The chapter is organized into five sections.

Section 5.2 discusses the ways in which waste wood processors can improve solid waste management in municipalities, states, and provinces. This is important because most waste wood received by processors would usually be discarded, either legally or illegally.

Section 5.3 describes the major characteristics of four types of facilities that process waste wood for fuel. Mobile facilities are distinguished from stationary facilities. Facilities that only process wood are distinguished from facilities that process multiple types of waste, such as construction and demolition debris containing rubble, metal, glass, and wood.

Section 5.4 describes the basic steps included in a waste wood processing line, and the sequence in which they occur. Information is provided about facilities that receive wood that is presorted from other types of waste. Information is also provided on facilities that receive wood that is commingled with other waste, such as construction and demolition debris. Factors that affect the selection of processing equipment are discussed, as well as factors that affect the ability to remove non-wood materials from the waste. Techniques used to sort, separate, and process both treated and untreated waste wood are explained.

Section 5.5 describes the equipment used in each step of a processing line, and explains the overall capabilities of the equipment. Information is provided on how waste wood with relatively small amounts of non-wood materials or contaminants is processed to meet air and ash standards of combustion facilities. Information is also provided on how wood with significant amounts of non-wood contaminants is handled, screened, and processed.

Section 5.6 provides a summary of waste wood facilities researched for this study. A table is included that lists major facilities in the study area. Another table notes the types of equipment used at eight facilities, five of which are in the study area.

Section 5.7 includes case studies of two waste wood processing facilities in the study area. The facilities were visited as part of the research for this study. The case studies include information about the equipment used as well as solid waste and waste wood management issues affecting the area where the facility is located.

Section 5.8 describes the role of tipping fees and disposal costs in waste wood processing for fuel. Tipping fees among several solid waste management facilities in the study area are compared. Factors affecting disposal costs for waste wood, particularly wood generated from construction and demolition activities are discussed.

5.1.1 Key Questions Regarding Waste Wood Processing

- What regulatory and economic issues affect the ability of processors to use wood from the waste stream?

- What types and sizes of facilities process waste wood for use as a fuel?
- What are the primary types of technologies used to prepare wood for fuel?
- What types of non-wood materials can successfully be removed from waste wood while processing the material for use as fuel?

5.1.2 Key Findings

- The decision to operate a waste wood processing facility is influenced by many factors. These include: the economic and regulatory climate that affects wood that may be "disposed" of at processing facilities; the way in which recycling and solid waste management authorities permit a processing facility; and, the status and requirements of markets that use processed waste wood for fuel or other uses.
- The four major types of waste wood processing facilities are defined by their size and the technology used. Three types of facilities (listed from smallest to largest) usually operate as physically independent facilities. On-site processing facilities are found adjacent to combustion units, and vary by size and requirements of the combustion technology being served.
 - Mobile waste wood processors;
 - Stationary wood-only processors;
 - Stationary multi waste processors, and;
 - On-site processors located at combustion facilities.
- Processing technologies continue to evolve in response to market demand for certain quality wood fuels, and economic incentives facing the recycling industry. In general, new metal recovery, screening, and washing technologies have improved the ability of processors to prepare waste wood that meets fuel specifications.
- Despite advances in processing technology, a key step in controlling the level of contaminants in wood fuel is through inspection and enforcement procedures "at the gate" of a processing facility. Several techniques are available for controlling unacceptable waste wood from entering a processing facility, including the use of contracts and economic penalties.
- When waste wood is accepted for processing, cleaning equipment designed specifically to detect and remove foreign metal, dirt, and other attached debris is capable of high removal efficiencies. Chemicals, stains, or preservatives that impregnate wood are usually unable to be removed during mechanical processing.

5.2 How Waste Wood Processors both Affect and are Affected by Solid Waste Management Issues

Substantial amounts of waste wood are generated by households, businesses, and industries in the U.S. and Canada. With the exception of mill residue generated by wood products industries, until the 1980's, most waste wood was disposed of either in permitted disposal facilities or through illegal backyard dumping and on-site burial. During the past decade, however, a variety of waste wood processing facilities have been developed stimulated by escalating tipping fees at other solid waste facilities, and by the availability of markets for products recovered from wood.

To date, most major waste wood processing facilities are privately owned. The facilities usually complement, rather than duplicate, existing solid waste management and disposal services. In general, waste wood processors improve the management of solid waste by accepting waste at competitive tipping fees, and by creating new reuse and recycling capabilities. Processors produce a variety of products that have market value, including fuel, potting soil, landscaping mulch, animal bedding, sludge stabilizer, compost amendment, and manufactured building products, among others.

5.2.1 Major Factors Affecting Processors

A variety of factors affect waste wood processing facilities. Processing facilities require successful operation of two distinct components. One component involves obtaining sufficient supplies of waste wood. This is partially a function of being able to charge tipping fees for waste delivered to the processing facility that are competitive with, or lesser than, fees charged at other disposal facilities. The second component involves securing a reliable demand, and suitable price, for products recovered from the wood. In some locations, there is an adequate supply of wood needing "disposal," but there are insufficient end-use markets. In other locations, the reverse is true.

Specific factors affecting the role and overall impact of waste wood processors in solid waste management vary. In some locations, a large demand for end products has a significant impact on processors. An example is California, where nearly 1,000 MW of power are produced (as of 1991) from 70 wood-fired facilities. This relatively large amount of power generation has resulted in substantial demand for wood fuel and increasing competition for waste wood by processors. In other locations, solid waste policies have a significant impact on waste wood processors. An example is Florida, where publicly owned landfills are banned from accepting wood for disposal. Municipal and private haulers are actively seeking new disposal, reuse, or recycling opportunities for waste wood; however, existing end-use markets are limited, especially for fuel.

Major factors affecting waste wood processors include: existing solid waste and recycling programs, policies, and regulations; the availability of waste wood for processing; the extent of end-use markets; and specifications for end products. These factors affect a processor's selection of equipment, determination of the appropriate capacity of a facility, and facility location. These factors are discussed in the following text.

5.2.2 Policy and Regulatory Factors

Federal, state, provincial, and local solid waste and recycling programs, policies, and regulations affect waste wood processing facilities in many ways. Examples are noted below.

- Solid waste management and recycling policies and programs that divert waste wood from landfills, and that encourage the reuse and recycling of the material can stimulate waste wood processing. Examples of such policies and programs include subsidies for the source separation of waste wood and tax incentives for processing equipment (Yvars, 1991). These approaches provide incentives for separating wood from other waste, and increase the availability of waste wood for reuse and recycling.
- Policies and regulations that establish guidelines for permitting waste wood processing facilities can clarify and

facilitate the development stage for a processor. In some states/provinces, the guidelines are unclear, untested, or developed on a case-by-case basis.

- Solid waste authorities that purchase waste wood processing equipment or help fund facilities can stimulate diversion of wood from landfills, and thereby extend their existing capacity for other wastes. An example is the purchase of a mobile tub grinder by a county solid waste district that is used by all municipalities in the district (Cech, 1991). This provides the infrastructure for processing waste wood obtained from public lands and municipal pick-up services.

5.2.3 Factors Affecting Waste Wood Availability

A variety of factors affect the availability of waste wood for processing. These are noted below.

- Bans or penalties on the disposal of waste wood in landfills are increasingly being used by solid waste authorities to maximize the remaining capacity of existing landfills (Moore, 1991) due to the high cost of siting, permitting, and building new landfills. The bans can result in short- or long-term surpluses in waste wood, and can stimulate investments in processing facilities.
- Tipping fees charged for "disposing" of waste wood at processing facilities are usually less than tipping fees charged at other disposal facilities, such as landfills and refuse-to-energy plants. This provides economic incentives to waste generators and haulers to provide waste wood to the processor, rather than to "dispose" of it at other facilities.
- The availability of other waste wood disposal options, such as on-site burning, burying, composting, or illegal dumping, affects the availability of waste wood for processing facilities. If other disposal options are readily available and cost-effective, it may be difficult for a processing facility to obtain adequate supplies of waste wood.
- Most processors have specifications for the types of wood accepted at their facility. Unless tipping fees at the facility are significantly lower than other facilities (or if on-site burning and other practices are allowed), it may not be convenient for generators and haulers to separate and sort wood to meet the specifications.
- In order to guarantee a stable, cost-effective supply of wood that meets their fuel specifications, wood-fired power plants are increasingly investing in or developing processing facilities that prepare fuel specifically for their facility (Allen, 1991; Fitzgerald, 1991). In some cases, power plant developers are investing in existing processing facilities that were originally independently owned (Fitzgerald, 1991).

5.2.4 Factors Affecting End-Use Markets

Many processors produce multiple products including, but not limited to, fuel. This allows the processor to supply material to more than one end-use market. At some facilities, prices paid for waste wood processed into fuel are lower

than prices paid for waste wood processed into potting soil, landscaping mulch, or other products (Remington, 1991). The ability to supply higher priced end-use markets can increase the economic feasibility of also processing and supplying lower priced fuel. Several aspects of end-use markets that affect waste wood processors are noted below.

- The availability of reliable end-use markets for processed wood is essential for the successful operation of a processing facility (Mittleman, 1991). In addition, the availability of multiple markets can offset seasonal fluctuations in demand for wood. Examples include the substantial variation in demand for wood by dispatchable power plants that only produce power when instructed to by regional power authorities. Another example is seasonal landscaping markets in northern climates.
- Market premiums may be paid for specific grades of processed wood, especially if there is strong competition for processed wood overall. The premium price paid will depend on specific wood product characteristics, such as moisture content, dirt content, chemical content, particle size, or heating value (Karakesh, 1991). Premium prices are preferred by processors, particularly if they have modified their facility specifically to produce a certain quality product.

5.2.5 Factors Affecting Treated Waste Wood Processing

Different equipment and manual techniques are used at facilities that receive and process significant amounts of treated waste wood than at facilities that do not. The willingness of processors to purchase appropriate equipment for handling and cleaning treated waste wood is a function of a variety of regulatory and economic issues. Specifications for end-use products usually determine the types and mixture of waste wood accepted and processed at a facility.

5.3 Types of Waste Wood Processing Facilities

In general, processors whose primary supply of wood is from municipal, commercial, or industrial sources use substantially different equipment and manual techniques than those whose primary supply is harvested waste produced by forestry and site conversion activities because waste wood from municipal, commercial, and industrial sources is more variable in size, physical contents, and chemical composition than harvested wood. In addition, the wood may be commingled with other waste. Depending on the equipment and techniques used at a processing facility, other waste may need to be separated from the wood before it is processed.

There are four types of facilities that process waste wood into fuel (and other products), including:

- Mobile waste wood processors;
- Stationary wood-only processors;
- Stationary multi-waste processors; and
- On-site processors at combustion facilities.

There are many sizes, or capacities, of processing facilities and there is not always a correlation between the type of facility and its capacity. In this report;

- "Small" processors are defined as facilities that generally have a capacity to process less than 50 tons per day of wood, or less than 15,000 tons per year. However, small facilities are usually mobile processors consisting of a tub grinder or hammermill which can be hauled by pick-up truck.
- "Medium" facilities usually have the capacity to process 50 to 200 tons per day, or 15 to 60,000 tons per year and usually include large mobile equipment transported on flatbed trailer(s), stationary wood-only facilities, or processors that operate on-site at a combustion plant.
- "Large" facilities have the capacity to process more than 200 tons per day, or more than 60,000 tons per year. Large facilities usually include the largest wood-only processors and most multi-waste processors. Large facilities are most likely to handle significant volumes of treated wood because they have economies of scale that allow for the purchase and use of more expensive processing equipment to sort and remove contaminants from treated waste wood.

Table 5-1 summarizes key characteristics of the different types of processing facilities. Information in the table is discussed in more detail below.

5.3.1 Mobile Waste Wood Processors

During the past ten years, mobile waste wood chippers and grinders have become available in various sizes that can be hauled from site to site. Some mobile equipment is designed to process only harvested wood. Other mobile equipment can process multiple types of harvested, municipal, commercial, and industrial waste wood. Other mobile equipment is designed to process waste wood that is commingled with other materials, such as rubble, metal, and glass found in construction and demolition debris. Mobile facilities usually charge a fee for processing and removing the material from a site. Earlier versions of the equipment were designed primarily for volume reduction. More recent versions are also designed to recover materials that have market value. Mobile waste wood processors are found throughout the study area. They range from home- and garden-scale chippers for yard, brush, and urban forestry uses, to commercial-scale tub grinders and shredders. Mobile processors are used at construction sites, during urban forestry programs, for maintaining utility rights-of-way, or to process wood gathered during municipal pick-up services.

Mobile processors handle waste wood in different ways depending on: the types of materials being processed; solid waste regulations that affect reuse, recycling, and disposal; and the availability of end-use markets including:

- Leaving wood on-site that has been "processed" simply to reduce the volume. The wood is then either buried or burned in open piles. Depending on the location, this is most common for site conversion wood, construction projects in rural areas, and some agricultural residue.
- Hauling the wood to a landfill, compost facility, or refuse-to-energy plant.
- Hauling the wood to a wood-only or multi-waste processor for further cleaning and processing.
- Hauling the wood directly to a combustion facility, if the wood is suitable for combustion with minimal or no further processing.

Table 5-1. Types of waste wood processing facilities.

Type of Facility	Typical Equipment Used	Materials Processed	Typical Quantity Processed	Markets Served
Mobile-waste wood	Small hammermills Tub grinders	Clean waste wood from logging, landclearing, or landscaping (for transport)	≤ 500 tons/day	Landscaping, compost, mulch, fuel, and landfill cover
Mobile-construction and demolition debris	Heavy duty impactor, crusher, or shredder. Primary screening or metal removal possible.	Demolition waste wood, scrap metal, concrete, glass, brick, rock, and rubble (for transport)	≤ 1,000 tons/day (mixed)	Typically do not serve markets directly. Material is removed for further processing or recycling. Waste wood typically requires further processing unless used for landfill cover.
Stationary-wood only	Inspection, weighing, sorting. Usually up to two processing lines. Tub grinder/hammermill. Primary screening and sorting. Secondary screening and sorting. Ferrous and nonferrous metal removal. Fuel storage and conveying.	Clean harvested wood. Construction and demolition wood. Some treated wood. Wood with tarpaper, shingles, or sheet metal attached. Industrial pallets, spools, shipping dunnage.	≤ 3,000 tons/week	Fuel, landscaping, compost, mulch, bulking agent for sludge, potting soil, cement additive, wood fiber for manufactured building products.
Stationary-multi-waste	Inspection, weighing, sorting. Usually up to three processing lines. Heavy duty impactor, crusher, or shredder. Tub grinder/hammermill. Primary screening and sorting. Ferrous and nonferrous metal removal. Fuel storage and conveying.	Clean harvested wood. Construction and demolition wood. Some treated wood. Wood with tarpaper, shingles, or sheet metal attached. Industrial pallets, spools, shipping dunnage. Non-wood materials include: metal, glass, brick, gypsum, concrete, wire, tubing, plastic, and rock.	≤ 10,000 tons/week (mixed)	Waste wood is typical sold to either fuel or mulch markets. Non-wood materials sold to other markets.
On-site combustion facility	Inspection procedures. Hammermill hoppers. Secondary screening, sorting, and ferrous metal removal. Fuel storage and conveying	Clean harvested, construction, and demolition wood. Primary and secondary mill residues.	≤ 1,000 tons/week	Combustion facility: may use wood as primary fuel or may be commingled with other fuels as a secondary fuel.

Small, mobile processors are primarily designed to chip branches, brush, saplings, logging slash, pallets, and wooden shipping containers that are fairly uniform in size. Mobile units are often sized to process wood that is up to, but not more than, six inches

thick. They are not usually designed to process waste wood that varies widely in size and shape. In addition, small mobile processors usually do not have the capacity to separate wood from other waste materials, or to reduce or remove potential contaminants in treated waste wood.

Larger mobile units may be able to process wood that varies significantly in size and shape, such as stumps, construction wood, or demolition wood. This will depend on the equipment's horsepower, torque, and the ability to adjust hammers to various sizes and shapes of material. Large mobile processors may have magnets that can separate ferrous metal from wood. They are sometimes used in conjunction with mobile screening equipment. The screening equipment, such as rotary trommels, may be hauled on a separate trailer and then attached to the hammermill at the site.

5.3.2 Stationary Wood-Only Processors

In addition to mobile facilities, a variety of stationary waste wood processing facilities are in operation that process and sell recovered waste wood. During the 1980's, an increasing number of stationary facilities were developed in the U.S. and Canada, particularly in or near urban areas. This was stimulated by new markets for recovered wood such as fuel and new regulatory constraints on the land disposal of waste wood (Moore, 1992).

Some stationary facilities are also involved in hauling waste, running a transfer station, operating a landfill, or managing a wood combustion facility. Others are "stand-alone" facilities not otherwise involved in the solid waste or power generation industries.

Some stationary facilities only process waste wood. Referred to in this report as "wood-only" processors, these facilities process wood from many different sources, such as harvested site conversion wood, mill residue, pallets, construction and demolition wood, and other waste wood produced by household, businesses, and industries. The types of wood processed may include clean harvested wood, painted wood, wood containing glues and resins, and/or wood treated with preservatives or other chemicals.

Numerous stationary wood-only processors are located throughout the study area. Although the facilities only accept wood for processing, some are similar to multi-waste facilities in their efforts to secure multiple end-use markets for different types and grades of processed wood. The markets include fuel chips with different moisture contents, mulch chips that may be colored or sized for specific uses or slightly composted to add moisture, and small particle "fines" for fertilizer. A blended fertilizer or "potting soil" may also be produced from a combination of wood fines and dirt removed during processing (Winzinger, 1991). Stationary wood-only processors sell processed wood for animal bedding, landfill cover, groundcover for horsetracks or animal arenas, and raw material for manufactured wood products, such as flakeboard and chipboard (Mittleman, 1991).

The ownership of stationary wood-only facilities varies. Most large facilities are privately owned. However, a growing number of municipalities and solid waste districts are investing in mobile or stationary processing equipment. The public facilities are being developed in response to mandated recycling goals, and to provide chips for landfill cover, compost projects, or sludge produced by wastewater treatment facilities.

5.3.3 Stationary Multi-Waste Processors

Other stationary facilities process materials in addition to wood, such as concrete, gypsum, rock, brick, metal, and glass. These "multi-waste" facilities may accept materials in commingled loads, or they may require a certain level of separation, prior to delivery to the processor. Waste is supplied by municipal and private haulers, drive-in residential sources, and C&D contractors. Once at the site, the waste may be processed in its commingled form, or materials such as wood may be separated before being processed depending on the type of equipment used, manual sorting techniques used, and specifications for the end-use product(s).

Tipping fees are usually charged by stationary multi-waste processors. The tipping fees are often lower than other disposal facilities in the area, such as landfills and refuse-to-energy plants. This provides a financial incentive for waste generators and haulers to "dispose" of their material at the processor, rather than at another solid waste facility. In addition, some processors charge lower tipping fees for wood that is segregated from other waste and presorted according to the processor's specifications, before being delivered to the facility. This provides a financial incentive for waste generators and haulers to provide the specific type of material wanted by the processor. A processor's specifications for material accepted at the facility are a function of specifications required by end users, combined with the technical capabilities of equipment used by the processor.

Stationary multi-waste processing facilities are common in the study area, especially in major metropolitan areas. The facilities may be developed as part of an integrated source separation and recycling program. Or, they may be developed as a result of increasing disposal costs at other solid waste facilities and the availability of end-use markets for recycled materials. Multi-waste facilities may consist of comprehensive, turnkey demolition processing systems built by a single manufacturer (Hawker, 1991). Or, they may consist of equipment from many different manufacturers that is configured in a way unique to each facility (Clark, 1991).

Multi-waste facilities operate as either stand-alone recycling centers, or as part of (or adjacent to) separation, volume reduction, and recovery efforts at landfills. In some states, such as California and New York, landfill operators are, or will soon be, required to prohibit designated "recyclable" materials such as wood from disposal in MSW landfills (Norman, 1991). This has prompted development of other forms of waste handling and processing at existing solid waste facilities.

5.3.4 On-Site Processors at Combustion Facilities

A fourth category of waste wood processors are facilities that operate at, or adjacent to, a wood-fired facility. Both small manufacturing facilities that burn wood, and relatively large stand-alone power plants own and operate waste wood processing equipment. For some facilities, such as a plywood manufacturer, the processing equipment used is a hammermill or hog that chips strips of plywood trim for use in the plant's boiler.

Other facilities use a more substantial and specialized processing system. This level of processing is most common at stand-alone

wood-fired power plants. The systems are usually designed as quality control mechanisms for fuel burned on-site. The need for the processing system is based on the physical and chemical contents of waste wood received, and on the importance of ensuring a consistent grade of fuel for the combustion unit. Many wood-fired power plants have on-site screening systems that provide a final level of dirt removal, metal removal, and/or sizing of the fuel, prior to combustion (Joseph, 1991). This additional fuel preparation is needed to minimize wear on the handling equipment, maintain combustion performance, and minimize corrosion of combustion and pollution control equipment. There are three potential disincentives for using waste wood processing equipment at a combustion site. First, there are substantial additional costs for the equipment, training, labor, maintenance, and space required. Second, in many states a variety of complicated (and from a developer's perspective, timely and costly) regulatory reviews are required, as a result of being both a solid waste management (or materials recovery facility) and a combustion facility. Third, for facilities that process substantial amounts of treated wood, it may be necessary to secure a disposal site for residuals produced during processing (Karakesh, 1991).

5.4 Processing Lines at Wood-only and Multi-waste Facilities

Wood-only and multi-waste processing facilities recover waste wood for processing in several ways. Wood may arrive in a mixed demolition load containing concrete, rock, sheetrock, insulation, and other materials. Or, it may arrive as mixed waste wood containing both clean and treated waste wood. Or, the facility may use tipping fee incentives to encourage the delivery of waste wood that is presorted, prior to delivery. The sorting may involve separating wood from other waste, or separating different types of wood based on its physical and chemical composition.

5.4.1 How Processors Define "Clean" and "Treated" Waste Wood

The precise definition of what constitutes "clean" and "treated" waste wood varies among states and provinces, and among individual facilities. Most processors consider pallets, plywood, spools and dunnage, furniture scraps, mill residue, particleboard, painted wood, and demolition wood clean and acceptable for processing into fuel. On the other hand, most processors consider wood that is treated with creosote, penta, or CCA to be "treated" wood, that may or may not be acceptable for fuel depending on the end user.

In some states, processors may define "clean" wood and "treated" wood differently than environmental officials. This is most common for plywood, particleboard or other wood containing glues and resins, painted, and demolition wood. Most processors consider this wood acceptable for processing, and acceptable as part of the mix of wood processed for fuel although the wood may be processed using different equipment and a different processing line than clean wood. However, regulators may not agree that these types of wood are acceptable for processing and use as fuel.

Regulators sometimes use the term "demolition" wood interchangeably with the term "treated" wood to describe potentially dirty wood that may be unacceptable for processing and use for fuel. Although processors may handle and process demolition wood differently than

other types of clean wood, they usually consider it as wood with the potential to be cleaned during processing. Demolition wood is frequently included under a broad definition of clean wood in specifications that describe materials that are accepted at the gate. Processors are confident that demolition wood, less the portion that is treated wood, can be sufficiently cleaned during processing so it can be reused. Their major priorities when processing fuel are to remove dirt, sand, metals, and non-wood chemicals because these materials can affect combustion performance, air emissions, ash contents, and maintenance requirements of combustion equipment at wood-fired facilities. There are examples of written specifications for waste wood delivered to two processing facilities in the study area in Appendix D.

5.4.2 Key Steps in a Processing Line

The first step at processing facilities is the delivery, inspection, and acceptance of waste wood. To maintain quality control, almost all processing facilities require visual inspection of a load, before it is unloaded at the processing site. If load is unacceptable, it is rejected and sent away.

When a load is accepted and unloaded, a variety of mechanical and/or manual sorting activities are conducted that provide the opportunity to further inspect the material.

Following the sorting and inspection procedures, waste wood and other debris is ground for handling and additional separation. Large multi-waste facilities use heavy duty C&D shredders or impact machines for the initial volume reduction (between 5:1 and 8:1) of bulky wastes, before additional processing. These are 600 to 800 horsepower (HP) machines capable of grinding a range of materials, such as wood, scrap metal, concrete, glass, and brick.

At wood-only facilities, initial volume reduction and primary sizing is accomplished with either a hammermill "hogger" or a tub grinder. These machines have smaller horsepower ranges than C&D shredders usually from 60 to 300 HP and are designed to only accept wood only. Although dirt, rock, bits of rubble, and small scraps of metal routinely pass through tub grinders and hammermills, facility operators strive to minimize the amount of non-wood material due to the extra equipment wear and maintenance caused by these materials.

Following initial grinding, a combination of screening, sorting, and cleaning technologies are used before waste wood is ground and sized for a final product. These technologies include float tanks, manual picking stations, rotary trommel screens, air classifiers, and disk scalping screens. A combination of at least two or more of these technologies is used to separate wood from other debris. These technologies are described in more detail in Section 5.4.

In newer turnkey systems, clean waste wood may be fed into a processing line at the point where dirtier wood has completed primary cleaning and screening stages. At this point, both types of waste wood enter the final sizing and screening portion of the processing line and are commingled as a final product. At other facilities, independent processing lines may be used to produce specific products. Compost and mulch chips from harvested wood waste, for example, are sometimes handled separately from wood separated from the waste stream (Zanker, 1991).

Overall, certain techniques and procedures are fairly consistent among processing facilities, especially inspection, presorting procedures, primary grinding equipment, the use of metal removal equipment, selection of screening devices, and fuel storage systems. Figure 5-1 illustrates a waste wood processing line, from initial inspection to the final preparation of recovered products. The actual system used varies among processors, depending on the type of waste wood accepted and end-use products produced.

5.4.3 Factors Affecting Removal of Non-Wood Material

Four factors affect the ability of processing equipment to remove non-wood contaminants from waste wood including:

- Amount of redundancy built into the processing line(s);
- Period of time a specific volume of waste wood spends at each step in the processing line that cleans the wood in some way (referred to as "cleaning stations" in this report);
- Composition of the material when it arrives at each cleaning station; and
- Rated design capacity of a given piece of processing equipment, compared to the amount and rate of wood handled by the equipment (Groscurth, 1992).

These factors are interdependent. For example, removal efficiency depends partly on the rate of throughput of material. It also depends on the amount of non-wood material already separated before the wood arrives at a particular point in the processing line.

Efficient separation of non-wood material generally results from a combination of system design, system redundancy, and operating techniques. At both wood-only and multi-waste processing facilities, this is accomplished by applying technologies that sort specific types and sizes of non-wood material, and that replicate the same screening or sorting procedure at multiple locations in the processing line.

5.4.3.1 Redundancy

One processing facility uses six magnets at different locations in the processing line to removal ferrous metal (Karakesh, 1991). However, the cost of redundancy in additional separation and screening equipment can become prohibitive, depending on prices paid for the processed wood. Processors select equipment on the basis of the types of waste wood they expect to process, the required quality, the expected end use, and the price paid for the end product. It is generally uneconomic for a processor to invest in high removal efficiencies if, for example, they plan to process wood only for landfill cover. Similarly, fuel specifications for a refuse-to-energy plant that also burns processed wood are usually less stringent than specifications for a wood-fired power plant (Gent, 1991).

5.4.3.2 Time Spent at Cleaning Stations

A second factor affecting the removal of non-wood contaminants is the time that a given volume of waste wood spends at key steps in the processing. This is a function of the equipment design, overall processing capacity of the facility, and desired production costs per unit of processed material. At most cleaning stations, a long residence time improves the separation of

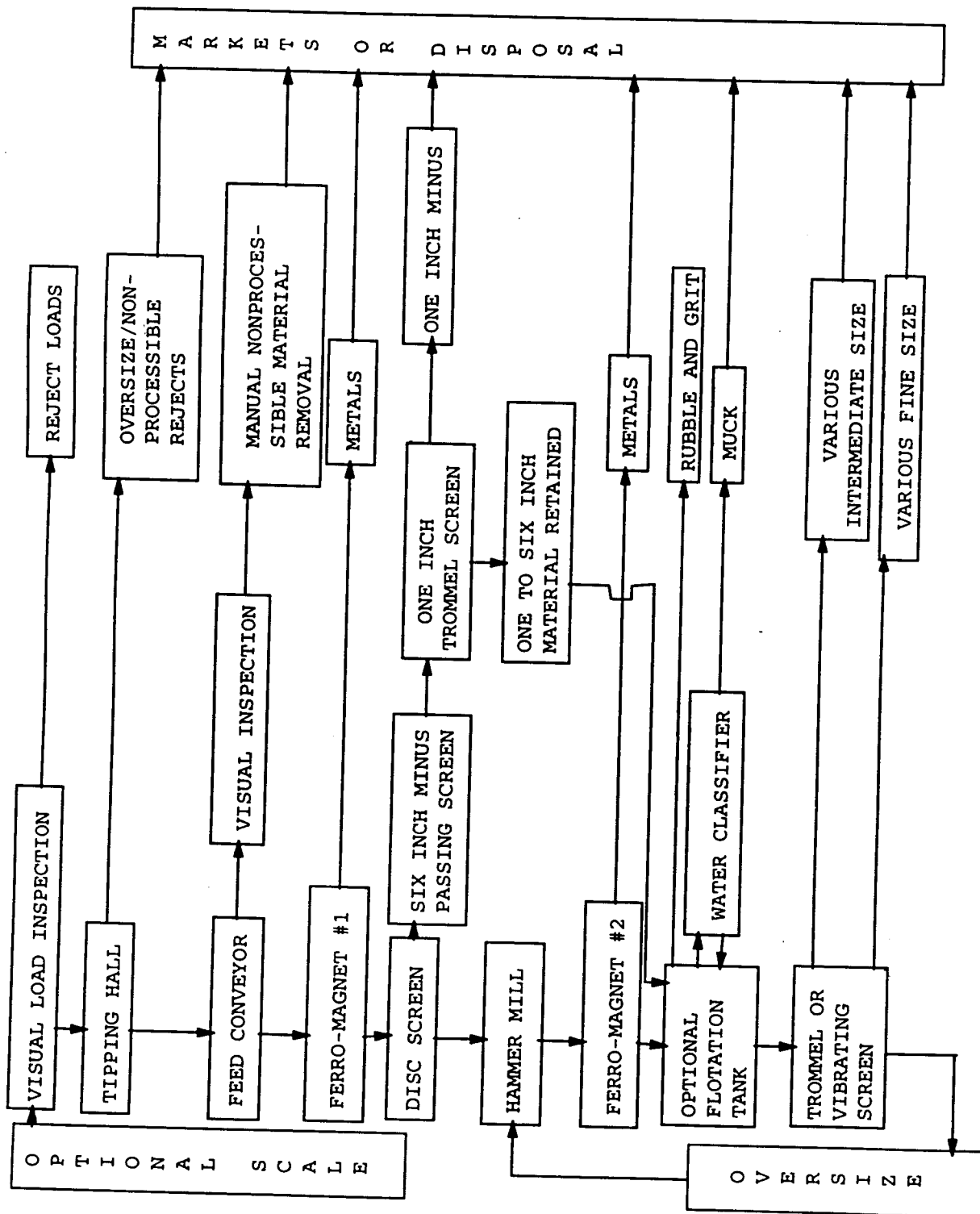


Figure 5-1. Generic wood waste processing facility

non-wood material. For example, additional revolutions in a rotary trommel screen produces a higher removal dirt and fines. Conversely, high conveyor speeds at manual picking stations may prevent adequate sorting of non-wood material, that in turn affects the capabilities of other cleaning stations in the processing line (Gent, 1991).

5.4.3.3 Waste Wood Composition

A third factor relates to the composition of waste wood material when it arrives at a cleaning station. For example, material that is thinly and evenly dispersed on a conveyor belt will achieve better metal removal efficiencies at crossbelt or plate magnet stations than material that is thick and lumpy (Karakesh, 1991). Waste wood that is sticky or forms clumps due to moisture or a film of composted material will shed less dirt and fines in a trommel screen than wood that is dry and loose (Gross, 1991).

5.4.3.4 Equipment Design Capacity and Use

The fourth factor relates to the manufactured design capacity of a specific piece of processing equipment, compared to the amount and rate of waste wood actually handled by the equipment.

Prior to the late 1980's, most processing facilities relied on processing equipment developed originally for either the forest products or mining industries (Groscurth, 1991). This has changed dramatically during the last several years, due to the growth in recycling. For example, as of late 1991, more than 30 North American industries manufacture and sell shredding and hogging machines for use in waste wood and demolition recycling (Recycling Today, 1991).

In addition, there is a trend by manufacturers to increase the versatility of their equipment to handle the varying compositions of different waste streams, changing climatic conditions, different moisture contents, and different end-use market requirements. Manufacturers are providing variable speed motors, a wide variety of trommel screen sizes, adjustable hopper feeders, and adjustable conveyor speeds (Ohanessian, 1992).

Most waste wood processing equipment in use today achieves from 60 to 95 percent removal efficiency of non-wood materials. However, the actual removal efficiencies depend on the specific type of equipment and the way it is installed, operated, maintained, and used. There may be certain types and brands of equipment that can achieve close to 100 percent removal of specific materials, such as nails or staples. For example, many trommel screen manufacturers indicate that under the right moisture conditions and feed rates, the removal of undersized material is better than 95 percent (Payne, 1991). The design and capabilities of specific equipment types are discussed in more detail in Section 5.5.

5.4.4 Separating Wood from Non-Wood Substances

The initial processing and separation of non-wood materials at wood-only and multi-waste processing facilities focuses on volume reduction for handling purposes. This is generally followed by the removal of dirt, rocks, and metal that can cause substantial wear and tear on sizing and sorting equipment (especially for equipment designed only to handle wood). At some facilities, all waste wood is sent through the same sorting and separation line regardless of how clean it is when it arrives. This may be true, although facility owners charge lower tipping fees for presorted, clean waste wood.

Other facilities handle demolition wood and treated wood accepted at a facility differently than clean, non-demolition wood. Frequently, demolition and treated wood are either unloaded at separate locations at the site, or are sorted on-site before entering the processing line. The demolition wood and/or treated wood is then processed in a separate line from the clean wood. The separate line for demolition and/or treated wood may include an industrial-scale C&D debris shredder, scalping screen for sorting large chunks of brick and rock, or float tank to rinse the wood before grinding and screening.

Following the sorting and cleaning steps, the demolition and/or treated wood may be commingled with clean wood, for the rest of the processing line depending on the requirements of the facilities' end use markets. Most wood-fired facilities have specifications for processed wood used for fuel. Fuel specifications may cause some processing facilities to keep a line for clean wood entirely separate from the line for demolition and/or treated wood. Separate processing lines are usually used by processors that have relatively different product specifications with specific customers. Examples include landscaping and fertilizer customers for whom small fractions of non-wood material is unacceptable, or fuel customers for whom only a certain percentage of non-combustible material (usually three percent or lower) is allowed as part of their purchase agreement with the processor.

An example of an on-site sorting and processing stage for demolition wood is provided by a multi-waste processing facility located in the study area that starts by feeding mixed construction and demolition debris into a heavy duty C&D shredder. Wood and debris then move up an inclined steel conveyor belt and fall onto a downward sloping large-mesh shaker screen that allows heavy material less than one-inch square to fall out. Six- to eighteen-inch wood pieces and other debris drop from the shaker screen into a float tank. Wood is floated off in one direction in the tank. Remaining pieces of heavy debris such as rock, brick, metal, and concrete are removed in the opposite direction by a drag chain located on the bottom of the tank. Wood from the float tank then passes through a manual picking station, where residual paper, plastic, or metal is removed. This preprocessing precedes the sizing and cleaning process steps. Subsequent steps in the processing line include a tub grinder, magnet, disk screen, and rotary trommel.

Facilities are configured differently, based on their individual design, waste wood supply, and end-use markets. Table 5-2 compares equipment used and quantities produced at eight waste wood processing facilities in the study area. The table provides a representative sample of the range of material processed, and equipment used at processing facilities.

5.5 Waste Wood Processing Equipment

This section describes equipment used at facilities that process waste wood for fuel and other products. The discussion includes both equipment used at facilities that only accept presorted waste wood, and at facilities that accept multiple types of waste, such as construction and demolition debris containing wood and other waste. A wide range of equipment types and sizes are currently available to wood processors in the U.S. and Canada. For example, at least 26 companies in North America supply screening equipment and at least 33 manufacturers supply grinding and chipping equipment (Recycling Today, 1991). Many manufacturers produce more than one size and model of equipment.

Wood processing equipment is evolving in response to fuel specifications and new demands for other products recovered from the wood. The types of equipment used by processors depend on each facility's unique circumstances

Table 5-2. Representative waste wood processing facilities.

Major facility characteristics*	A	B	C	D	E	F	G	H
GENERAL								
Incoming tipping fee ^{b,c}	\$18-27	\$40	\$12-24	\$24-72	\$15	\$25-29	\$61-110	\$50-60
Processing capacity, tpy	300,000	100,000	15,000	30,000	72,000	88,000	200,000	75,000
Average moisture content of wood fuel	20-25%	15-25%	20-30%	7-15%	20%	20-25%	9-15%	15-20%
INSPECTION								
Visual inspection at the gate	X	X	X	X	X	X	X	X
Written standards for acceptable waste wood ^d	X	X						X
Pressure treated or creosote wood not accepted	X		X					X
Receives "dedicated" loads of waste wood					X	X	X	X
Material is weighed before unloading		X		X	X	X	X	X
PROCESSING LINE(S)								
Pre-sorting/primary classification:								
Front-end loaders or cranes		X	X	X	X	X	X	X
Manual picking station before grinding		X						
Rotary trommel classifier(s)	X							
Rotary or "scalping" screen classifier				X	X	X	X	X
Float tank for metal/rock/dirt removal				X	X	X	X	X
Sizing equipment:								
C&D multi-waste shredder or impactor	X			X			X	X
Tub grinder/hogger				X				X
Hammermill shredder		X		X			X	X
Rotary trommel screen(s)			X	X	X	X	X	X
Oscillating deck or finger shaker screen(s)								
Major removal equipment used:								
Ferrous metal separation before grinding		X			X	X	X	X
Ferrous metal separation after grinding			X		X	X	X	X
Electronic metal detection		X			X	X	X	X
Specialized rock/metal air classifier	X							
Secondary classification equipment:								
Trommel screens			X					
Air knives or classifiers			X					
Manual picking station		X						
Dust control equipment used:								
Indoor facility-								
Hood and vacuum system								
Cyclone particulate separator(s)								
Baghouse								
Specialized system								
Water spray								
Outdoor facility-								
Water spray				X		X		X

Table 5-2. Representative waste wood processing facilities (continued).

WOOD PRODUCTS PRODUCED										
Soil/fines (< ¼ inch)										
Mulch/compost (¾ - 1 inch)			X						X	X
Fuel chips (1 - 4 inches)			X						X	X
MAJOR MARKETS										
Wood-fired power plants		X								
MSW incinerator										
Landscaping/nurseries material			X						X	X
Compost material			X						X	X
Bulking material for sludge										
Landfill cover										
Flakeboard manufacturing								X		X

Notes:

- a. Facilities are reported anonymously in this research.
- b. Several facilities use a tiered pricing schedule based on the level of contaminants in the wood. For example, at Facility A a \$9 per ton surcharge is added for waste wood containing "observable quantities of rock and dirt." Facility D charges \$4 per cubic yard for "clean" sorted waste wood, wood with any metal attached starts at \$6.50 per cubic yard, and wood containing significant amounts of dirt, rock, metal or non-wood material may be charged as much as \$12 per cubic yard.
- c. Several processors charge a higher fee, as much as double the normal amount, for excessively dirty loads. Alternatively, processors will frequently charge a lower tipping fee to haulers who bring "dedicated" loads of pre-sorted wood material. For example, in the case of Facility E, a hauler is charged #4 per ton less for pre-sorted, dedicated waste wood than the normal fee of \$29 per ton.
- d. The rule for most waste wood processors is no more than 5% of a load can be contaminated with painted, CCA-treated or creosote-treated wood.

other materials) accepted at a facility are circulated to haulers and posted at the processing facility. Appendix E. contains the written specifications for waste wood received at two processors in the study area. Although specifications vary among processors, these are believed to represent the level of detail and overall approach used in the U.S. and Canada.

- A deposit is collected and held by a processing facility until after a load of waste wood is dumped and checked. This deposit may be twice the normal tipping fee (Kenedy, 1991). If the load contains unacceptable materials, the deposit is held to cover the cost of either disposing of the material, or reloading it into the hauler's truck.
- A surcharge is added to the tipping fee if the load contains excessive amounts of unacceptable material. The surcharge covers either the additional handling and processing costs, or additional handling and disposal costs if the material must be discarded.
- Lower tipping fees are charged for haulers who provide "dedicated loads" of presorted, acceptable material (Tomasso, 1991). The lower tipping fee is offset by lower processing costs for handling, sorting, and screening the material.

5.5.2 Waste Wood Sorting

Many processing facilities sort material on-site before processing it, to separate clean wood such as pallets and construction scrap from wood with a high dirt content, non-wood material attached to the wood, or other commingled waste. Sorting on-site is common at multi-waste facilities that accept and process a wide range of materials. Sorting on-site may be done at wood-only facilities, especially to separate clean from treated wood.

Several factors affect the type of effort involved in sorting at processing facilities. At some facilities, when wood is determined acceptable during inspection at the gate, further on-site sorting is considered unnecessary. The belief is that inspection at the gate and/or tipping fee incentives successfully restrict unacceptable materials. At other facilities, on-site sorting is constrained by the site layout and lack of sorting space. If there is not sufficient room on-site for sorting, more emphasis is placed on inspection at the gate. In addition, if a facility receives large numbers of relatively small loads (i.e., pick-up trucks) then emphasis is placed on inspection at the gate because the unloading area can quickly become congested, and the time involved in unloading can be inconvenient for haulers.

On-site sorting is used at facilities that have separate processing lines for different types of waste wood and for different end products recovered from the material. This is especially true for processors that have large landscaping mulch or fuel customers that require the end product to meet certain specifications. In addition, the use of processing systems that introduce clean material at intermediate stages in the processing line often require waste wood sorting in the yard.

On-site sorting is usually accomplished in one of the following ways.

- Trucks are directed to unload at separate locations in the yard, depending on which processing line will be used for the material. This occurs at both wood-only and multi-waste facilities.
- All material is unloaded in the same area and a bobcat tractor or front-end loader sorts it into discrete piles, based on visual characteristics of the wood and other debris. When wood and other

materials are sorted in the yard, they are moved to the appropriate processing lines primarily at multi-waste facilities.

- All material is unloaded in the same area at, or near, the beginning of the processing line. As material is loaded onto a conveyor at the beginning of the line, it is sorted either mechanically or manually.

5.5.3 Primary Grinding Equipment

The size reduction of bulky waste wood, an essential step in preparing wood for fuel, is primarily accomplished by grinding the material. At many facilities, a tub grinder or C&D impactor is used early in the processing line to grind the material and reduce its volume, because the efficient performance of other processing equipment requires material that has had its volume reduced. Loose, fairly uniformly sized wood chips are easier to sort, handle, and convey than bulky waste of widely varying sizes and shapes.

Grinding also loosens non-wood material attached to waste wood, such as plaster, paint, or nails. The loose material allows for more efficient screening and removal at other stages. Secondary grinders, such as high-speed hammermills, may be used later in the processing line for final size classification, especially waste wood processed into fuel, since a consistent and uniform particle size is significant in maintaining combustion performance.

At one facility, wood containing large amounts of dirt and rock travels through a series of rotary trommel screens before being ground to remove the dirt and rock. The oversize pieces are carried through the screens to a manual picking station, before the initial grinding.

Three major types of grinding equipment are used at processing facilities including hammermills designed specifically for waste wood, hoppers and tub grinders designed specifically for waste wood, and construction and demolition debris shredding machines designed to accept mixed, bulky construction and demolition debris. Major features of these types of grinding equipment are summarized below.

Hammermills:

- Used for primary size classification;
- Usually horizontal shaft, swing-hammer types;
- Usually 100 to 500 horsepower;
- High torque, high speed;
- May be mobile or stationary;
- Produce particle sizes from 1 to 5 inches
- Typically grind 10 to 50 tons/hour of wood; and
- Use different hammer configurations, depending on type of wood and end product.

Hoppers and Tub Grinders:

- Used for primary size classification;

- Consist of either gravity fed, horizontal rotor machines with "punch and die" hammers, hourglass cutting knives, or articulated hammers;
- Typically 60 to 300 horsepower, depending on volume and demand;
- High torque, high speed;
- Produce particle sizes from 1 to 5 inches;
- May be equipped with metal detection equipment;
- Process 10 to 50 tons/hour of wood; and
- Use different cutter configurations, depending on the type of wood and end product.

C&D Shredders and Impactors:

- Used for initial volume reduction of oversized construction, demolition, and bulky waste;
- Typically 600 to 800 horsepower;
- Either high or low torque, depending on the type of waste;
- Wood requires further size classification and screening after shredding;
- Produce wood sized from 6 to 18 inches; and
- Typically processes 100 to 500 tons/hour of material.

5.5.4 Float Tanks

Float tanks can be used to separate rock and metal from waste wood. Currently, most facilities do not use float tanks, although several facility operators interviewed are considering installing them. Key advantages are the avoidance of additional screening equipment or manual picking, and the high removal of dirt and sand. Newer float tank systems with pressurized jets can wash off fine dirt residues and can prevent waterlogged wood from dragging along the bottom of the tank (Payne, 1991).

Key disadvantages of using float tanks are wastewater discharge concerns, difficulty in operating in cold weather, waterlogged wood, and binding material in underwater drag chains used to clean settled material out of the tank. At least one processor heats water in the float tank. The operator believes this helps the wood float and alleviates potential binding or clogging (Vinagro, 1991). Some facility operators use chemical flocculents that cause fine material to clump, or they treat the water to lessen the frequency of replacement. Water replacement is necessary eventually, however, since wood absorbs water while in the tank.

Float tanks are used in the middle of the processing line, usually after initial grinding and screening. At one multi-waste facility, for example, the float tank is located between a primary shredding machine and tub grinder. The wood arrives at the tank in fairly bulky pieces, 6 to 18 inches long. At another facility, the float tank is located after demolition wood passes through two trommel screens, a handpicking station, and an air knife. The

wood passes through the float tank and then through a hammermill, magnets, and disk-shaker screen.

The most unique float tank system observed in the study area consists of a rectangular open pit or lagoon (approximately 20 by 40 feet), rather than an actual tank. At one end of the lagoon, a disk-shaker screen empties wood and remaining debris into the water. At the opposite end, a conveyor lifts wood out of the water and conveys it to a tub grinder. Two backhoe tractors with front bucket loaders are situated on opposite sides of the lagoon. They use the backhoe boom to scrape heavy debris out of the bottom of the lagoon. The debris is then piled on the side of the lagoon. The material is removed to other locations using the front bucket loader.

5.5.5 Manual Picking Stations

Manual picking stations are common at multi-waste facilities and are used to a lesser extent at wood-only facilities. Manual picking stations tend to have one to five people per shift. Picking stations provide an important visual check for material entering the processing line. In addition, the use of picking stations helps prevent excessive equipment wear or breakage by sorting materials that may bind moving parts on mechanical systems.

Larger picking stations of four to five people remove oversize pieces of rock, brick, concrete, or stumps. These materials are usually "picked" from a moving conveyor bed and tossed or sorted into bins or roll-off boxes located directly behind, or beneath, the picking station. The picking station is usually located near the front of the processing line, after initial screening by a rotary trommel or disk scalper, and before primary grinding for size classification.

Smaller picking stations of one to two people are usually located after initial grinding, screening, and washing, but prior to final grinding and screening. The smaller stations screen for small pieces of metal or plastic still attached to the wood. In addition, a facility may have a one-person station situated at the base of the final conveyor belt that leads to the fuel storage pile. The purpose of this station is to remove small bits of paper or plastic that may cling to the processed wood chips (Gross, 1991).

5.5.6 Mechanical Screening Equipment

Mechanical screening systems are widely used for sorting, cleaning, and sizing waste wood. Major types of equipment include disk or scalping screens, rotary trommel screens, oscillating or shaker screens, and air classifiers. Major features of screening equipment are:

Disk Screens:

- Usually designed as a primary screen for use prior to, or immediately following, initial grinding. The screens typically sort material from one to six inches minus in size.
- Screens consist of either wire mesh screens, a series of metal "scalping" disks arrayed across a series of spinning axles, or a series of rotating metal "fingers."
- Screens are designed to sort material while also conveying material through the processing line.

Rotary Trommel Screens:

- Use steel or urethane cloth mesh screens ranging from 3/8-inch to 2-inch mesh. Larger meshes are used for specialized waste streams or screening bulky materials. Depending on the drum size, waste wood composition, mesh size, and power rating, rotary trommels can be used at multiple processing stages.
- Typically process from 15 to 75 tons per hour using 100 to 150 horsepower motors; finished output is 100 to 150 cubic yards per hour.
- Removal efficiency is highly dependent on the moisture content and physical composition of the material.
- Typical drum sizes are 6 to 10 feet in diameter and 16 to 40 feet long.
- Newer models utilize variable speed motors for feeder hoppers, conveyors, and trommel drums.

Air Classification and Air Knife Separators:

- There are two basic types. High velocity blowers push lighter materials, such as wood and paper, across an opening where heavy material, such as rock, metal, and glass, falls out. Vacuum systems pull material out of the processing line.
- High velocity air streams are used for the primary classification of heavier material, such as rubble and other debris, from lighter material, such as wood, paper, and plastic (Killigas, 1991).
- Vacuum systems, commonly referred to as "air knives," are used for fine screening, such as pulling small bits of paper, plastic, and other light debris out of the waste stream.

Oscillating and Shaker-Deck Screens:

- Horizontal or inclined deck screens are used primarily near the end of the processing line (often referred to as the "finishing" line) to separate residual wood particles and other small particles, or "fines," from the finished fuel chips.
- Screens operate in a reciprocating or circular shaking motion. The decks may be inclined 15 to 25 degrees.
- Decks range in size from 2 by 4 feet, to 7 by 20 feet. They are powered by electric motors ranging from 10 to 30 horsepower.
- The screens can be stacked in double or triple decks to provide more complete screening capabilities.
- The output capacity varies widely, based on the type and size of deck, and the wood material.

5.5.7 Metal Removal

Initial metal separation is achieved through inspection and screening procedures previously discussed, or manual picking stations that screen oversized rock, metal, rubble, concrete, and other non-wood items. Picking

stations may be accompanied by float tanks that settle nails and other small, loose pieces of metal undetected by manual sorting or visual inspection.

Magnets are commonly used to retrieve ferrous metal, such as nails, wire, or staples. Three types of magnets are widely used, including rotary belt magnets, bar and plate magnets, and magnetic head pulleys on conveying systems.

Rotary belt magnets are positioned directly before and after grinding equipment. They range in size from one foot to several feet wide. With tub grinders, magnets are typically located just after the grinding process. At one facility, a manual picking station for metal, plastic, and paper was located between a C&D shredder and a tub grinder, with additional magnets located following the tub grinder. At least two rotary belt magnets are found in most large scale waste wood processing lines. The magnet picks up metal fragments, and deposits them in a bin located adjacent to the conveyor. A second or third magnet, such as a stationary bar magnet, may be used towards the end of the processing line.

Rotary magnets are usually suspended from eight- to twelve-inches above a moving conveyor. Rotary magnets are self-cleaning and require minimal maintenance. Bar magnets are suspended closer in order to pick up the smallest residual fragments. Bar magnets must be cleaned periodically to remain effective. Magnetic head pulleys are provided with many conveying systems. A typical design used is on an inclined conveyor. When material reaches the top of the conveyor, ferrous material "sticks" to the conveyor belt as wood proceeds to the next processing stage. The metal is then carried by the belt part way around the head pulley, and is dropped into a bin underneath the conveyor.

Metal detection and removal technology is changing. At least one facility in the study area uses a special metal detection system built into the hammermill unit that detects pieces of ferrous and non-ferrous metal above a certain size and electronically shuts the hammermill off before the metal can damage the cutters. Metal detection units operate by passing material between electronic sensor coils. The sensors shutdown the conveyor or hopper, if metal is detected (Beck, 1991). At another facility, waste wood passes through a series of four rock and metal separation stations using air classifiers. At each station, lighter wood is blown past the heavier metal and other debris with high-velocity air nozzles (Phillips, 1991). Heavy materials fall out at each station, successively cleaning the wood to a higher degree. In this process, the redundancy results in thorough metal removal.

5.5.8 Fuel Storage Systems

Three fuel storage systems are used at waste wood processing facilities: open, uncovered fuel piles; partially covered fuel piles, such as pole barns that contain a roof and open sides; and enclosed storage bins or hoppers. Major factors affecting fuel storage systems are summarized below.

- Large processing yards located in dry climates such as California, typically store fuel outside in uncovered conical, triangular piles or "tabletop" piles. As part of fire safety precautions, outdoor facilities are usually required to maintain fire lanes and follow minimum height and spacing standards between fuel piles. Common height standards are 20 to 50 feet. Common standards for spacing between piles are 20 feet.
- Where storage space is minimal or where air pollution regulations require it, some facilities store fuel in enclosed

bins. The bins provide additional dust control and allow the facility to meter chips that are sold fairly accurately.

- Typically, fuel is loaded into 150 cubic yard tractor-trailer vans using front bucket loaders. Depending on moisture content, the vans carry 24 to 30 tons of fuel. Facilities with overhead bins can mechanically drop fuel chips into the vans, while simultaneously weighing the truck.
- Facilities usually follow (or are required to follow) a "first in-first out" policy for fuel deliveries to avoid excessive biodegradation of the fuel. In some cases, however, fuel processed from urban waste wood is too dry for some combustion systems; it is purposely allowed to slightly decompose to raise the moisture content (Remington, 1991).

5.5.9 Dust Control Systems

The primary factors affecting the use of dust control systems at waste wood processing facilities are whether the facility is located outdoors, and whether the climate is commonly dry and windy.

Outdoor processing facilities in the western U.S. may be required to provide several levels of dust control. This can include permit conditions that require watering storage piles and certain locations at the facility during specific intervals, or while certain equipment is operating. An example is the requirement to continuously wet the staging area where a grapple crane loads waste material onto a conveyor (Gross, 1991). Other facilities (located either indoors or outdoors) must provide ventilation and fabric filter particulate collection systems. For example, an outdoor waste wood processing facility recently permitted in California is required to use three fabric collectors, that have 5,000, 2,000 and 3,000 square feet of filter area. The collectors feed a dozen hood ventilation stations located in the processing line (Kern County Air Pollution Control District, 1991).

5.6 Summary of Processing Facilities in the Study Area

This section describes waste wood processors observed and interviewed for this research. Table 5-3 and Table 5-4, respectively, list major stationary waste wood processing facilities in and outside of the study area. It is important to note that facilities listed in the table are not necessarily only wood fuel processors. Most facilities process wood for multiple markets. Due to the similarity of certain types of equipment used among processors, many have the capability to process wood for fuel in the future, if a market were available.

5.7 Case Studies of Processing Facilities

Case studies of two waste wood processing facilities are presented below. The first describes an indoor facility that only accepts and processes wood. The second describes an indoor/outdoor facility that accepts wood and mixed construction and demolition debris. The facilities are described anonymously, due to agreements made concerning their participation.

5.7.1 Wood-Only Processing Facility

This processor has the capacity to process 350 tons per day of wood, or 100,000 tons per year. The facility averages an output of about 200 tons per day. The wood waste processing equipment is located on a two-acre site. Although the wood processing facility is on a self-contained site, it is part

Table 5-3. Waste wood processing facilities in the study area^{a,b}

California		Connecticut	New York	North Carolina	Virginia	Washington	Wisconsin
Fiber Fuel Products, Costa Mesa	PLC Organics, Inc., Sun Valley	Automated Waste Disposal, Danbury	BQE Wood Recycling, Brooklyn	Cumberland County Solid Waste District, Fayetteville	Wood Recycling, Inc., Lorton	Redmond Demolition, Redmond	Northern States Power, LaCrosse and Ashland
Artesia Sawdust Products, Gardena	Zanker Materials Recovery, San Jose	Manafort Brothers, Plainville	Hubbard Sand & Gravel, Bayshore	City of Winston-Salem	Interstate Pallet, Roanoke	Pacific Topsoil, Seattle	Brunette Box Factory, Rice Lake
Kellogg Supply, Inc., Carson	Waste Management, Norwalk	Waste Management, Norwalk	Industrial Recycling Systems, Croton-on-Hudson	Wrico Construction, Highpoint	Cooper Wood Products, Rocky Mount	Murray Pacific, Tacoma	Forest Fuel Corp., Iron River
Recycled Wood Products, Monterey Park and Berkeley	Recycled Fibers of CT, Manchester	Recycled Fibers of CT, Manchester	Karta Recycling, Peekskill	City of Highpoint	Direct Wood Products, Barhamsville	Olympic Fiber, Grays Harbor	Anderson Wood Fuels, Spencer
City of Bakersfield	Stapleton Resource Recycling, Bridgeport	Stapleton Resource Recycling, Bridgeport	Red Hook Recycling, Brooklyn	City of Charlotte	Pallet Service, Lynchburg	Simpson Timber Co., Shelton	Rouse Wood Chips, Shawano
Waste Fiber Recovery, Hayward and Auburn	McCauley Enterprises, Hartford	McCauley Enterprises, Hartford	Star Recycling, Woodside	City of Charlotte	United Biofuels Inc., Richmond	Faxport Inc., Tacoma	Nagel Lumber Co., Land O'Lakes
United Pacific Corp., Sun Valley and Santa Fe Springs	Supreme Forest Products, Bristol	Supreme Forest Products, Bristol	Town of Beacon		Allen Chipping, Emporia	Edman Co., Tacoma	Enercon, Hartford
Marine Resource Recovery, San Rafael					Hillco Inc., Fairfax	Girard Pallet, Puyallup	Brandner Timber Corp., Westboro
Community Recycling & Recovery, Sun Valley					S.W. Rogers Co., Gainesville	Harbor Chipping, Tacoma	Woodchip, Corp., Merrill
Hayden Brothers, Sun Valley					William Hazel Inc., Chantilly	Daily Landclearing, Tacoma	
Delano Biomass Energy, Delano					Rabanco Waste Services, Seattle		

Notes:

- a. Includes only major stationary multi-waste and wood-only recycling and processing facilities. It does not include processing equipment such as mobile tubgrinders, stump grinders, chippers, or mobile waste processing facilities.
- b. New Brunswick and Vermont have no major stationary waste wood processing facilities currently operating

Table 5-4. Examples of waste wood processing facilities outside the study area.

United States			Canada
Rhode Island New England Ecological Development, Johnston	New Jersey Advanced Enterprises, Newark	Massachusetts Jet-A-Way, Inc., Boston	Ontario Harkow Aggregates & Recycling, Toronto
Truk-Away, Warwick	Mr. Chips, East Brunswick	Partyka Resource Management, Chicopee	Canadian Eagle Recyclers, Brampton
Florida Wood Resources Recovery, Inc., Gainesville	Tony Canale, Egg Harbor Township	Regional Waste Services, Peabody	Monto Industries, Toronto
Delaware C&J Associates, New Castle	Winzinger Recycling Systems, Hainesport	Recycled Wood Products, Woburn	Wood Waste Solutions, Toronto
Delaware Recyclable Products, New Castle	New Hampshire Environmental Resource Retur Corp., Portsmouth	C.J. Mabardy, Cambridge	Eco-Wood Products, Toronto
Maine Fuel Technologies Inc., Lewiston	Granite State Natural Products, Salem		Wood Conversion Inc., Brampton
	M-R Land Excavation, Merrimac		

of a larger, integrated recycling operation that also sorts and processes metal, glass, paper, and other items.

As of late 1991, tipping fees at the facility are \$6 per yard, or approximately \$30 per ton. All types of "urban" and demolition wood are accepted, except loads containing visible amounts of creosote- or penta-treated wood.

The unloading area and processing line are located in an enclosed building. The facility receives most wood through a regional construction, yard waste, and an urban wood recycling program. Wood is brought to the facility by private haulers, contractors, landscapers, and homeowners. Cars, trucks, and trailers are weighed and visually inspected at a booth outside the building, before proceeding to concrete unloading docks inside the building.

The unloading dock is organized into 6 to 8 bays where vehicles back up to a low concrete berm. Wood waste is either dumped or thrown off a one-foot drop onto a concrete floor. A front-end loader pushes wood that is visibly clean onto a three-foot wide belt conveyor that leads directly to a hammermill. Construction and demolition wood, or wood with non-wood materials attached to it is pushed onto a conveyor that leads to a three-person picking station. Following separation at the picking station, wood is returned to the hammermill conveyor. The facility operator plans to install two rotary trommel screens to further separate dirt and fines, before wood is sent from the picking station to the hammermill.

The 400 horsepower hammermill unit includes an electronic metal detection device that detects ferrous and non-ferrous metals before wood enters the hammermill. The detection system automatically shuts the hammermill off, if metal above a certain weight or volume is detected in order. This is done to protect the hammers. Very small metal fragments which pass through the hammermill are retrieved by a rotary magnet positioned after the wood chips and fines emerge from the hammermill.

Wood then travels to a horizontal vibrating disk screen that sorts the wood for either fuel chips or wood fines. Fines consist of 1/4- to 3/4-inch minus material and are conveyed to a roll-off box for shipment to a soil and fertilizer manufacturer. Fuel chips between 3/4- to 3-inches are conveyed to two overhead hoppers that hold approximately 180 yards apiece. Tractor-trailers enter the back of the building and drive onto an electronic scale directly underneath the hoppers. The chips are then loaded into the trucks for delivery.

A unique feature of this facility is the system used to control dust and odor. This was the primary reason for constructing an indoor facility since the facility is located adjacent to a busy commercial area. In addition, along the processing line, there are four hood and vacuum systems that feed dust and particulates to a cyclone located near the hammermill. From the cyclone, remaining dust and pollutants are pumped outside the building, directly into a 40-foot baghouse filter system located next to the main building. At the unloading bays, water is sprayed to control dust approximately every 30 minutes.

Wood fuel with a moisture content of 10-20 percent is purchased by three power plants. The hauling distance is typically 100 to 200 miles one way. The facility operator reports that the power plants he ships to are very sensitive to moisture and dirt content. For example, wood fuel in excess of 20 percent moisture is rejected. Installation of trommel screens for additional dirt removal will, according to the plant operator, further satisfy his fuel customers.

5.7.2 Multi-Waste Processing Facility

This facility has the capacity to process up to 1,500 tons per day of mixed construction and demolition debris. This includes the capacity to process up to 300 tons per day, or approximately 90,000 tons per year, of wood. The facility receives a steady supply of wood, due to recent landfill bans on wood disposal at a major landfill located nearby. The site is situated on 11 acres. In addition to wood, mixed C&D waste, newspaper, glass, concrete, gypsum, and crushed rock are accepted and processed. Machinery is housed in two facilities that feature a mix of indoor and outdoor processing stations.

Wood is delivered to the facility by public and private haulers, construction and demolition contractors, landscapers, and homeowners. In late 1991, tipping fees for presorted wood were \$25/ton and for mixed C&D waste were \$29/ton. Trucks are weighed and inspected from a catwalk bridge located ten feet above grade which allows visual inspection from the second floor office. The facility posts a list of materials accepted for processing at the gate, and also relies on personal communication and contracts with regular haulers. According to the processors' specifications, all types of construction, demolition, and other waste wood is accepted, excluding pressure-treated and creosote-treated wood.

Wood enters the processing line at two locations. Mixed demolition, construction, and treated wood start on one line, referred to as the "demo

line." Clean wood, such as pallets, lumber, spools, and yard waste start at another line, referred to as the "finishing line."

After wood is processed at the demo line, it is brought to the finishing line to be processed along with the clean wood. Wood is sold as landfill cover and as fuel. The fuel has an average moisture content of 20 to 30 percent and is usually handled by a regional wood fuel broker.

The Demo Line: The demo line starts with a grapple excavator that feeds wood and rubble into a hopper. From the hopper, wood is conveyed directly into two, three-foot diameter rotary trommel screens that are aligned end to end. The first trommel screens wood for fine dirt and loam using a 1/4-inch screen. Wood and debris then pass under a rotary magnet, before being conveyed to a second trommel. The second trommel uses a 3/4-inch mesh screen for separating stone, concrete, and other aggregate material.

From the second trommel, wood is conveyed into a building where it passes by a 4-person picking station roughly thirty feet long. Large rocks, stumps, pieces of litter, chunks of concrete, aluminum, and shingles are removed at the picking station and thrown into separate roll-off boxes. Not all material that could be removed at the picking station is actually removed, due to the high speed of the conveyor. At the end of the picking station, wood and debris drop into a float tank. As the wood and material fall, an air knife pulls residual bits of paper and plastic into a chute and litter bin located under the end of the conveyor before the material falls into the float tank. The float tank is heated by a small wood burner. According to the plant operator, the warm water causes the wood to float better and allows the tank to be used in cold weather. Every 15 minutes, a drag chain pulls rock, brick, and other material off the bottom of the tank. This material is conveyed outside to a roll-off box. Operation of the tank requires one full-time operator. The operator catches heavy material that binds the drag chain, and ensures that no materials other than rock, brick, or concrete are sent to the roll-off box.

From the tank, wood is floated onto another drag chain and conveyor system where it passes by a one-person picking station. This person sorts any non-wood material still attached to the wood, before it is emptied into a roll-off box outside the building. This "cleaned," slightly-wet, demolition waste wood is then trucked to another location to enter the finishing line.

The Finishing Line: The finishing line begins inside a separate building, where a small bobcat pushes wood onto an inclined steel conveyor belt. The belt conveys the wood to a separating hopper. At the hopper, pieces of wood less than three inches are screened and conveyed directly to a shaker screen. Pieces larger than three inches are sent to a hogger that grinds wood to a one- to four-inch size. From the hogger, wood passes under a rotary magnet and is dropped onto an oscillating horizontal shaker screen. The screen sorts fuel chips and wood fines of 1/2-inch minus. The fines are conveyed outside the building to a roll-off box. After fuel chips leave the shaker screen, they pass under another rotary magnet before being conveyed to an outdoor fuel pile.

5.8 The Effect of Tipping Fees and Disposal Costs on Waste Wood for Fuel

Factors that influence the determination of tipping fees and how tipping fees affect the availability of waste wood for fuel are discussed. Also discussed are issues related to disposal costs faced by major generators of waste wood. These sections provide insight into the major economic factors that affect the disposal of waste wood and its availability for fuel.

5.8.1 Tipping Fee Factors

Tipping fees are an important aspect of the economic infrastructure that affects waste wood fuel availability and cost. Tipping fees vary by region based on demographic, geographic, and economic characteristics. Highly populated urban regions, for example, typically face higher disposal costs than rural areas. This is due to the relative lack of landfill space, trucking and hauling costs, and the cost of siting and building new solid waste management facilities. The metropolitan area of New York City, for example, ships a portion of its municipal solid waste as far away as Ohio at costs of over \$150 per ton. Differing regulatory requirements between states also affect the establishment of tipping fees. Many states, such as Vermont, have added surcharge taxes to tipping fees to fund recycling programs, site assessment studies, or to ensure that money is available for landfill remediation and closure.

Tipping fees also vary by the type of solid waste management facility. Low-risk, relatively inert wastes are usually less expensive to dispose of than waste streams containing higher potentially hazardous materials such as medical wastes. Construction and demolition debris (C/D) landfills or "inert" debris landfills, for example, normally charge less for disposal than MSW landfills. Hazardous waste landfills usually charge more than MSW landfills.

Tipping fees correspond to both the demand for disposal capacity and the costs associated with permitting, siting, operating, and maintaining a facility. In many regions, however, tipping fee schedules do not follow an obvious pattern. In some states tipping fees at MSW landfills exceed tipping fees at waste-to-energy plants while in other areas the opposite is true. This results from the interaction of several factors including but not limited to:

- The unique size, type, and operating characteristics of a particular disposal facility;
- Differing contractual arrangements to dispose of waste with private and public entities;
- Differing regulatory policies, standards, and required control technologies among states/ provinces;
- Differing facility requirements concerning the types and amounts of wastes accepted for disposal; and
- The level of competition among similar or alternative disposal facilities.

Table 5-5 compares tipping fees in the study area among four general types of solid waste management facilities that may accept waste wood for disposal. These include MSW landfills, waste wood processing facilities, C/D landfills, and waste to energy facilities. As the table shows, tipping fees at C/D landfills and waste wood processors tend to be lower than tipping fees at either MSW landfills or waste to energy facilities. In addition, fees at waste wood processing facilities are slightly lower than C/D landfills while fees at MSW landfills are slightly lower than fees at waste-to-energy facilities.

With respect to waste wood processed for fuel, other cost issues also affect the determination of tipping fees. These include the cost of processing and hauling wood fuel, prices paid for fuel by combustion facilities, and potential competition for wood waste among other end-use markets. Processing

and hauling costs vary, depending on the type of wood, the design and operation of the processing facility, transportation distances, and a variety

Table 5-5. Tipping fees in the study area, \$US(1991)/ton^{a,b}.

State/Province	MSW landfills	Waste wood processors ^c	C/D Landfills	Waste to energy
California	10-50	10-30	NA	20-30
Connecticut	60-100	50-100	50-70	60-85
New Brunswick, CAN	25-35	NA	0-35	NA
New York	40-150	30-75	30-75	15-90
North Carolina	10-25	0-10	40-60	45-50
Vermont	20-70	NA	4-70	NA
Virginia	20-60	10-20	20-50	35
Washington	30-45	10-20	30-40	60-95
Wisconsin	15-60	NA	10-50	50-60

Notes:

NA = not applicable

- a. Based in part on data from Biocycle, April 1991.
- b. Based in part on interviews with state solid waste officials and facility operators.
- c. Depends on the types of wood to be disposed of, the level of contamination, the extent to which wood is commingled with other wastes, and the costs of disposal at other solid waste facilities.

of other factors. An important consideration for processors are the hauling and processing costs not recovered by the price paid for fuel. The cost not recovered is compared to the tipping fee otherwise charged for disposal. If the cost not recovered is less than the tipping fee, then it is more cost-effective to process and haul the wood for fuel than it is to pay for disposal.

As previously noted in Sections 5.2 and 5.5, the level of contamination and presorting of waste wood prior to disposal may affect the tipping fee assessed. In addition, processors must compare fuel prices to prices paid for end uses other than fuel. If the fuel price is less than the price paid when selling wood for other uses, then it may be more profitable to sell wood for non-fuel uses. Cumulatively, these issues have a strong role in the determination of tipping fees at waste wood processing facilities that operate as disposal sites for waste wood and other materials. In general, a processor that faces strong markets for fuel and other processed wood products is less reliant on revenues from tipping fees than a processor who faces weak end-use markets for processed waste wood. In other cases, however, the avoided cost of landfilling waste wood is sufficiently high to offset processing and transportation costs. In this situation a processing facility is less reliant on prices paid by end users since the tipping fee charged at the gate compensates for operating the facility.

In most parts of the Northeast, Southeast, and New Brunswick, there is generally a much larger supply of wood fuel than there is demand. The western states of California and Washington, however, are more constrained in the availability of harvested waste wood due to changes in forest practices. As a result, the demand and prices paid for processed urban wood are higher than in other regions of the study area. This is particularly true in California. Based on information provided by brokers and suppliers in the Northeast, however, prices paid for both harvested and non-harvested wood chips for fuel have not increased substantially during the last five years. In fact, some prices have decreased, particularly when inflation is taken into account. In this situation, processors depend on the avoided costs of landfilling (high tipping fees) to make up for the costs of processing and hauling fuel.

It is expected that waste wood processing facilities will be able to secure supplies of wood only if their tipping fees are competitive with the cost of other disposal options. This involves comparing tipping fees to be charged by waste wood processors with fees charged by other disposal facilities. It also involves comparing existing or proposed solid waste management regulations which can have a direct impact on tipping fees. Significant penalties on the disposal of certain types of waste wood used at many landfills affects the rate of waste wood separation and diversion from municipal and commercial waste streams. In addition, the increasing use of landfill bans on waste wood disposal, such as in the province of Ontario, replaces the monetary incentives created by tipping fees. Landfill bans can be expected to strengthen the role of tipping fees at facilities that provide alternative disposal options, such as waste wood processing facilities.

It is important to emphasize that the factors that affect tipping fees are interdependent, changing, and localized among regions. As shown in Table 5-2 tipping fees at waste wood processing facilities vary by almost \$100 from a low of \$12 per ton to a high of \$110 per ton. This discrepancy results from direct price differences such as high disposal costs in certain areas, varying processing and hauling costs, and varying prices paid by end users. Indirect, non-monetary issues also play a role. These include expectations about the permitting of other disposal facilities, the development of reuse or recycling markets for certain materials, or the perceived impacts of new solid waste regulations.

5.8.2 Disposal Cost Factors

There are many types of residential, commercial, and industrial activities that generate waste wood. The disposal costs for wood vary based on the type and scale of activity, the types of waste wood generated, and solid waste management policies and regulations in specific regions. This discussion focuses on urban waste wood since disposal costs are typically a larger concern for waste wood generated as a result of manufacturing or construction than from harvesting or forest management activities.

Harvested waste wood from landclearing, landscaping, or primary mill residue, however, may face similar disposal cost concerns due to specific solid waste regulations and the type of waste generated. Disposal costs for harvested wood and primary mill residue, however, typically range from no-cost (left on-site or given away) to costs associated with hauling and disposal at either a C/D landfill, inert landfill, compost facility, MSW landfill, or waste to energy facility. Transportation costs are a primary disposal cost faced by generators of harvested waste wood in urban or suburban areas where material is often required to be removed from the site. The majority of urban waste wood generation is related to various types of construction activity that occurs among all economic sectors, and mill residue generated from secondary wood products manufacturing. Treated mill residue,

for example, may have to be managed and disposed of as a solid waste if it is not reused or burned on-site. Most wood products industries, however, are able to reuse, give away, or sell their mill residues for fuel, animal bedding, soil amendments or other uses.

Waste wood from construction activities may be generated by new construction, renovation, or demolition activities (GTHA, 1991). The largest user of new wood products among these categories is residential construction. This does not necessarily mean that new home building generates the most waste wood however. Renovation and demolition projects may generate more waste wood on a square footage basis than new home construction. A higher percentage of total project costs are usually allocated to waste disposal for renovation jobs rather than for new construction. According to research conducted by the Greater Toronto Homebuilders Association (GTHA), up to 8 percent of the total job costs of renovation may be budgeted for waste disposal.

According to the same study, waste disposal costs for new homes contribute 4 percent to overall job costs. The GTHA estimated that a typical 2,000 square foot, two-story home produced as much as 2 1/2 tons of waste per house of which 40 percent (or one ton) is estimated to be waste wood. By comparison, another large commercial and residential contractor in the southwest region of the U.S estimates that 12 cubic yards (slightly over two tons) of waste is created for homes from 1600 to 1800 square feet (Kush, 1991.) These figures, however, are higher than "cleanup" estimates for new home construction given by the National Homebuilder's Association (NHA). According to a 1990 national study of new home construction costs by metropolitan areas, the NHA estimated that cleanup costs ranged from no more than 0.4 percent of total costs in the east and southeast and up to 1.5 percent of total costs in the west and northwest area of the U.S. (Martenson, 1992).

Unlike the disposal costs associated with renovation and new construction, demolition activities are by nature a "disposal cost." In addition, other types of disposal costs such as hauling may be added to the cost of demolition. Disposal costs from demolition activities are incurred for a variety of reasons including preparation for new construction, removal of health and fire hazards, or creation of open space. Demolition projects are usually not a component of any particular commercial activity. Thus reliable estimates about their impact on total project costs can be made only on a case-by-case basis.

Similar to off-site disposal of harvested waste wood, transportation costs can play a major role in the overall costs of disposing of urban waste wood. Hauling costs are affected by how the waste is transported and whether the waste is processed prior to shipment. Large demolition projects, for example, may use a mobile shredding machine to reduce the volume of material in order to maximize hauling capacity and improve handling ability. Wood and other wastes that are shredded prior to shipment are typically hauled at costs of \$2 to \$5 per loaded mile. Hauling costs for bulky wastes vary. They are often absorbed as part of a flat fee offered by private hauling companies to dispose of a certain volume of material, such as a 30 to 40 cubic yard roll-off container. Alternatively, fees may be charged on the basis of variable hauling costs and fixed disposal costs for a specified volume at a disposal facility. An example is the use of flat fees for various truck sizes such as \$30 for a pickup truck at a Virginia C/D landfill. In addition to this fee the hauler adds the variable costs of trucking.

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6.0 WASTE WOOD COMBUSTION FACILITIES

6.1 Introduction

This chapter describes combustion facilities that burn waste wood for fuel. Emphasis is placed on facilities that burn wood that is separated from the waste stream and processed into fuel. The processed wood is derived from a variety of municipal, commercial, industrial, agricultural, construction, and demolition waste streams and is commonly referred to as "urban," "recycled," "treated," and/or "demolition" wood. In this report, the wood is referred to as "waste wood" when it is in its preprocessed form, and as "processed wood" when it has been processed and prepared for fuel. Most facilities that use processed wood for fuel also use harvested wood that is a byproduct of site conversion, commercial logging, and forest management activities. In addition, combustion facilities located in areas with wood products industries frequently use mill residue for fuel. Similarly, combustion facilities located in areas with large amounts of agriculture frequently use agricultural residue for fuel.

This chapter also discusses key issues concerning fuel specifications and procurement, fuel delivery and feeding equipment, furnace and boiler designs, and pollution control equipment for combustion facilities that use processed wood for all, or a portion, of their feedstock. The discussion applies to power plants that burn processed wood exclusively for electrical generation, and industrial facilities that burn processed wood to produce thermal and/or electrical energy.

Section 6.2 provides an overview of major factors affecting the combustion of processed wood for energy. The discussion is based on interviews with regulatory officials, power plant operators and developers, site visits to combustion facilities, and review of published material on the design and performance of combustion systems.

Section 6.3 details wood fuel procurement specifications and techniques used by facilities that burn processed wood. As emissions and ash disposal standards are developed for facilities that burn processed wood, more attention is being paid to fuel content and quality. This in turn is causing the development and use of fuel specifications at combustion facilities.

Section 6.4 describes fuel delivery, storage, and equipment used at facilities in the study area that burn, or would like to burn, processed wood. Although a wide variety of equipment is in use, emphasis is placed on equipment used to deliver, store, and feed non-harvested wood that was separated from the waste stream and processed into fuel.

Section 6.5 describes combustion equipment used at facilities that burn, or would like to burn, at least some processed wood as part of their feedstock.

Section 6.6 provides a summary of combustion facilities researched for this study. Three tables are presented that compare equipment used by the facilities. Each table includes information on facilities in a different size range, based on boiler capacity. Information is included on the type of facility, rated furnace or boiler capacity, type and amount of processed wood and other wood fuel consumed, and combustion equipment used.

Section 6.7 includes case studies of two wood-fired combustion facilities located in the study area. One facility uses a bubbling fluidized bed combustion system. The other uses a grate-burning, spreader-stoker system.

Both facilities are independent power plants that burn substantial amounts of processed wood.

6.1.1 Key Issues Regarding Waste Wood Combustion Facilities

- What are the major issues affecting the decision to burn processed waste wood at a combustion facility?
- What issues affect wood fuel procurement by combustion facilities? Are there different specifications for wood fuel that is derived from the waste stream?
- What are the major types of equipment used to handle and combust processed waste wood?

6.1.2 Key Findings

- The choice to use processed waste wood fuel at combustion plants is affected by several factors: specific fuel requirements at facilities; the availability of wood fuel from conventional sources; local air quality conditions and regulatory familiarity with waste wood combustion technologies; and, the ability of combustion equipment to handle and burn various types of fuels.
- Wood fuel specifications, particularly for processed waste wood that may contain treated wood, are becoming more specialized. Conventional fuel contracts usually specify only the delivered price and acceptable moisture and ash content. Increasingly, fuel procurement managers are focusing on physical and chemical tests to determine the types and levels of non-wood material in wood fuel. In addition, they are offering tiered price schedules for varying fuel qualities.
- Two major types of combustion systems, grate-fired and fluidized bed, are used to burn processed waste wood in the study area. There are substantial variations in the performance, size, grate and boiler design, excess air requirements, level of add-on pollution controls, and other factors among the combustion systems indicate that combustion units can be carefully matched to specific fuel characteristics.
- Wood fuel derived from wood in the waste stream is used primarily by large stand-alone power plants or large industrial cogeneration facilities with boiler capacities greater than 100 MMBtu/hour. These facilities generally experience economies of scale that allow for the use of high efficiency control equipment for an array of pollutants.

6.2 Issues Affecting Waste Wood Combustion

A variety of factors affect the decision to process and use waste wood for fuel and the selection of equipment at a wood-fired facility including: availability, price, and characteristics of the waste wood; design, engineering, performance, and cost of combustion equipment; and regulatory issues, among others. For facility operators, uncertainty about the availability and price of waste wood with consistent combustion characteristics can affect fuel and technology choices. For regulators, uncertainty about combustion performance at facilities that burn processed wood can be a major

factor during the permitting process. Interviews with facility operators and regulators indicate the following concerns and issues regarding the processing and subsequent combustion of waste wood for energy.

- As with any steam, heat, or power generating facility, the overall issue affecting the selection of combustion equipment depends on the purpose of the facility. Technology selection is most strongly influenced by such factors as the size and scope of power sales contracts for power plants, the ability of equipment at existing facilities to convert to and burn alternative fuels, and the process steam demands in industrial settings. Factors that affect a plant's interest in using processed wood are typically secondary to these other issues. However, the availability and price of processed wood may be a critical factor in the overall economic viability of a facility.
- Most, if not all, facility operators believe that combustion equipment that is commercially available and commonly used at wood-fired facilities is capable of burning processed wood in compliance with existing air and ash regulations. Their experience operating facilities indicates this is true if the waste wood is processed well, good combustion practices are followed, and sufficient stack controls are used.
- The familiarity of regulators with the performance, air emissions, and ash contents of combustion systems that burn processed wood has a major affect on the permitting and development of facilities. Many states do not have specific standards for facilities, especially those that plan to burn treated wood. Facilities are often reviewed on a "case-by-case" basis.
- Ambient air quality in the region where a wood-fired facility is located greatly affects the type of pollution control equipment used and, in some cases, the type of furnace or boiler used. As discussed below, air quality problems and regulations in California have prompted the construction of several fluidized bed systems. Emissions standards and the performance of fluidized bed systems are shared through a "BACT clearinghouse" of state and regional air quality regulators that helps determine required performance standards for new facilities (Terry, 1991).
- When adapting existing wood-fired facilities to burn more processed wood, facility operators are more likely to modify their fuel handling, screening equipment, or furnace combustion controls rather than the actual combustion equipment due to the concern about fuel cleaning, sizing, and mixing (Joseph, 1991). In addition, the lower moisture content of processed wood compared to other wood fuels may require adjusting air-to-fuel ratios or adding a NO_x control system.
- Most wood-fired facilities are not designed to burn only processed wood. They are usually designed to burn one or more types of wood such as harvested wood, mill residue, and agricultural residue in addition to the processed wood. Although many plant operators would like to increase their use of processed wood, most facilities have a limit on the amount of dry, finely sized material that can be burned due to the need to

minimize wear on combustion equipment and maintain permit compliance (Karakesh, 1991).

- Economies of scale affect whether combustion facilities can use processed wood fuel. As previously discussed, this is due to the more detailed regulatory review and more complex permitting process often required, if a facility intends to process and/or burn waste wood rather than just harvested wood, mill residue, and agricultural residue. It is also due to capital and operating costs associated with the equipment needed to control air emissions and ash contents.
- Many small, older industrial facilities that burn wood fuel are equipped with simply a cyclone or multicyclone for particulate control. They may also monitor opacity and carbon monoxide to check combustion efficiency. These facilities typically burn harvested wood or mill residue generated on-site. Regulators usually view these feedstocks as predictable, uniform, and appropriate for combustion for energy. However, small or medium size industrial facilities may not have the resources to modify their facility to meet regulators' concerns about the combustion of processed wood obtained from multiple off-site sources. The modifications could include adding continuous stack emission monitors, fabric collectors, and/or electrostatic precipitators and NO_x control systems.

6.3 Wood Fuel Procurement

Currently, the use of processed wood for fuel is most common at stand-alone wood-fired power plants developed by independent power producers (IPP), and large industrial facilities. Most of these facilities use at least 100,000 tons per year of wood, a portion of which is processed wood. Several fuel suppliers and numerous sources of waste wood may be used to maintain an adequate supply of fuel at the facilities. Typically, major wood-fired facilities using processed wood rely on ten to twenty sources of fuel although they may be served by only one or two brokers. A wood-fired power plant in California, for example, relies on more than 50 different fuel suppliers. A pulp and paper mill in Minnesota burns mill residue, whole tree chips, coal, and railroad ties (processed on-site) hauled from as far away as Washington state (Gray, 1992). Other facilities, however, have established dedicated processing facilities to prepare fuel specifically for one or two power plants.

6.3.1 Wood-Fired Power Plants

Wood-fired power plants may use processed wood for fuel based on a need to have diverse and readily available fuel sources. In some states such as California, the use of processed wood for fuel is motivated by increasing competition and prices for other types of wood fuel, such as harvested wood and mill residue. However, the supply and demand for all types of wood fuel varies greatly among different states and provinces. Western states, such as California and Washington, have experienced significant declines in forest harvesting and primary wood products industries which result in less logging slash and mill residue for fuel. This increases demand for fuel from other sources of wood in those states. By comparison, in the northeastern U.S. many professional foresters note the substantial amounts of low quality wood in the forest that are not economic to harvest without increased demand for fuel chips. The foresters state that increased harvesting for fuel is essential for accomplishing major timber stand improvement to increase the value of the forest over the long term. Without increased fuel demand, the forest will

continue to be poorly managed, overstocked with low value species, and the true resource potential for timber will not be realized.

Opportunities to acquire wood from the waste stream at no- to low-cost can be an important incentive for combustion facilities to use processed wood. As landfills become full and it becomes increasingly expensive to permit and site new ones, there is growing interest in processing bulky waste, such as wood, for fuel and other uses. In some locations, processed wood is available for fuel at no or low cost due to the avoided cost of not having to pay for disposal of the material in a solid waste facility. The waste generator and/or hauler has saved money, by recovering the wood rather than paying tipping fees. In some locations, the avoided tipping fee is larger than the total cost of processing the wood and delivering it to a combustion facility. Facility operators also use processed wood due to its lower moisture content and higher heat value.

6.3.2 Wood-Fired Industries

In addition to power plants, numerous wood products industries burn mill residue on-site that includes a mixture of wood waste, such as bark, planer shavings, plywood, particleboard, painted wood, laminated wood, and stained wood. These industrial boilers are used for process steam, space heating, water heating, and kiln drying. They sometimes cogenerate electricity that is used on-site and/or sold to an electric utility. Two important differences exist between large wood-fired power plants that burn significant amounts of waste wood and smaller industrial boilers that burn mill residue. These differences directly affect the opportunities and constraints associated with modifying the facilities to burn processed wood for fuel.

The first difference is that industrial facilities that burn mill residue produced on-site have substantial control over their fuel source because they are both generators and consumers of a relatively homogeneous supply of waste wood. This means that the combustion system at these facilities burns a specific, and fairly constant type (or mix) of fuel. There is reduced potential for changes in combustion efficiency and air emissions due to the consistency of the feedstock. Although an industrial boiler may burn treated waste wood, emissions control and boiler efficiency can be relatively predictable assuming a consistent fuel source and good combustion practices are used. Sometimes referred to as an "enclosed" system of fuel generation and consumption, this has important implications for the regulation and permitting of facilities that burn processed wood (Getz, 1991). Several states, such as New York, regulate industrial boilers that burn mill residue produced on-site less stringently than a combustion facility that relies on diverse sources of fuel obtained off-site (N.Y., D.E.C., 1991).

The second difference concerns the economies of scale that affect the degree to which industrial wood-fired facilities can rely on diverse sources of wood fuel from off-site sources. The regulatory scrutiny and expense is magnified for off-site sources of wood fuel that may contain chemicals or preservatives. Large wood-fired power plants frequently conduct fuel sampling and testing programs to maintain fuel quality and control the frequency of equipment maintenance and repairs. The expense involved in operating fuel sampling and testing programs can limit the number of industrial facilities interested in burning waste wood processed from multiple sources located off-site. It is essential that waste wood processors be able to provide fuel that consistently meets combustion specifications for size, moisture content, Btu value, and acceptable levels of non-wood and non-combustible material.

6.3.3 Wood Fuel Procurement

Specifications and techniques used for procuring wood fuel have a significant impact on the ability of wood-fired facilities to meet combustion efficiencies, air emissions standards, and ash contents established by federal and state environmental regulations, especially facilities that use processed wood as part of their feedstock. Procurement strategies vary, depending on the type and quality of fuel needed, requirements of the combustion system, and wood fuel prices. Some wood-fired facilities operate an ongoing fuel testing program to assure that moisture content, heating value, and the percentage of non-wood material is within acceptable limits (Schroeder, 1991). At other facilities this is unnecessary. Many boilers at wood products industries, for example, burn fuel that is a byproduct of the manufacturing process. The fuel characteristics are well known at the facilities, since manufacturers are familiar with working with specific species and grades of wood.

Wood fuel procurement at wood-fired power plants can be sufficiently complex to necessitate using either in-house or third party brokers for maintaining fuel quality and supply. This is especially necessary if wood fuel is obtained from diverse off-site sources that require individually negotiated fuel contracts with each supplier. Contracts specify fuel quality for several physical and chemical parameters. In some states, such as California, it is not uncommon for a wood fuel broker to supply several power plants simultaneously. For each plant, the broker must provide a sufficient supply and quality of fuel that meets the combustion and permit requirements of the facility (Kaylor, 1991).

Relatively large combustion facilities that use professional fuel procurement managers usually write their own fuel contract standards; however, air quality permits may also contain specific language on the types of fuels that are allowed to be burned. In air permits, unacceptable wood fuels are frequently defined to be any type of "treated" wood; however, this term is imprecise for many facility operators. During the past several years, regulators in some states have become more specific about the types of waste wood products that are acceptable for use as fuel (Buss, 1991). In addition, air permits may require operators of combustion facilities to maintain detailed records on the types and amounts of fuel burned. This may be required to confirm eligibility for emission reduction credits or to demonstrate compliance with fuel specifications in the air permit (Keest, 1991).

Examples of recent wood fuel permit and recordkeeping provisions are contained in permits for two fluidized bed wood-fired power plants in California. One permit is for a 28 MW facility; the other is for a 30 MW facility. Both facilities burn a combination of harvested wood, agricultural residue, and processed wood (referred to in the permit as "urban-wood"). Condition A specifies acceptable wood fuels for the 28 MW facility. Note the broad range of acceptable "urban-wood" wood fuels. Condition B specifies wood fuel recordkeeping provisions for the 30 MW plant.

(A) "...Fuels for the boiler shall be limited to the following untreated wood fuels without prior District approval:

1. Orchard prunings and removals,
2. Urban-wood fuel (secondary wood); clean, new construction waste; tree and brush trimmings; wood-product industries (cabinet makers, log cabin and prefab structures, furniture mfg., boats and boating mfg, millwork mfg., sawmills and pallet mfg.),
3. Stone-fruit pits,
4. Assorted nut shells,
5. Whole, tree chips,

6. Natural gas."

(B)"...The applicant shall maintain records of fuel acquired and the mass of fuel burned on a daily basis, including records of compliance with fuel blend requirements. In addition, daily records are required of mass, type, and geographic origin of the biomass received, accompanied by certifications by the fuel supplier and applicant that any creditable biomass has been historically burned openly in the basin."

These permit conditions demonstrate the importance of fuel procurement practices, particularly for facilities that intend to burn significant amounts of processed wood, and "treated" wood. Despite regulatory requirements and permit conditions, primary fuel specifications are usually determined by the type of combustion system and the expected "woodshed" (or supply region) of a proposed combustion facility. Some combustion systems are more sensitive to dirt, moisture, and other non-wood materials than others. The selection of the combustion unit relies strongly on the expected amounts and types of fuel(s) (Hanson,1992). Table 6-1 compares typical fuel values for a variety of wood fuels. Differences in combustion systems are discussed in Section 6.4.

6.3.4 Wood Fuel Specifications

As noted above, both regulators and combustion facilities are placing more emphasis on fuel quality and composition. At some facilities, fuel content standards are explicitly stated as permit criteria in order to ensure performance standards for the control of stack gas emissions. At other facilities, the primary check on fuel content and acceptable limits of non-wood and non-combustible material is found in fuel contracts with specific suppliers.

Major issues addressed by fuel specifications developed by combustion facilities are discussed below. In addition, Appendix F provides examples of wood fuel specifications used by two wood-fired power plants in the study area. The facilities use a mix of harvested wood, mill residue, agricultural residue, and/or processed wood. Chapter 7 discusses in detail the combustion, chemical and environmental properties of "treated" and "clean" wood fuels. The following discussion indicates the importance of these parameters in designing and operating a combustion process.

6.3.4.1 Wood Chip Size

The first specification in a fuel contract usually addresses wood chip size because uniform particle size increases combustion efficiency and helps achieve consistent emissions. Generally, wood fuel that varies significantly in size causes uneven rates of combustion. Excess fine particles can cause unpredictable, spontaneous combustion above the combustion bed. Oversized material may lead to poor combustion. Maintaining consistent fuel size is also important in minimizing bridging and blockage in fuel handling systems and in ensuring steady delivery of fuel to the furnace. Unpredictability in fuel delivery can result in damage to refractory and boiler components.

Combustion systems are matched with the size of the fuel. Grate burners usually use fuel that ranges in size from no less than 1/8-inch on any side up to a maximum of 5 inches on any side. Preferred ranges are one to three inches in size, or approximately eight cubic inches of material. Air permit standards may also establish a limit on the percentage of fine wood (i.e. material that is less than 1/8- or 1/4-inch) that is acceptable to burn, especially for stoker-fired systems using pneumatic or other mechanical feeding stokers. Pile burning, grate systems may accept a wide range of fines

and bulky wood material up to several feet in length. The primary limitation for pile burning facilities is the size of the feed chute or stoker mechanism, since the fuel is "piled" onto a mass-burn combustion bed with less regard to size or shape.

Table 6-1. Characteristics of common waste wood fuels^a.

	Harvested Wood	Primary Mill Residue	Secondary Mill Residue	Processed Wood	Refuse-Derived Fuel (RDF) (b)
Sources and Types	Logging, landclearing, landscaping	Hogged bark, trim slabs, planer shavings, sawdust	Sander dust, planer shavings, sawdust, pulverized scraps	Municipal, construction, demolition, and other commercial/ industrial sources	Separation and processing of combustible portions of MSW
Moisture Content (wet basis)	> 45%	> 20%	8-12%	10-30%	15-30%
Typical Particle Size of Fuel	1.0-4.0"	< 1.0-4.0"	< 1.0"	0.5-4.0"	Uniform pellets, briques, or "fluff"
Ash Content	1.0-3.0%	3.0-4.0% bark 0.1-2.0% other	0.1-3.0%	1.0-10.0%	5.0-30.0%
Typical Btu's per Pound	4,500	4,500	7,500	6,000-7,500	5,000-6,000
Typical Combustion Systems Used	Grate Burners, Fluidized Beds	Grate Burners, Suspension Burners, Fluidized Beds	Suspension Burners	Grate Burners, Fluidized Beds	Grate Burners, Fluidized Beds, Rotary Kilns

(a) From Campbell, A.G., 1989; Junge, D.C., 1989; and Tillman, D.A., 1991.

(b) RDF is listed for comparative purposes since it is technically considered a solid waste fuel, not a waste wood fuel. RDF consists of the separated, combustible portion of municipal solid waste that may contain varying amounts of waste wood. This fuel is generally prepared by a densification process that results in a uniformly sized, easy to handle fuel pellet, brique, or fluff material. RDF, however, is known to contain much higher concentrations of non-wood contaminants, such as plastics or metals, than waste wood fuel.

Combustion performance in fluidized bed systems is more affected by variations in the particle size of fuel for two reasons. First, the high degree of turbulence in fluidized bed systems tends to even out hot and cold spots across the bed. Second, the fluidized bed allows various sizes of material to "float" in the bed, until complete combustion is achieved. Fuel sizing criteria for a recently built bubbling bed facility specifies that all wood fuel must be less than six inches in size. At least 90 percent of the fuel must be less than four inches, and no more than 25 percent can be fines of less than one-quarter inch. Fuel sizing criteria can be more important in a

circulating bed than a bubbling bed due to the higher velocities required in circulating bed systems (Hanson, 1992).

6.3.4.2 Moisture Content (MC)

The moisture content of wood fuel is a critical parameter because moisture is directly related to usable heat value, combustion efficiency, and furnace design. In general, grate burners can be set up to tolerate low moisture content fuel or high moisture content fuel. When the moisture content range is established, the fuel feed must be relatively consistent within that range. This means, for example, that a grate burner can burn wood from 10 to 25 percent MC, or from 45 to 60 percent MC (wet basis). Alternatively, both moisture content fuels can be burned together as long as the fuels are sufficiently blended. Some wood-fired facilities purposely seek an "average" fuel moisture content, such as 35 to 40 percent, by mixing dry processed wood and wet, harvested wood (Fitzgerald, 1991). It is important that dry and wet fuels be well mixed in grate systems because slagging, clinkering, and swings in stack gas emissions can result from an abrupt and uneven introduction of fuels containing wide variations in moisture content.

Recent fluidized bed combustion technologies allow substantial flexibility in wood fuel types because the process of pyrolysis and heat transfer are dramatically different in fluidized bed systems than in grate systems. Fluidized bed systems are generally less susceptible to changes in combustion performance caused by a changing moisture content in the fuel. Turbulence in the combustion bed causes high rates of heat exchange between the fuel and the bed which prevents slagging and ensures rapid drying and pyrolysis. The moisture specification for one fluidized bed system that burns processed wood, for example, ranges from 8 percent to 30 percent (Hanson, 1992).

Fuel contracts usually stipulate acceptable moisture content in fuel in one of three ways. The simplest way is for a facility to set an absolute limit, such as 60 percent, on the moisture content of any wood fuel to be accepted. The facility may also encourage and contract fuels with lower moisture contents. A second method establishes a ceiling for any single delivery. However, the contract may also prescribe that deliveries meet a weighted average for moisture content on an annual or monthly basis that is lower than the ceiling. The third method is to establish individual moisture standards on the basis of the type and source of fuel delivered. An example is a 25 percent moisture content limit on processed wood compared to a 44 percent moisture content limit for harvested wood used by a power plant in Pennsylvania (Viking Energy, 1991).

Standards for moisture content are enforced several ways. One way is through contracts with fuel suppliers that establish fines for delivered fuel that exceeds the acceptable limits. A second way involves weighing trucks before and after they unload fuel. The weight of the loaded fuel and truck is compared to the empty weight to determine the weight of the delivered wood. The moisture content of the fuel is determined by drying a sample in a microwave oven according to specific test procedures. After subtracting for the water weight, fuel payments are made on a bone-dry basis (Schroeder, 1991). A third way is to scale fuel prices according to varying moisture levels. Under this system, moisture specifications may also be linked to other wood fuel characteristics, such as fines or ash content. Regardless of the mechanism used to enforce moisture content, combustion facilities usually reserve the right to either reject loads if moisture standards are not met, or to assess monetary penalties.

6.3.4.3 Physical and Chemical Composition

Combustion facilities may also be required to sample and test their fuel on a regular basis to monitor fuel quality from individual suppliers. For example, one proposed facility that planned to use 40 percent of its feedstock from processed wood was required by its draft permit to test fuel for physical and chemical criteria including daily and monthly samples for ultimate and proximate analyses, and total metals tests. In addition to size and moisture content, tests included a vapor detection test for volatile organics. Physical and chemical content specifications were developed for fuels with moisture contents of 25 percent, 40 percent, and 50 percent. The specifications are listed in Table 6-2 and were introduced during permitting of a facility in Connecticut. The fuel specification pertaining to processed wood is presented in the column for fuel containing no more than 25 percent MC. The metals standards apply to all types of wood fuel to be accepted at the facility. It should be noted that the frequency and extent of testing requirements implied here are not typical. Furthermore, plans for this facility have been withdrawn.

Standards for non-combustible material are usually specified in terms of acceptable ash content. As shown in Table 6-2, a higher ash standard for processed wood is listed (up to 10.4 percent by weight) than for other types of wood fuel. However, it is difficult to test fuel when it is delivered for the amount of non-combustible material that will be present in the ash when the material is combusted. Yet, failure to control excessive non-combustible material in fuel can result in accelerated corrosion of fuel handling, furnace, and stack equipment. It can also affect combustion efficiency by deterring complete combustion and promoting clinkering and slagging in the fuel bed. Some facilities require that suppliers provide ash and ultimate/proximate tests, prior to accepting fuel for delivery. This is more common if the combustion facility does not have previous experience with the supplier. When an initial delivery is made, the supplier and combustion facility may agree on a regular testing program.

Alternative tests for non-combustible material are used at some facilities to catch "dirty" loads before they enter the combustion unit. One method consists of rinsing a measured sample of fuel and weighing the residue material. If, for example, the residue material consists of more than 0.01 percent of the total weight of the sample, the fuel is rejected (Karakesh, 1991; Hanson, 1992). Another method uses a dry screening process to shake off the fine dirt and other residue. Similar to the wet test, this sample is compared to the overall weight of the fuel sample.

6.3.4.4 Potential Contaminants

Controlling for and testing fuel for unacceptable levels of non-wood chemicals or preservatives is more difficult than testing for size, moisture contents, and physical and chemical composition due to the range of possible contaminants in wood fuel, and a lack of quick and inexpensive test methods. One exception is the proposed vapor detection test used for volatile organics previously mentioned. However, it is difficult to discern, for example, between old painted wood containing high lead concentrations, and wood containing newer water-based paints. Several testing approaches may be needed to screen unacceptable treated wood from fuel used at a combustion facility. Some mechanisms have already been discussed, such as testing and monitoring in the permit process. Mechanisms for controlling fuel contamination that apply specifically to fuel procurement are listed below. Two or more of these mechanisms are generally used in fuel procurement negotiations.

- Fuel contracts usually refer to the right of a combustion facility to refuse any hazardous waste designated by RCRA

Table 6-2. Example of wood fuel specifications used by a proposed wood-fired power plant^a.

A. Physical Contents.

Ultimate analysis, percentage by weight			
	25	40	50
Moisture			
Carbon	33.6 - 39.8	26.9 - 31.9	22.4 - 26.6
Oxygen	25.0 - 33.4	20.8 - 26.7	17.3 - 22.3
Hydrogen	4.0 - 5.0	3.2 - 4.0	2.7 - 3.3
Nitrogen	0.06 - 1.1	0.05- 0.9	0.04 - 0.8
Ash	0.6 - 10.4	0.5 - 8.3	0.4 - 6.9
Sulfur	0.02 - 0.3	0.02- 0.25	0.015- 0.2

Nominal size of fuel to be burned: 2 inch by 2 inch chips

Acceptable wood fuel: Whole tree chips and sawdust from forest management, land clearing operations, sawmills, and wood product manufacturing.

Processed wood fuel sources from construction activities which have been sorted to remove non-wood materials.

Unacceptable wood fuel: Railroad ties, telephone poles, marine pilings, demolition wood, treated wood.

B. General Wood Fuel Specification for Metals Content. (ppm by weight)

Arsenic	15.00
Cadmium	1.3
Mercury	0.20
Nickel ^b	---
Silver	1.60
Chromium	17.00
Copper	20.00
Lead	244.00
Barium	47.00
Antimony ^b	---
Iron ^b	---
Selenium	4.40
Chlorine	0.09
Sulfur	0.14

Notes:

- This specification was developed as part of a permit proceedings for a wood-fired power plant that intended to burn 40% processed wood.
- These metals were not analyzed.

Subtitle C, or contaminated wood waste that fails EPA toxicity characterization tests.

- Fuel contracts may single out specific wood product types, such as wood containing CCA or pentachlorophenol, as unacceptable for delivery.
- Depending on permit requirements, fuel specifications may disallow any type of "treated" wood to be accepted at the combustion facility due to the risk of obtaining excessive amounts of treated wood fuel.
- Fuel contracts may set a visible standard for the percentage of specific types of "treated" wood that may be contained in any fuel delivery, such as no more than 5 percent of painted wood or 10 percent plywood (Kenedy, 1991).
- Similar to standards for non-combustible material, combustion facilities may base their acceptance of fuel from a supplier on results of comprehensive fuel sampling and testing.
- Fuel contracts may specify that wood from a particular source (such as wood from demolition activities), or wood stored at particular sites (such as wood stored on a arsenic-contaminated smelter slag pile) cannot be accepted (Leone, 1991).
- Fuel contracts may reserve the right of combustion facility operators to perform unannounced inspections of processing facilities to check on the types of wood accepted for processing.
- Similar to other fuel criteria, monetary penalties may be assessed for fuel contamination, or a combustion facility may reserve the right to cancel a contract if unacceptable contaminated fuels are detected.

6.4 Fuel Delivery, Storage, and Feeding Equipment

The fuel handling system used at a combustion facility greatly affects the ability to use wood fuel, especially processed wood that may be obtained from waste wood sources that contain non-wood contaminants. Several handling systems exist for wood fuel burned in chipped form. All handling systems consist of three basic components: fuel delivery and unloading equipment, storage areas or buildings, and feeding equipment that provides fuel to the boiler. A fourth processing component may also be included, if waste wood is processed on-site for fuel. On-site processing equipment is discussed in Chapter 5.

Two major concerns affect the design of fuel handling systems at wood-fired combustion facilities. One is maintaining an adequate supply of fuel to meet the combustion requirements of the furnace or boiler. The second concern is potential fuel supply disruptions that can result from excessive wear, clogging, or bridging caused by handling equipment that is insufficient for the fuel(s) being used. Other factors affecting fuel handling include the size and rate of delivered loads of fuel, seasonality of certain supplies, seasonal changes in physical composition of the fuel, and fuel storage conditions (Tischler, 1991).

Different wood fuel types vary the handling equipment and techniques needed. Important considerations include the angle of the conveyors, flow ability of

the material, tendencies to compact, density of the material, tendencies to bridge or "felt" (i.e. form a mat), and the potential for dust and spontaneous combustion (Vranizan, et. al., 1987). In cold climates, wet hogged fuel or dry fuel that becomes wet can freeze into solid masses and cause handling problems. Systems designed to handle dry, processed wood fuel must generally be able to handle compaction and classification of fines, dust control, and the potential for ignition. Processed wood tends to be less stringy than wet hogged fuel; however, construction and demolition wood has a tendency to form long splinters that may encourage bridging on conveyors and in metering bins (Welder, 1991). An advantage of fuel with a low moisture content (such as processed wood) is that fuel drying equipment which may be used for wet hogged fuels is unnecessary. Fuel drying equipment is usually placed in the fuel handling line prior to fuel entering the fuel feed auger or metering bin.

Fuel handling systems can be either fully automatic or semi-automatic. At facilities that generate their own mill residue, automatic systems may consist of a system that conveys mill residue directly from a manufacturing line into a fuel silo. Or, at facilities that obtain fuel from off-site, fuel handling systems may consist of unloading bins or hoppers that allow delivered fuel to be conveyed directly to screening equipment and subsequently to a fuel metering bin (GLRBEP, 1986). Automatic systems are typically used only when fuel quality and consistency is assured.

Semi-automatic systems require operator control or supervision at key points in the unloading, storage, and fuel feeding line. These key points are typically the following:

- During fuel unloading, where fuel inspection and sampling may take place.
- At sorting, screening, or chipping stations where the potential presence of non-wood material may damage handling equipment.
- At the point where fuel is loaded onto a conveyor to begin the fuel feeding process. This is necessary to make sure that an even flow and composition of material enters the line.
- In the operation of equipment that places fuel into a metering bin or into the combustion unit itself. 10,000 to 50,000 cubic foot silos or rectangular bins are typically used for fuel storage by small industrial boilers. In larger systems, similar sized silos and bins provide temporary storage to fuel augers that meter fuel to the boiler (Grimm, 1985). These systems are necessary for stoker-fired combustion units that require an even flow of fuel for the spreading mechanism to function properly. Other systems operate much differently, however. An example is a pile-burning system that uses a grapple crane attached to an overhead track. The track leads from an outdoor fuel pile into an enclosed building that drops wood fuel directly into the gravity chute that feeds the furnace (Tunney, 1991).
- In the management of fuel piles to assure a first-in, first-out supply of fuel and to prevent fuel decay. Outdoor fuel piles typically need to be turned every two to four weeks to minimize buildup of moisture, loss of heat value, odors, and the risk of spontaneous combustion.
- Where dust control systems are necessary, frequent watering or ventilation equipment may be required.

At some facilities, one or two people can perform nearly all of the functions listed. At large combustion facilities, however, a person may be needed for each function, especially if the facility operates fuel processing equipment as part of the fuel handling system. Schematics of four fuel handling systems are shown in Figures 6-1 and 6-2.

6.5 Combustion Equipment

Overall, there are five types of combustion systems that have the capability to burn solid fuels such as wood, including grate burning systems, fluidized bed systems, conventional suspension burners, rotary kilns, and advanced suspension systems that use gasification.

Grate burning systems and fluidized bed systems are the two types of combustion systems commonly used for wood fuel, especially at facilities above 100 MMBtu/hr. Typical grate systems include spreader stokers, underfeed stokers, and pile burners. Fluidized bed systems include atmospheric bubbling bed and circulating bed systems. Conventional suspension burners are commonly used in small, wood-fired industries. The energy produced is used for kiln drying or veneer pressing.

Rotary kilns and advanced suspension systems that use gasification have more specialized uses, such as the combustion of pulverized coal, pre-dried wood, solid waste, or hazardous waste. Rotary kilns are most frequently used in the combustion of medical waste, hazardous waste, and other contaminated debris (Tillman, 1991). Advanced suspension systems that use gasification techniques are designed primarily for coal; however, these systems are being actively researched for both solid and liquid biomass fuel use in the future. Rotary kilns and advanced suspension systems that use gasification are not discussed in this chapter.

6.5.1 Furnace and Boiler Designs

There are significant variations in size and design parameters between the grate burning, fluidized bed, and conventional suspension burning systems. Key differences in grate burning systems are in size ranges, type of grate system, boiler design, level of excess air, fuel handling, and pollution control systems. Variations in fluidized bed combustion systems are related to the type of bed medium used, boiler design, air velocity, and fuel handling.

A comparison of grate burning and fluidized bed combustion systems is provided in Table 6-3. In addition, the major advantages and disadvantages of grate burning and fluidized bed systems are compared in Table 6-4. As shown in the tables, fluidized bed systems have advantages in the control of certain emissions such as NO_x. However, they also have high operating and maintenance costs compared to grate burners. Figure 6-3 illustrates a grate burning combustion system. Figure 6-4 shows a fluidized bed system.

6.5.2 Grate Burning Systems

There are four types of grate burning systems including: spreader stokers with either fixed or traveling grates; underfeed stokers; inclined grates; and pile burners. Grate burning systems have been used for more than several decades, and their design, operation, and maintenance requirements are well understood. Numerous equipment manufacturers design, build, and install grate burning systems throughout the U.S. and Canada.

Grate burning systems are widely used at wood-fired facilities. Grate burners are generally capable of burning wood fuels with a wide variety of moisture

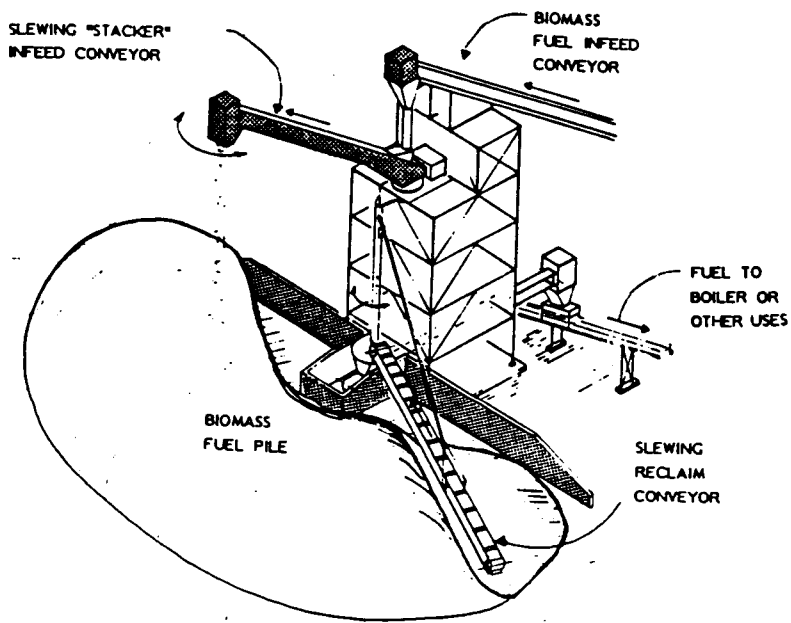
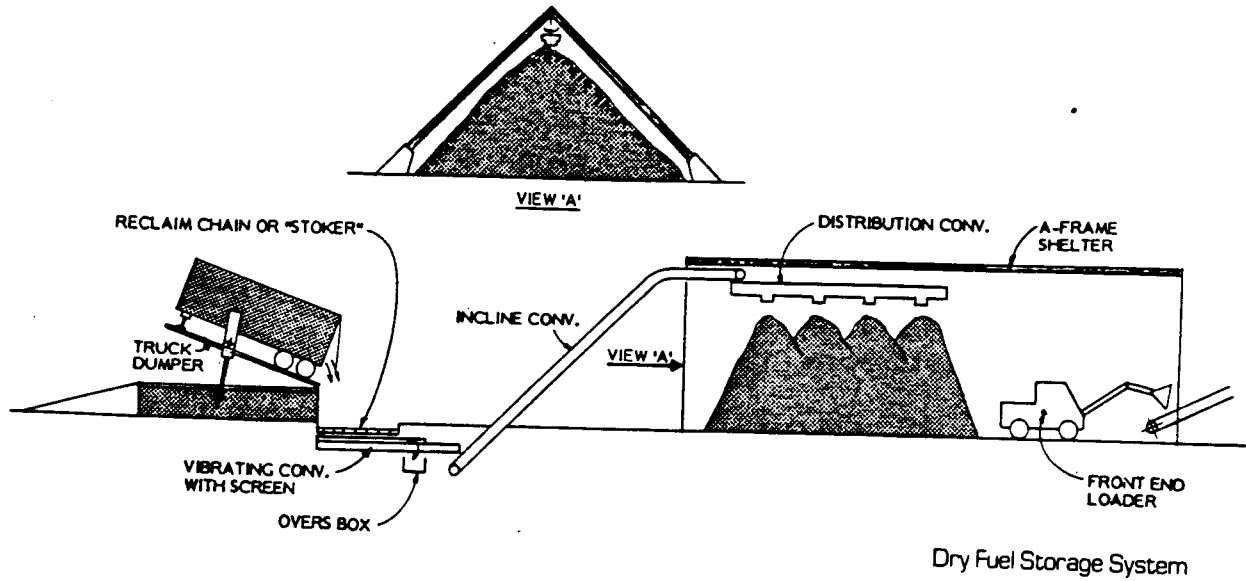
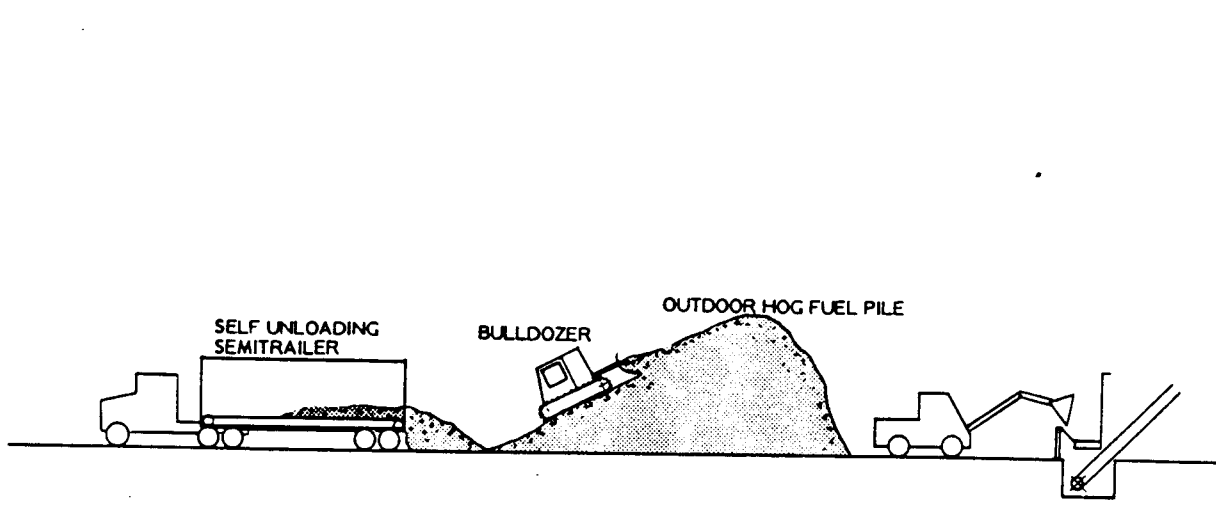
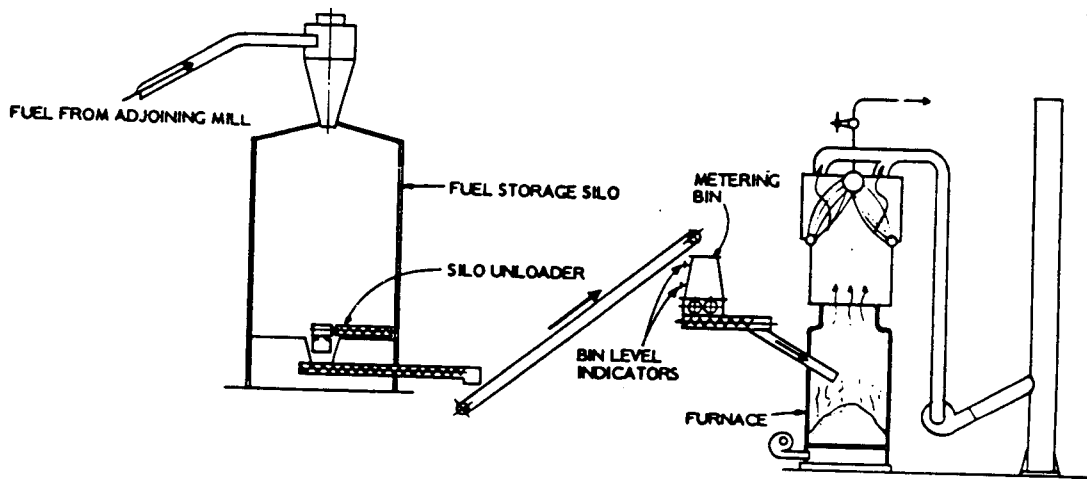


Figure 6-1. Examples of waste wood fuel handling systems (Vranizan, 1987).



Fuel Delivery and Retrieval System



Automatic Fuel System

Figure 6-2. Additional examples of waste wood fuel handling systems (Vranizan, 1987).

and ash contents. Fuel may be burned on a thick-bed, such as in a pile burning system, or on a thin-bed fixed, inclined, or travelling grate system. Wood fuel is injected into the furnace from either a gravity fed hopper, or it is mechanically or pneumatically stoked by spreading fuel across the grate. Stokers may introduce fuel from the top, side, or through the floor of the grates.

6.5.2.1 Pile Burners

Pile burners are typically of the Dutch Oven type, and are most prevalent in facilities constructed before 1940. Newer pile burning systems are patterned after the Dietrich fuel cell design. Pile burners are usually sized up to 50 MMBtu/hr heat input. The grates may be fixed-horizontal or inclined. They are usually fed by a gravity feed chute from a surge hopper or other type of metering bin. Pile burners are two-stage combustion systems where charring and gasification takes place in a primary combustion chamber and volatile gases are burned in a secondary chamber.

One type of pile burner, the Wellons fuel cell, is used in railroad tie combustion. This is a two-stage system made in various sizes for steam production up to 60,000 pounds per hour (pph) on fixed, water-cooled grates. Volatile gases are burned in a secondary chamber with secondary air. This arrangement prevents fuel particles from burning in suspension and lowers particulate concentrations in the stack gas (Campbell, 1989). The fuel cell has a rated efficiency of 65 to 75 percent.

6.5.2.2 Spreader Stokers

Spreader stoker units burn fuel in two- to four-inch beds on top of fixed or travelling grates. Grates are usually air-cooled for boilers up to 20,000 pph and water cooled for larger sizes. The largest systems (larger than 100 MMBtu/hr) use pneumatic fuel stokers and travelling grates which deposit bottom ash into an ash sluice or conveyor system (JPR, 1984). Large spreader stokers that burn harvested and processed wood have been installed in sizes up to 600 MMBtu/hr, with steam capacities of more than 400,000 pph of superheated steam. An example is a facility operated by Washington Water and Power in Kettles Falls, Washington. This facility uses a travelling grate spreader stoker with a water tube boiler. The plant generates an average of 435,000 pph steam and approximately 50 MW of electrical generation.

Other stoker systems include medium-sized underfeed stokers that deliver fuel through the grate intermittently with a ram or continuously with an auger. The most common type of underfeed stoker uses a horizontal feed, side ash discharge mechanism that requires manual cleaning. Underfeed stokers are rare in sizes above 35 MMBtu/hr and are typically used when steam demand is less than 100 pph (GLRBEP, 1986). An example is the Ethan Allen Furniture Company in Spruce Pine, North Carolina which burns mill residue and processed wood in a 10,350 pph fixed-grate boiler. Fuel is fed by an air-cooled underfeed screw.

6.5.3 Fluidized Bed Systems

There are three types of fluidized bed combustion systems including: atmospheric bubbling beds; atmospheric circulating beds; and pressurized fluid beds. Both the atmospheric bubbling beds and circulating beds are commercially available. The pressurized fluid beds are in research and development. The use of fluidized bed systems for wood combustion began in the 1980's, although fluidized bed technologies have been used for coal for many years. They are increasingly common at power plants that plan to burn significant amounts of processed wood and agricultural wastes. Fluidized bed

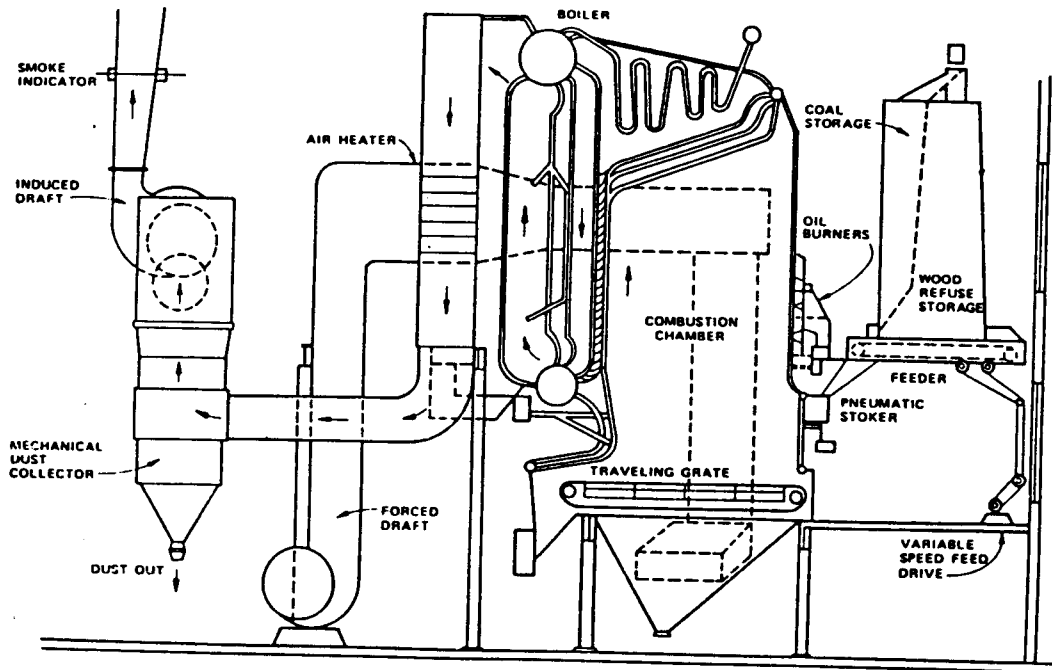


Figure 6-3. Schematic of a spreader stoker (Boubel, 1977).

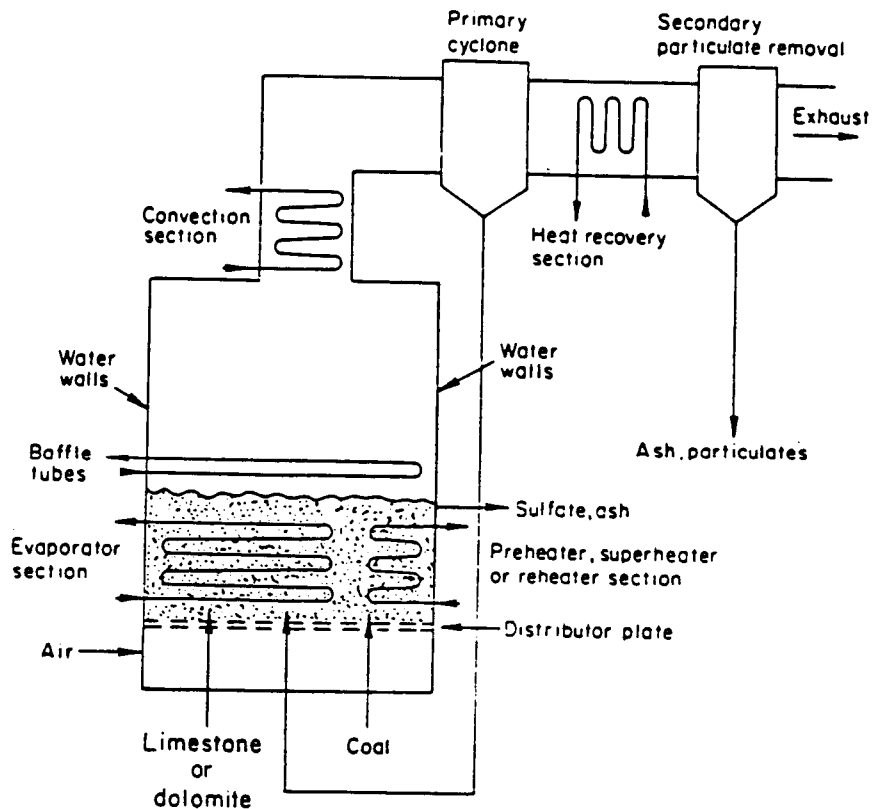


Figure 6-4. Schematic of an atmospheric fluidized bed combustion system (Murphy, 1977).

Table 6-3. Overview of major types of combustion systems used to burn waste wood fuel^{a,b}.

	TYPE OF COMBUSTION SYSTEM			
	GRATE BURNERS		FLUIDIZED BED BURNERS	
	Thin-Bed Stoker Systems	Thick-Bed Pile Burners	Atmospheric Bubbling Bed	Atmospheric Circulating Bed
Typical Size Ranges	Travelling-grate underfeed: 10-35 MMBtu/hr Stationary-grate underfeed: 10-20 MMBtu/hr Stationary-grate overfeed: 50-300 MMBtu/hr Travelling-grate overfeed 50-300 MMBtu/hr	Dutch Oven < 50 MMBtu/hr Wellons or Dietrich fuel cell < 50 MMBtu/hr	15-500 MMBtu/hr	10-500 MMBtu/hr
Boiler Designs	Vertical watertube: (waterwall, water drum) 25,000 - 600,000 pph Horizontal firetube: < 40,000 pph	Two-stage combustion in watertube or firetube	Vertical watertube with flue gas recirculation	
Grate Design	Fixed, inclined, travelling; Air or water cooled; Pinhole, vibrating, or dumping	Fixed or inclined; Air or water cooled; Vibrating or dumping	Perforated Grate	Perforated Grate
Type of Stoker System (c)	Overfeed or underfeed pneumatic ram, mechanical auger, or paddle	Gravity feed chute or underfeed auger	In-bed pneumatic, In-bed auger feed Overfeed mechanical or pneumatic stoker	same as BFB
Typical Fuel Moisture Range	10-55%	40-65%	0-65%	0-65%
Typical Steaming Range	Underfeed stoker: < 100,000 pph Overfeed/stationary grate: up to 450,000 pph Overfeed/inclined-travelling: up to 700,000 pph	Dutch Oven: < 50,000 pph Fuel cell: < 60,000 pph Flat/travelling grate: up to 150,000 pph Inclined grates: up to 500,000 pph	50,000-300,000 pph	100,000-250,000 pph
Typical Flame Temperature	1,800 - 2,600 deg.F	1,500 - 2,500 deg.F	1,500 - 1,750 deg.F	1,500 - 1,800 deg.F
Combustion Efficiency (d)	60-80% in older units 80-99% in newer units	45-65% Dutch Oven 60-80% Fuel cell	90-97%	95-99%
Typical Air Flow Distribution	Gas velocity 15-22 ft/sec. (1:1 ratio underfire/overfire)	10-20 ft/sec.	2-7 ft/sec (3:1 ratio underfire/overfire)	15-30 ft/sec

(continued)

Table 6-3. Overview of major types of combustion systems used to burn waste wood fuel (continued).

	GRATE BURNERS		FLUIDIZED BED BURNERS	
	Thin-Bed Stoker Systems	Thick-Bed Pile Burners	Atmospheric Bubbling Bed	Atmospheric Circulating Bed
Air Flow Control (% Excess Air)	25-50%	50-100%	20-25%	10-20%
Typical Range of Stoichiometric Ratio (e)	1.25 - 1.50		1.35 - 1.40	1.35 - 1.40
Typical Boiler Turndown Ratio (f)	4-5:1	5:1-10:1	3:1	3:1
Typical Stack Gas Controls (d)	Cyclone, Multicyclone, Wet or Dry ESP Urea or Ammonia Injection for NOx (non-catalytic reduction) Limestone Injection for SOx CEM for NOx, CO, CO2, O2, SOx NH3, opacity, NMH, and VOC's. Exxon thermal De-NOx	Cyclone or Multicyclone CEM for opacity, CO	Same pollution equipment for BFB and CFB: Cyclone or Multicyclone Wet or Dry ESP Fabric Filter Baghouse Urea or Ammonia Injection for NOx (non-catalytic reduction) Limestone Injection for SOx CEM for NOx, CO, CO2, O2, NH3, opacity, NMH, and VOC's. Exxon thermal De-NOx	
Ash Handling System	Pneumatic and mechanical conveyors for fly and bottom ash, central conveyor to silo. Small systems may use manual collection procedures	Manual collection typical	Dry, drag chain conveyors, screw conveyors, central transfer conveyor, ash storage silo.	
Percent Ash Distribution	50-70% flyash 30-50% bottom ash	50-70% flyash 30-50% bottom ash	75% flyash 25% bottom ash	75% flyash 25% bottom ash

(a) Based on information from Tillman, D.A., 1991; Tillman, D.A., 1981; Great Lakes Regional Biomass Program, 1986; Northeast Regional Biomass Program, 1984; Grimm, 1985; Junge, D.C., 1989; Yandle and Loi, 1990; Wilhelm and Simbeck, 1990; Campell, A.G., 1989 and; Riley Stoker Corporation, 1992.

(b) Suspension burners are not profiled here, although they may be used to burn certain specialized types of waste wood. These systems typically use sawdust or dry, pulverized mill residue as fuel in small industrial settings (< 50 MMbtu/hr). They do not typically utilize sources of recycled waste wood.

(c) The major differences in grate burners relate to the fuel feeding or stoker mechanism, and the design of the grates.

(d) Combustion efficiency describes the percentage of fuel burned with the amount of fuel supplied. It typically represents the amount of residual unburned carbon. Thermal efficiency, however, expresses the total heat loss from combustion due to factors such as moisture in the fuel and air supply, losses through dry stack gases, and losses from unburned carbon in the ash.

(e) Stoichiometric ratio describes the condition at which the air-to-fuel ratio is such that all combustible products are completed burned with no oxygen remaining.

(f) Turndown ratio indicates the ability of the boiler to operate efficiently at less than maximum design loads. A turndown ratio of 5:1, for example, means that a boiler can operate efficiently from 20%-100% of capacity.

(g) This only lists the types of control equipment used. Few, if any, systems employ all these control devices simultaneously. Continuous emissions monitoring (CEM) is typically prescribed by air quality permits for major new wood-fired combustion facilities. These are typical stack gas pollutants that facilities may be required to monitor under their air quality permits.

Table 6-4. Comparison of major combustion characteristics between grate-burning and fluidized bed waste wood combustion systems^a.

PARAMETER	GRATE BURNERS	FLUIDIZED BED BURNERS
1. Boiler Designs	Wide selection of furnace and boiler designs that allows developers to match fuel with other operating conditions.	Fluidized bed for wood combustion is maturing from the "first generation" stage in 1980's. Modifications from problems encountered in early designs are underway.
2. Acceptable Fuel Types	Ability to burn wide variety of waste wood fuels, however, wood fuel must be prepared and mixed. Cofiring of wood and other fuels in spreader stokers allows for high steam production (up to 700,000 pph.)	Can burn wide variation in fuel moisture and physical and chemical content. Boiler operation stable with fuels between 0-50% moisture content. Turbulence in the bed allows for rapid fuel drying and pyrolysis of fuel.
3. Fuel Delivery	Gravity overfeed, horizontal mechanical auger, or underfeed stoker mechanism. For overfeed systems, air classification of fines may occur leading to uneven combustion.	Typically mechanical or pneumatic stoker. Inconsistent fuel size can lead to uneven combustion.
4. Flame Temperature	1800-2600 degrees F	1500-1800 degrees F Temperature exceedence can prompt clinker formation that inhibits bed efficiency and may require costly system shut down and repair.
5. Thermal Efficiency	Higher thermal efficiency from hotter flame temperatures than fluid beds. Large mass of thermal refractory in many grate burners aids in preliminary drying of fuel.	Thermal efficiency constrained by limits on temperature.
6. Combustion Efficiency	60-80% for older units 80-99% for newer units	High combustion efficiency (up to 99%) yields low CO and THC emissions.
7. Excess Air	Careful control of excess air necessary since combustion efficiency and stack emissions are adversely affected by poor air supply and distribution.	Excess air is allowed to vary based on differing fuel characteristics, however, bed temperature is stabilized by high mass of bed media.
8. Typical NOx Controls	Higher flame temperature contributes to higher rates of NOx formation, however, recent LAER permit standards for NOx are comparable to fluid beds.	Low flame temperature reduces level of NOx emissions. NOx is also reduced through ammonia injection in the furnace rather than post-combustion controls.
9. Particulate Controls	Greater reliance on post-combustion controls, (i.e. multicyclone, ESP, baghouse) or fly ash reinjection than fluidized bed systems.	High combustion efficiency contributes to lower particulate formation. Typically utilize multicyclone and, where necessary, baghouse. Fly ash or char reinjection unnecessary.
10. Air Toxic Controls	Dependent on fuel quality control, combustion design, and operator proficiency. Complex organic emissions (i.e. POM's or PAH's) typically result from poor combustion and operating practices.	Same as Grate Burners
11. Ash Collection System	Most spreader-stokers have automatic ash collection, however, pile burners and small systems may require shutdown for manual raking.	Ash formation is critical in fluidized bed because of potential for fusion. Use mechanical collection systems for bottom ash.
12. Maintenance & Operating	Potentially high maintenance costs on grate systems with high level of refractory and/or moving grate parts. Generally higher availability than fluid beds and able to respond to load swings better.	Comparatively high maintenance costs in first generation units from bed plugging, erosion in combustor and heat exchangers, low availability, and high power demand for blower motors.

(a) From Langr, K. 1992; Miles and Miles, 1991; Hanson J.L., 1992, JPR Associates, 1984; Schultz, S., 1992

systems rely on the interaction and pyrolysis of wood fuel with heated particles of sand or limestone to achieve combustion. The bed medium and fuel are suspended by high velocity underfire air injected into the bed.

The two major types of fluidized bed systems, atmospheric bubbling bed and circulating bed systems, are both used to combust processed wood, although bubbling beds have been used more extensively. The modern era of fluid bed combustion with processed wood began with a determination by California air quality regulators in 1984 that fluid bed combustion represented the requisite Best Available Control Technology for biomass combustion (Schultz, 1992). Their popularity, however, has increased since their application use fuels with widely divergent physical and chemical properties.

However, use of fluidized beds in California for wood and biomass applications was largely made possible because of high power rates inspired by PURPA legislation (Miles, 1992). Historically, wood fuel was available from the pulp, paper, and forest product industry. Combustible solid waste from agricultural wastes and urban wood wastes were also becoming a problem due to decreased landfill capacity and open field burning. A dramatic increase in the cost of fossil fuels due to the energy crisis of the 1970s created an opportunity to reduce operating costs in these industries by using waste wood and biomass fuels. Many wood conversion projects were undertaken to substitute low cost waste wood and biomass for fossil fuels.

The energy market created by PURPA legislation in 1978, solid waste problems, and air quality concerns were the factors that brought wood waste fuels and fluidized bed technology together in California in the mid 1980's (Schultz, 1992). However, the business of converting wood waste to energy was predicated on making economic sense. Due to the combination of high capital, operational, and maintenance costs of fluidized bed technology with rising wood fuel costs (due to increased demand), most of the plants built in California would not be economically feasible today with fluidized bed boilers. Moreover, several of these plants are no longer economically viable even under their existing power purchase agreements and have filed for bankruptcy due to this combination of factors.

6.5.3.1 Bubbling Bed Systems

Bubbling bed systems are cylindrical, refractory lined chambers, filled with an inert bed medium of 2-4 feet consisting of either sand, gravel, or limestone. The bed media is fluidized by preheated underfire air that is usually distributed through a perforated grate. Auxiliary fuel such as natural gas is used to pre-heat the bed. When the bed temperature is sufficiently high to support combustion, the auxiliary fuel is turned off and wood fuel is introduced through a stoker mechanism. The high temperature of the bubbling bed ignites the fuel and the turbulence of the bed allows for rapid and complete combustion (Junge, 1989). Non-combustible ash filters down through the bubbling bed, and can be removed either continuously via the use of a mechanical conveyor, or intermittently when the bed media is replaced. Most commercially sized bubbling bed units use water tube boiler designs to allow for superheated steam generation.

The key combustion parameter with a bubbling bed is temperature, which is controlled by varying excess air levels. If the temperature is too high, the potential fusion of ash and bed material can "choke" the fluidizing process and result in repairs. For this reason, fluidized bed systems operate at much cooler temperatures than grate burning systems. An example of a bubbling bed system is the 25 MW Ultrapower Chinese Station in Jamestown, California that burns a combination of agricultural residue and wood processed from

construction waste. The plant is powered by a bubbling bed with a nameplate capacity of 208,000 pph steam at 1,350 psig and 955 °F.

6.5.3.2 Circulating Bed Systems

Circulating beds were developed primarily to correct for potential problems in temperature control and ash agglomeration experienced by bubbling beds. Gas velocities in circulating beds are strong enough so that both the bed media and the fuel are physically transported as combustion takes place. If temperature rises too quickly and threatens ash fusion, then the gas velocity can be increased to cool the bed temperature (Junge, 1989). At the end of the primary combustion zone, stack gases are separated by a cyclone and sent to either firetube or watertube boilers. The remaining separated solids and bed material are recycled back into the combustion zone. Temperature fluctuations of heat exchange between the fuel and the bed material. An example of a circulating bed is the 49 MW Colmac Energy facility in Mecca, California which burns urban waste wood processed from the Los Angeles area and agricultural residue. This power plant is currently under construction. Once completed, it will use two 232,000 pph circulating beds for steam pressure at 1,255 psig and 925° F.

6.5.4 Conventional Suspension Burners

Suspension burners that combust wood fuel are usually found in primary and secondary forest products industries and are used where very fine, dry fuels are available such as dry sawdust or kiln-dried mill residue from furniture, particleboard, or veneer manufacturing. In addition, large scale pulverized coal systems using suspension technology currently provide roughly half the electrical generation in the U.S. (Tillman 1991). To the extent that coal-fired power plants invest in fuel switching technologies, the co-firing of wood fuel may be more prominent in these facilities in the future.

The primary feature of conventional suspension burners is that the fuel must be dry (less than 15 percent MC), very small (less than 1/2-inch), and evenly divided. Fuel is injected pneumatically into the combustion chamber where it burns rapidly in suspension. A refractory grate at the base of the chamber may be used to catch excess ash or chips that settle without complete combustion. However, grate cleaning associated with conventional grate burning systems is essentially eliminated (Yandle & Loi, 1990). An advantage of suspension burning is high fuel combustion efficiency (up to 85 percent) and the ability to respond quickly to changes in process heat or steam requirements (Campbell, 1989). Unless the fuel is already dry and prepared as a result of manufacturing, however, a major disincentive to suspension burning is fuel preparation costs. Certain types of suspension burners, such as cyclonic furnaces, require a "wood flour" fuel consistency with particles sizes of less than 1/8-inch. In addition, since fuel feed mechanisms are more apt to foul with very small particle sizes, auxiliary fuels are need to prevent flameouts, pulsing, or explosions in the combustion chamber (Junge, 1989).

The use of suspension firing for mill residue and processed wood is typically limited to systems smaller than 50 MMBtu/hr. Wood-fired suspension burners are not used for large scale power plants or industrial facilities. They have more limited tolerance for differences in fuel moisture, size, and other characteristics than grate or fluid bed systems. An example is the use of a 45 MMBtu/hr suspension burning system at the Hardel Mutual Plywood manufacturing facility in Olympia, Washington, that burns fine sander dust and hog fuel from plywood trim scraps generated during manufacturing.

6.6 Summary of Waste Wood Combustion Facilities in the Study Area

The following sections present three sets of summary information on waste wood fired combustion systems. The first set consists of a series of three tables (Tables 6-5 through 6-7) that compare combustion and control equipment used at specific wood-fired facilities that burn various types of waste wood. Systems within three size classifications are compared. These are systems with a heat input capacity of greater than 100 MMBtu/hr, systems between 10 MMBtu/hr and 100 MMBtu/hr, and systems smaller than 10 MMBtu/hr. The tables provide a representative sample of the range of combustion technologies currently used for combustion. The tables do not represent all the possible configurations of combustion technology that may be used for wood fuel but emphasize facilities whose feedstock includes processed wood, particularly fuel that may contain non-wood contaminants.

Table 6-8 lists major wood-fired power plants in the study area that use processed wood, mill residue, and agricultural residue in addition to harvested wood for fuel. It does not include small- and medium- size industrial facilities that burn primarily mill residue and harvested wood. Such a list would be very long. For example, North Carolina alone has more than 200 small and medium sized industrial boilers (SERBEP, 1986). Lists of these facilities can be obtained from state or provincial energy offices or, in the U.S. from the Regional Biomass Programs funded by the U.S. Department of Energy.

6.7 Case Studies of Combustion Facilities

Case studies of two waste wood combustion facilities are presented. Both facilities burn a mixture of waste wood from construction, demolition, municipal solid waste, agriculture, and wood products manufacturing. The facilities were chosen due to differences in combustion technology, location, size, and operating parameters. The facilities are described anonymously, due to agreements made concerning their participation in this study.

6.7.1 Fluidized Bed Combustion Systems

This combustion facility is located in a federal non-attainment area for particulates and ozone. It is designed to meet a stringent level of emissions control using modern combustion and control equipment. Permit requirements contain specific fuel and stack gas requirements. The combustion unit is a bubbling fluidized bed system rated at 315 MMBtu/hr with 255,000 pound per hour of steam at 1,350 psig and 955° F. The facility is designed to burn a combination of processed ("urban") wood, and orchard agricultural waste.

The combustor is 20 feet deep, 45 feet wide, and 56 feet tall. A forced-draft fan supplies air to a preheater and the windbox for fluidization. Preheating the bed is accomplished by using a 15 MMBtu/hr natural gas preheater. When the combustion bed reaches sufficient temperature, fuel is supplied by an overbed induced air feed tube. Overfire air is split from the forced draft fan outlet and is adjustable to 35 percent of the total air supplied. Flue gas recirculation is used for overfire air and fuel bed fluidization. According to plant operators, flue gas recirculation allows the combustion of drier fuels than would otherwise be possible.

This fluidized bed system also uses a patented bed draw-down system that pulls residual non-combustible material such as nails or rock from the fuel. The bed draw-down operates on a continuous basis with up to 10,000 lbs/hr of bed material being cleaned and reinjected. The ability to handle large quantities of non-combustible material allows the system to burn a higher amount of low

Tables 6-5. Examples of technologies used by "large" waste wood combustion systems (>100MMBtu)^a.

TYPE OF FACILITY	SIZE	BIOMASS FUEL PERMITTED (a)	WOOD FUEL USED (tons/year)(b)	COMBUSTION SYSTEM	TYPE OF POLLUTION CONTROL(S)
A. Power plant	315 MMBtu/hr; 32 MW (phase 1); 24.5 MW (phase 2) to be built	AG, HW AG, UW*	270,000	EPI bubbling fluidized bed with flue gas recirculation	Multicyclone & baghouse system; Ammonia & Limestone injection; CEMS for opacity, SO ₂ , NO ₂ , CO & O ₂ .
B. Pulp & Paper Mill (process steam)	2 boilers 270 MMBtu/hr ea. Combined steam 390,000 pph	TR, rr, pit	75,000	Foster Wheeler spreader stoker, travelling grate	Multicyclone with ESP CEMS for NO _x , CO, SO _x
D. Power Plant	3 boilers; 175,000 pph steam each; 50 MW total	HW, CW, MR pit, pit	750,000	Zurn spreader stoker with travelling grate	Multicyclone with ESP system
E. Power Plant	2 boilers; combined steam 427,520 pph; 49 MW total	AG, CM*, (TR)	400,000	EPI circulating fluidized bed	Cyclone, baghouse filter, air preheater, Ammonia and limestone injection, 5 flue gas monitors
F. Power Plant	2 Boilers at 200,000 pph each	MR, HW, CW	170,000	Babcock & Wilcox spreader stoker	Multi-tube mechanical collector Electric gravel bed filter
G. Power Plant	435,000 pph combined steam 50 MW electric generation	HW, CW	350,000	Combustion Engineering spreader stoker, travelling grate	ESP with mechanical collector
H. Power Plant	50 MW 300 MMBtu/hr	HW, CW pit	150-450,000	Zurn spreader stoker	ESP with mechanical collector CEM for opacity, NO _x , CO ₂ & O ₂ .
I. Pulp & Paperboard (process steam and dryers)	1,180 MMBtu/hr heat 700,000 pph combined steam 30 MW electric (woodfuel portion)	HW, MR	233,000	6 Erie City fixed grate 1 Foster Wheeler travelling grate	Wet scrubbers with ESP
J. Power Plant	3 boilers 360 MMBtu/hr ea. 2 steam turbines, 45 MW ea.	HW, MR, RDF, CW, (TR), pit	356,000 (per boiler)	3 spreader stokers	Multicyclone with ESP SNCR urea injection

(a) A key to symbols used in this column is found in Notes to Tables following Table 6-7

(b) This column represents the portion of wood fuel consumption only. For price and fuel supply reasons, large wood-fired power plants frequently co-fire wood with coal, natural gas, oil, or refuse derived fuel (RDF).

Table 6-6. Examples of technologies used at "medium" size waste wood combustion systems (10-100 MMBtu)^a.

TYPE OF FACILITY	SIZE	BIO MASS FUELS PERMITTED (a)	WOOD FUEL USED (ton/year)(b)	COMBUSTION SYSTEM	TYPE OF POLLUTION CONTROLS
A. Industrial Cogeneration	72,000 pph steam district heating	DW,CW,MR,TR ply,prt,pnt,plt	50,000	KMW 2-stage, inclined step-grate, pile burner (50,000 pph) Dutch Oven pile burner (12,000 pph)	Flue gas afterburner
B. Industrial	20 MMBtu/hr, 12,800 pph steam	HW, MR frn,ply	9,000	IBC underfeed stoker IBC 400 horsepower, two-pass boiler	Multicyclone, mechanical collector
D. Industrial	40 MMBtu/hr furnace 31 MMBtu/hr furnace	HW, MR test on ply	14,000 19,000	McConnell grate burner Konus underfeed stoker	Cyclone, multicyclone, electric gravel bed Cyclone and fabric filter, CEM for opacity
E. Industrial Cogeneration	100,000 pph steam 7.5 MW electric	AG, MR, UW, HW ply,plt		Yank Energy fluidized bed Wickes boiler	Multicyclone, ESP, ammonia injection, CEM
F. Industrial	45 MMBtu/hr 32,000 pph steam	MR ply,prt	22,000	Coen suspension burner Pacific Marion firetube boiler	Multicyclone
G. Power Plant	Two 39 MMBtu/hr, 60,000 pph steam, 3 MW electric	UW,CW,DW,MR,HW ply,prt,pnt,plt,frn	36,000	Huret underfeed stoker Huret firetube boiler	Multicyclone
H. Industrial Process Steam	27 MMBtu/hr 20,000 pph at 175 psig	MR plt,frn		Bigelow fixed grate spreader stoker with HRT boiler	Multicyclone, fly ash reinjection
I. Industrial Cogeneration	40,000 pph	HW, MR coal/star sludge	25,000 wood 60 sludge	Wellons Fuel Cell, water-cooled grates, firetube boiler	Multicyclone, CEM for opacity, and CO
J. Industrial	48.6 MMBtu/hr	MR, HW, creosote sludge rr test	24,000 wood 100 sludge	Babcock & Wilcox spreader stoker	2 multicyclones, CEM for opacity

(a) A key to symbols used in this column is found in Notes to Tables following Table 6-7

(b) This column represents the portion of wood fuel consumption only. For price and fuel supply reasons, medium size wood-fired facilities may co-fire wood with coal, natural gas, oil, or refuse derived fuel (RDF).

Table 6-7. Examples of technologies used at "small" waste wood combustion systems (<10 MMBtu).

TYPE OF FACILITY	SIZE	PERMITTED BIOMASS FUELS	WOOD FUEL USED (tons/year)(a)	COMBUSTION SYSTEM	TYPE OF POLLUTION CONTROLS
A. Industrial	10 MMBtu/hr	MR, HW	3500	Sylva 2-stage spreader stoker, inclined-reciprocating grates	Cyclone
B. Industrial	10 MMBtu/hr	MR	NA	York-Shipley fluidized bed	Zurn multicyclone
D. Industrial Heat	1.3 MMBtu/hr	MR	500	G & S Mills model #K42 with mechanical stoker	
E. Industrial	219 horsepower steam load	MR	2,500 (dry tons)	Bigelow pile burner	
F. Industrial	3.5 MMBtu/hr 150 HP steam	MR	NA	Erie City fixed grate boiler	
G. Industrial	6 MMBtu/hr 6,000 pph steam	HW, MR	3,000 (dry tons)	Suspension gasifier with Cleaver Brooks boiler	Flash collector
H. Industrial	9 MMBtu/hr 10,000 pph steam	MR firn	15,000	Wellons fuel cell with Erie watertube boiler	Multicyclone
I. Industrial	3,150 pph steam	MR firn	5,000	Dutch Oven with Erie City fire tube	
J. Industrial	4,300 pph steam	HW	5,300	Energy Resource System pneumatic spreader stoker with pinhole grate	

(a) A key to symbols used in this column is found in Notes to Tables following this Table.
NA Not available

NOTES to Tables 6-5, 6-6, and 6-7

The following is a key to the wood fuel types in the tables. Symbols followed by a "*" indicate waste wood terms actually used in the facility permit. Terms in upper case, such as "CW" indicate general waste wood types acceptable for combustion. Terms in lower case, such as "rr" indicate specific types of "treated" waste wood or potentially "dirty" wood that are acceptable for combustion.

AG = Agricultural wastes	HW = Harvested waste wood	rr = Creosote railroad ties or utility poles
UW = "Urban" waste wood	DW = Demolition waste wood	ply = plywood or laminated waste wood
CM = "Commercial" Wood wastes	CW = Construction waste wood	prt = particleboard or flakeboard
TR = "Treated" waste wood	MR = Mill residue waste wood (from manufacturing)	pnt = painted wood
RDF = Refuse derived fuel (e.g. pellets or fluff)		plt = pallets or shipping crates

quality wood fuel. In-bed pollution controls include a limestone injection system with a pneumatic 0.75 ton/hr metering system and blower, and an Exxon thermal de-NO_x system.

Feedwater is preheated to 400° F and supplied to in-bed fin tubes and non-finned vapor space tubes in the combustor unit. According to plant operators, the finning of boiler tubes helps minimize tube erosion from the fluidization process. Flue gases pass into a waste heat boiler and then into a vertical screen tub section where the gas cools approximately 400° to about 1,350° F. Due to problems at similar units, this facility was re-equipped with vertical superheater tubes in the boiler unit. Earlier units reported problems with slag bridging in horizontal tubes. In addition, soot blowers were installed to control ash buildup on the boiler tubes. From the boiler, gas passes through a secondary economizer, multicyclone, and primary economizer. Flue gas is then mixed with preheated air, and passed through a baghouse for final particulate control. The stack exit temperature is approximately 320° F.

Design criteria for acceptable fuels allows a moisture content between 8.7 percent and 30 percent, although acceptable test ranges are up to 50 percent. The desired composite fuel moisture is from 20 to 30 percent. Fuel must be sized between one-quarter inch and four inches and the composite fuel ash concentration should not exceed 3 percent. Processed ("urban") waste wood must consist of no more than 20 percent moisture and ash content is expected to be no more than 2.5 percent by weight. Specific permit requirements include limits on fuel content of nitrogen and sulfur based on higher heating value standards. The nitrogen standard is 0.91 lbs/MMBtu. The sulfur limit is 0.25 lbs/MMBtu.

Fuel handling equipment consists of several components. Two 60-ton truck dumping platforms are used to receive incoming fuel. Two fuel receiving hoppers consist of a 2,000 cubic foot covered hopper with a live-chain bottom discharger and a similar 4,800 cubic foot hopper. The hoppers are followed by a disk scalping screen, 250 horsepower swing-type hammermill, and belt-type magnet. The fuel handling area also includes an extensive dust ventilation system connected to several fabric filters.

Table 6-8. Independent power plants that burn waste wood in the study area^{a,b}.

CALIFORNIA			NEW YORK	NEW BRUNSWICK, CANADA
Auberry Energy Auberry, CA	Honey Lake Power Wendel, CA	Sierra Pacific Ind. Hayfork, CA	Hubbard Sand & Gravel Bayshore, NY	University of New Brunswick Fredericton, N.B.
Big Valley Lumber Co. Bieber, CA	Hudson Lumber Anderson, CA	Sierra Pacific Ind. Loyalton, CA	Diamond Energy Lyonsdale, NY	<u>FACILITIES PLANNED OR IN THE PERMITTING PROCESS (c)</u>
Blue Diamond Growers Cogen Plant Sacramento, CA	Imperial Resource Recovery Project El Centro, CA	Sierra Pacific Ind. Quincy, CA	KES Chateaugay Chateaugay, NY	Bio-Gen Systems Torrington, CT
Burney Mountain Power Burney, CA	Koppers Industries Oroville, CA	Sierra Pacific Ind. Susanville, CA	<u>NORTH CAROLINA</u>	ARS Killingly Killingly, CT
Chowchilla Biomass Power Plant I Chowchilla, CA	Lincoln Cogeneration Lincoln, CA	Signal Energy Systems Anderson, CA	Craven County Wood Energy New Bern, N.C.	Uniroyal Naugatuck, CT
Chowchilla Biomass Power Plant II Chowchilla, CA	Louisiana Pacific Samoa, CA	Soledad Energy Soledad, CA	<u>VERMONT</u>	Atlantic Energy Systems, Inc. Geddes, NY
Collins Pine Company Project Chester, CA	Madera Power Plant (CAPCO) Madera, CA	Susanville Forest Prod. Susanville, CA	Burlington Electric McNeil Station Burlington, VT	Atlantic Energy Systems, Inc. Rome, NY
Clomac Mecca Project (under constr.) Mecca, CA	Manell Cogeneration Manell, CA	Tracy Biomass Plant Tracy, CA	Ryegate Energy East Ryegate, VT	Diamond Energy Lyonsdale, NY
Delano Energy Co., Inc. Delano, CA	Mendota Biomass Power Ltd. Mendota, CA	Ultrapower/Blue Lake Blue Lake, CA	<u>VIRGINIA</u>	Enerfore Sussex, N.B.
Dinuba Energy, Inc. Dinuba, CA	Mt. Lassen Power Westwood, CA	Ultrapower Chinese Camp, CA	Chesapeake Corp. Westpoint, VA	Enerfore Kedgwick, N.B.
El Nido Biomass Power Plant El Nido, CA	North Fork Energy North Fork, CA	Ultrapower/Fresno Malaga, CA	Stone Container Corp. Hopewell, VA	
Fairhaven, Power Co. Eureka, CA	Pacific Lumber Co. Scotia, CA	Ultrapower/Rocklin Rocklin, CA	Westvaco Covington, VA	
Fairhaven Power Co. Eureka, CA	Pacific Oroville Power Oroville, CA	Woodland Biomass Power Ltd. Woodland, CA	<u>WASHINGTON</u>	
Fibreboard Corp. Standard, CA	Redding Power Delmarva Redding, CA	<u>CONNECTICUT</u>	Washington Water Power Co. Kettle Falls, WA	
Georgia Pacific Corp. Fort Bragg, CA	Sierra Pacific Ind. Burney, CA	No currently permitted independent wood-fired power plants	<u>WISCONSIN</u>	
			Northern States Power Co. Eau Claire, WI	
			Northern States Power Co. Ashland, WI	

NOTES TO TABLE 6-8

- (a) This table only includes major wood-fired power plants and cogeneration facilities that utilize processed waste wood, mill residue, and agricultural residue in addition to harvested wood. It does not include numerous small-and medium-sized industrial facilities that burn primarily mill residue (obtained on-site) and harvested wood.
- (b) All facilities on this list are known to burn at least "clean" waste wood. Some also burn varying amounts of processed waste wood containing treated wood.
- (c) These facilities are in the planning and/or permitting process. Similar to operating facilities, the interest by proposed facilities to fuel containing treated wood varies by the types of facility, permit standards, and available fuel resources.

6.7.2 Underfeed Stoker Combustion System

This facility is permitted as a stationary combustion unit. It produces 3.2 MW of gross power and slightly less than 3 MW net. The balance is used on-site. The furnace design is an underfeed fixed grate type with a combination ("hybrid") watertube and firetube boiler system. Each boiler is rated at 39 MMBtu/hr and 30,000 lbs/hour steam. Current total steaming capacity is 45,000 lbs./hr at 580°F superheated. The furnace temperature is typically 1,800°F with stack gas exit temperatures of approximately 300°F.

Approximately 80 percent of the waste wood fuel is from dry, mixed urban wood sources. The wood has an estimated average moisture content of 10 to 15 percent. The remaining 20 percent of waste wood is green solid wood received from landscaping, landclearing, and residential yard wastes.

This facility has an extensive fuel processing system adjacent to the combustion facility. The facility operates both as a disposal site for waste wood haulers and as an independent power producer. The facility is permitted as a solid waste management facility for the wood processing line; the combustion unit is permitted as a small stationary source under air quality rules. The solid waste permit is necessary since the facility receives mixed sources of construction and demolition debris, and wood waste from 30 to 40 regional haulers. The advantage of the processing line is that this facility has a high level of control over fuel preparation.

The processing system is capable of producing 15 to 20 tons per hour and consists of two main processing lines. All material starts on a four foot wide conveyor belt that leads to a 3/4-inch mesh shaker screen. From the shaker screen, oversize material larger than six inches is sent to a processing line that starts at a bi-level picking table. Undersize material is sent to another processing line that begins with a trommel screen.

The picking table consists of two stations. The first and upper level uses four people that sort for painted material, rock, rubble, metal, and other non-wood debris. The second lower level is operated by two people and provides an additional level of sorting for non-wood material sorting. From the picking station, wood moves up an inclined conveyor and drops into a 200 horsepower hammermill shredder. From the hammermill, wood is carried up an inclined conveyor that has a magnetic head pulley at the end. The magnet screens ferrous metal before the wood drops onto a disk screen. From the disk screen, oversized wood greater than three inches is conveyed to the trommel screen, while smaller material is conveyed to the fuel pile.

The trommel screen has 1/4-inch mesh for separating dirt and wood fines. This material is blended with fly ash, composted, and sold as potting soil. Oversized material from the trommel screen travels up an inclined conveyor that has a magnetic head pulley and then onto a disc screen with 5/8-inch separation. Undersize material from the disk screen goes directly to the fuel pile. Oversized material drops into a smaller 100 horsepower hammermill for final sizing, before being added to the fuel pile.

A front-end loader starts the fuel delivery line by loading wood onto a slow-moving walking floor conveyor. Whereas the processing lines and fuel pile are outside and open to weather, the walking floor and the rest of the combustion system is enclosed. The walking floor meters fuel onto Conveyor #1 which has another magnetic head pulley at the end. Wood material passes through one more disk screen to catch any pieces of long wood scraps, brick, or non-ferrous metal missed at earlier processing stages. After the disk screen, wood material is loaded onto Conveyor #2 which in turn feeds a two-foot wide horizontal auger screw.

The auger passes over two fuel hopper bins at a fuel feed rate of roughly four to six tons per hour. Each bin, however, holds only 500 pounds of fuel. When the first bin is topped off, fuel is automatically carried by the auger to the second bin. If both bins are full, then excess fuel is placed on a conveyor to be returned to Conveyor #1. The fuel bins are negatively inclined to prevent bridging. Each bin feeds an eight-inch metering screw which in turn feeds two underfeed stoker screws for each boiler. There have been problems with wear on the fuel augers from fine dirt and sand residue. However, the facility has made several adjustments considered to be proprietary to compensate for this problem.

A unique aspect of this facility is the high proportion of processed wood used. Plant operators frequently spray water on the fuel, especially on drier wood in the summer, as it approaches the stoker screws. Wetting fuel increases the moisture content slightly and cools the furnace temperature. This is done to prevent flashing and clinker formation in the bottom ash. Although the current flame temperature is around 1,800°F, plant operators would like to lower the temperature to around 1500 to 1600°F.

Bottom ash and clinkers are raked off the fixed grate after they build up to approximately four to five inches on the bed. Depending on the dirt content of the fuel, the bed may need to be raked once a day or as much as three times a day. The bottom ash is then sent to a nearby concrete crushing facility to be recycled as road base material. Overall fly and bottom ash production is four to six cubic yards per day.

There have been some problems with undue expansion of the waterwalls in the superheater and performance of the stack gas economizers. It is unclear whether these problems are attributed to system design or system operation. However, plant operators believe the problems are not affected by the type of fuel burned. As a result, the boilers run at about 60 percent capacity and overall thermal efficiency is lower than the designed plant capacity.

Pollution control systems consist of a multicyclone particulate separator. The facility does not use, nor is it required to use, any in-furnace combustion controls. The facility plans to install an electrostatic precipitator within the next two years.

Overall, plant operators are confident of their ability to burn fuel from mixed urban wood sources, provided that it is properly prepared for combustion.

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7.0 CHEMICAL AND PHYSICAL PROPERTIES OF WASTE WOODS AND THEIR ASHES

7.1 Introduction

This chapter describes the chemical and physical properties of waste woods and the ash produced from the combustion of these materials. The purpose of this chapter is to quantify the properties of waste wood materials. To date there has been very little information on the chemical and physical properties of waste woods in the technical literature. There has been some information on "clean" wood but it is also extremely limited and is not completely applicable to waste wood combustion. Since there is increased interest in using waste wood for the production of energy it has become extremely important to understand its properties and to be able to predict the environmental impact from its burning. The type of information gathered in this study is needed to evaluate the emission of trace metals from the combustion of waste wood and to understand the metal contaminants in the ash. Table 7-1 is a summary of wood and ash analyses performed for this study. The waste wood data collected and reported here can be used by developers, regulators and other interested parties:

- In evaluating combustion and pollution control alternatives;
- In predicting air pollution emissions and ash properties from the combustion of waste woods and;
- In evaluating the environmental impacts due to the combustion of waste woods.

This study used random sampling techniques to obtain waste wood and ash samples from six waste wood processing and two combustion facilities located in the United States and Canada that employ various processing and combustion approaches. These samples were then ground to a fine size, blended and analyzed to obtain information about their chemical and physical properties. Ash samples were obtained from combustion facilities and by laboratory ashing of the collected waste wood samples. This chapter and its associated Appendices discusses:

- How the waste wood and ash samples were collected.
- The types of analyses performed.
- The analytical results and their variance and ranges.
- The statistical significance of the analytical data.
- Recommended values for development studies.
- Recommendations on how to limit variability of waste wood properties.
- Recommendations for future data collection.
- The data collected are further evaluated in Chapter 8 to assess their environmental impact and to predict whether waste wood can be properly combusted and still meet environmental regulatory standards.

The waste wood samples were collected from various types of wood processing facilities. By reviewing the descriptions of the processors and evaluating the data collected at each individual facility the reader can draw some

Table 7-1. Wood and Ash Analyses.

ANALYSIS

ABBREVIATED NAME

WOOD ANALYSIS

<u>Ultimate/Proximate (w/Cl)</u> Determination of total water, ash, Btu, volatile, fixed carbon, sulfur, total carbon, H, N, O, Cl Alkalies as NaO	Ult/Prox
<u>Total Elemental Metals (dry)</u> Include As, Ba, Cd, Cr, Pb, Ni, Hg, Zn, Cu, Ti	Total Met
<u>Total Elemental Metals For Five Metals (dry)</u> Include As, Pb, Zn, Ti, Cr	5 Met
<u>TCLP (Metals and Organics)</u> Analysis includes ZHE and rotary extraction	TCLP Total
<u>TCLP (Metals Only)</u>	TCLP Met
<u>Phenols (Method 8270 or 8040)</u> Phenols and chlorophenols	Phenols

ASH ANALYSIS

<u>Mineral Analysis</u> Includes oxides of Si, Al, Ti, Fe, Ca, Mg, K, Na, S, P Pb, Zn	Min Anal
<u>TCLP (Metals and Organics)</u>	TCLP Total
<u>TCLP (Metals Only)</u>	TCLP Met
<u>Total Elemental Metals</u> Same metals as for wood	Ash Metals

conclusion based upon the types of waste woods processed and the processing methods used. This information will be helpful in designing future waste wood processing systems and in understanding the quality of waste wood fuel which could be produced.

Homogeneous waste wood samples were also collected and analyzed in this study. Some of these samples were collected from facilities burning these homogeneous

materials. In those instances, ash samples were also collected and studied. The following types of homogeneous waste woods were collected and analyzed:

- plywood;
- CCA pressure-treated wood;
- particle board;
- creosote-treated wood;
- furniture scraps; and
- laminated woods.

This chapter defines the scope of the testing program, identifies the types of waste wood that were tested from sources characterized in Chapters 5 and 6, describes the methods used to obtain and analyze samples, and provides a statistical summary of the results. This chapter is organized into the following sections.

- Section 7.2 describes the development of a sampling plan and the statistical treatment of the data.
- Section 7.3 provides an overview of the sampling and analysis plan, specifying the sample sizes and sources of each sample unit.
- Section 7.4 is a detailed description of the sampling methodology used to obtain the wood and ash samples.
- Section 7.5 describes the analytical methods used by the laboratories to determine the wood and ash characteristics.
- Section 7.6 presents the sampling results and the conclusions that can be drawn from them. This section also details the concerns about the variability of the data, test repeatability, and differences in analytical methods.

7.1.1 Key Issues

- What are the major contaminants in waste woods and homogeneous waste wood types?
- What is the variability in the level of contaminants?
- What is a maximum level of contamination?
- What is a realistic contamination level to use for permitting facilities and evaluating environmental concerns?

7.1.2 Key Findings

- Data on energy values, chemical and minerals analyses and concentration of metal contaminants in "clean" and "treated" wood and its ashes.
- Data on energy values, chemical and minerals analyses and concentration of metal contaminants in homogeneous wood types and their ashes.

- The variability of the preceding physical and chemical parameters within the waste wood fuel stream at each specific test site and among the various sites tested. These parameters and their variability are important factors in the design of waste wood processors and combustion facilities.
- Suggested values of these physical and chemical parameters to be used in estimating a waste wood combustion system's environmental emissions.

7.2 Statistical Sampling Techniques

A major objective of the project was to estimate various chemical and physical properties of processed and homogeneous waste woods and to establish their variance and mean, within a prescribed level of precision. These waste wood properties were to be estimated from operating facilities throughout the United States and Canada. Therefore, the various analytical data obtained during this study was reviewed to determine:

- maximum and minimum levels;
- mean, median and log normal mean values; and
- confidence levels.

The aim of the study was to determine chemical and physical parameters and to use that data to establish guidelines for predicting fuel parameters from:

- any waste wood processing facility without regard to the type of waste wood received and the processing methods employed, and
- waste processors preparing a higher quality wood fuel due to quality control of the wood received at the facility or to the types of processing used to remove contaminated wood streams.

Another major goal was to determine the variance of wood and ash properties among and within individual facilities to assess the effect of site-specific factors on product quality by treating each facility as a distinct "population" and applying a uniform statistical sampling method. Sufficient samples were collected to estimate confidence levels of the analyzed properties.

Waste wood is a bulk material, compared to a group of unique, discrete units. Therefore, the physical methods and statistical aspects of bulk materials sampling were used (Bicking, 1967), (Duncan, 1974), (Schilling, 1982). The wood and ash is classified as "Type A" materials, a term referring to bulk material on a conveyor or pile which is not composed of distinguishable segments. For sampling of Type A bulk material, sample units must be created. ("Type B" bulk materials are segmented into primary sample units, such as bags or boxes).

Several specific terms used throughout this chapter are defined as follows:

- Lot: The mass of bulk material under study. In this study, the entire stockpile of a processor or combustor, plus the production during the sampling day is the lot. Stockpile storage capacities are usually several days.
- Segment, and Primary Sample Unit: A segment is any specifically demarked portion of the lot, actual or

hypothetical. Segment size depends on the process and material. For this project, a segment is considered to be nominally equal to the volume of one half to two truckloads at a processing facility. The primary sample unit is a sample of a segment. Primary sample units were analyzed to determine variance within the lot (variance between segments).

- Increment, or Secondary Sample Unit: Those portions of the lot initially taken into the sample. In this study, increments were drawn from segments and composited into primary sample units. Increments were also analyzed separately to estimate variance within segments and provide additional data points for statistical averaging.
- Reduction: The process by which a sample is split for subsequent analysis. Increments were reduced so that a portion was analyzed individually and another was composited with other increments into a primary sample unit. Some analyzed portions of increments were reduced for duplicate analyses. Primary sample units and composites of primary sample units were reduced for laboratory analysis.
- Sample vs. Sample Unit: A sample is comprised of individual sample units, each of which are analyzed for a particular characteristic. Sample size refers to the number of sample units available for a characteristic at each site.

A schematic representation of these terms, as they apply to the current project, is provided in Figure 7-1.

Since it was physically impossible to sample the wood stock piles at different depths no special stratified sampling techniques were used. It is probable, however, that the stockpiles are not homogeneous; different segments, and different increments, probably have varying characteristics due to variations in the quality of wastes from which the processed material is derived. Most processors do not deliberately mix up wood fuel in the stockpile, but rather form piles sequentially so that wood from a series of at least two or three waste trucks forms one pile. The sampling plan for stockpile sampling was designed to identify heterogeneity. In addition, production samples from the line were taken to identify the characteristics of the wood produced during a typical sampling day.

7.2.1 Statistical Sampling Methods

Careful attention was given to the sampling methods used to insure the validity of the data. Great care was taken to develop a plan that revolved around bulk materials sampling. A bulk sampling process consists of the following steps (Bicking, 1967):

1. Collection of a relatively large amount of material in a systematic manner from the lot;
2. Selection from this large amount by subdividing (e.g., quartering) enough material of the same average composition for the required analytical test; and
3. Crushing, grinding and mixing the collected material (if necessary) for subsequent analysis.

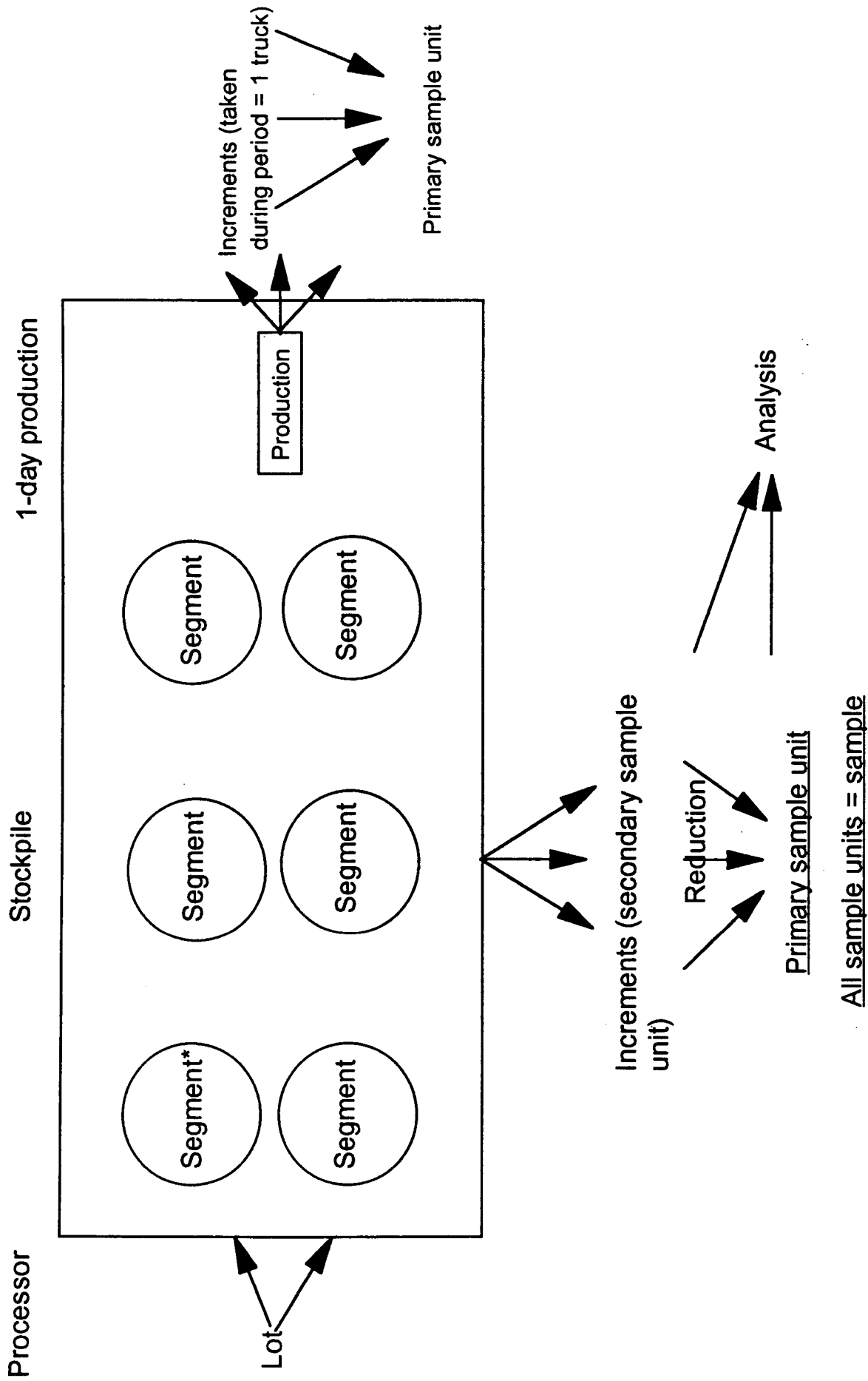


Figure 7-1. Sampling Terminology.

* One truck

The concept of random sample selection is critical in this sampling plan. At each incremental sampling location a relatively large sample was collected compared to the amount necessary for analysis. Rather than taking a grab sample from this increment and, thus, possibly biasing subsequent tests, samples were reduced by a method known as "quartering." This is described in greater detail later in Appendix F, but generally consists of taking the available material and dividing it into four equal parts. Two opposite parts are then combined, thoroughly mixed, and quartered again. This process is continued by dividing samples in half in a random fashion until the proper amount necessary for analysis remains. The bulk of the material sampled in this project consisted of hogged or shredded wood chips of two to four inches nominal size. To prevent any analysis from representing only one or two pieces of wood, quartering was halted when the sample was reduced to one gallon of material which was then milled into quarter-inch splinters or smaller particle size before being reduced further for analysis.

7.2.2 Statistical Concepts

To understand the significance of the data from this project, it is necessary to understand the basic difference between normal and skewed data distribution. A normal distribution, or "bell curve," is defined by the mean and standard deviation of a data set. The mean in this case, is an arithmetic average of the data collected. The normal distribution, as shown in Figure 7-2, is a curve symmetrical about the mean. For every number of samples that fall a certain distance below the mean an equal number of samples should register that distance above the mean. In an ideal normal distribution the arithmetic mean and the median of the data fall on the same value. The median is the point where 50 percent of the data points fall to either side. Another property of the normal distribution is that 68 percent of all data are within ± 1 standard deviation from the mean and that 95 percent of all the data fall within ± 2 standard deviations. It is possible, if a sample data set follows a normal distribution, to calculate confidence intervals about the mean. A confidence interval for the mean is a range of values in which it is believed the true mean of the population lies. Thus, if a 95 percent confidence interval is determined, then the mean of any similar random sample, from the sample population would have a value within that range 95 percent of the time. This can also be said of the median.

When dealing with environmental concerns, emphasis must also be placed on knowing the "maximum average" value rather than the average or minimum value. Therefore in this project it was more appropriate to determine the upper confidence interval. This upper bound value was determined, within a fixed confidence level of the calculated mean.

Unfortunately, for heterogeneous fuels a lognormal distribution of their properties is more commonly seen than a normal distribution. Lognormal distributions are skewed to the left with some outlying data points producing a diminishing tail to the right (Figure 7-2) because different contaminant concentrations are associated with different waste wood fractions (see Section 7-4). Therefore, a variation in the concentrations of different waste wood streams will produce widely differing contaminant levels. In a lognormal population, the arithmetic mean (sum of the values divided by the number of values) can not be used to estimate the population's true average unless the number of samples taken is very large. A better estimate of the true mean is the median of the data. As before, with normal distributions, confidence intervals can be calculated for lognormally distributed data sets. The median of a lognormal distribution may be estimated by the geometric mean. Therefore, in evaluating emissions from wood burning facilities the geometric mean of the various contaminants should more closely represent true average operating conditions.

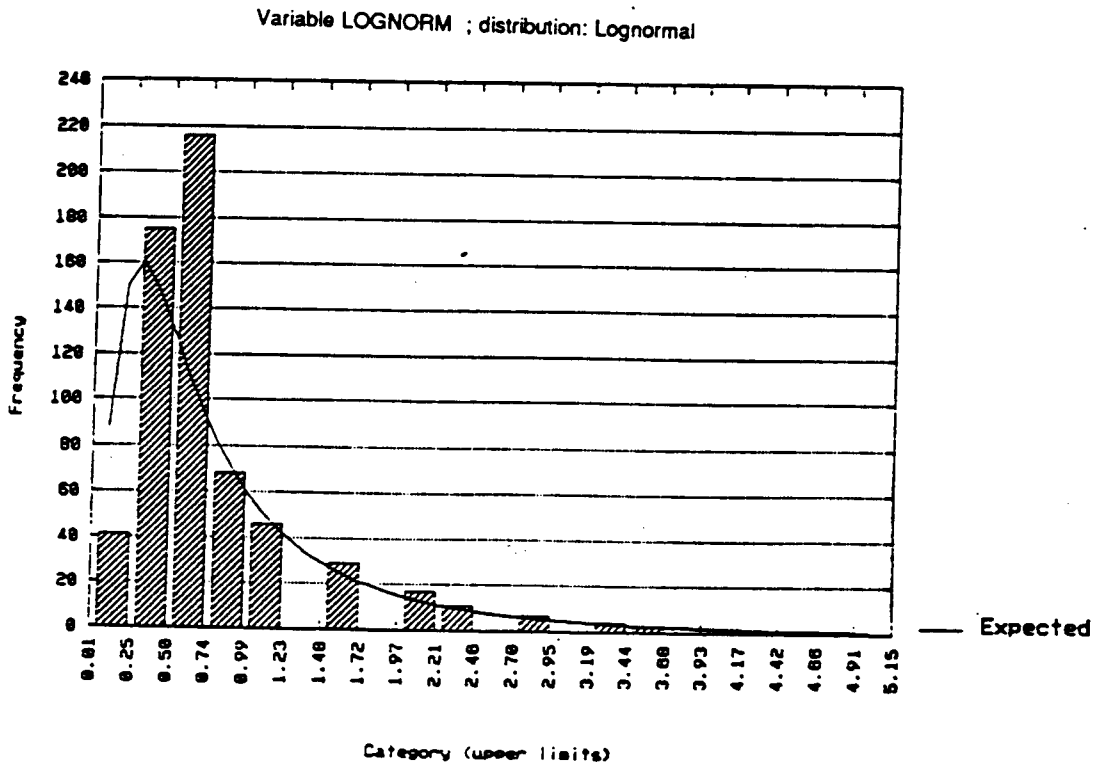
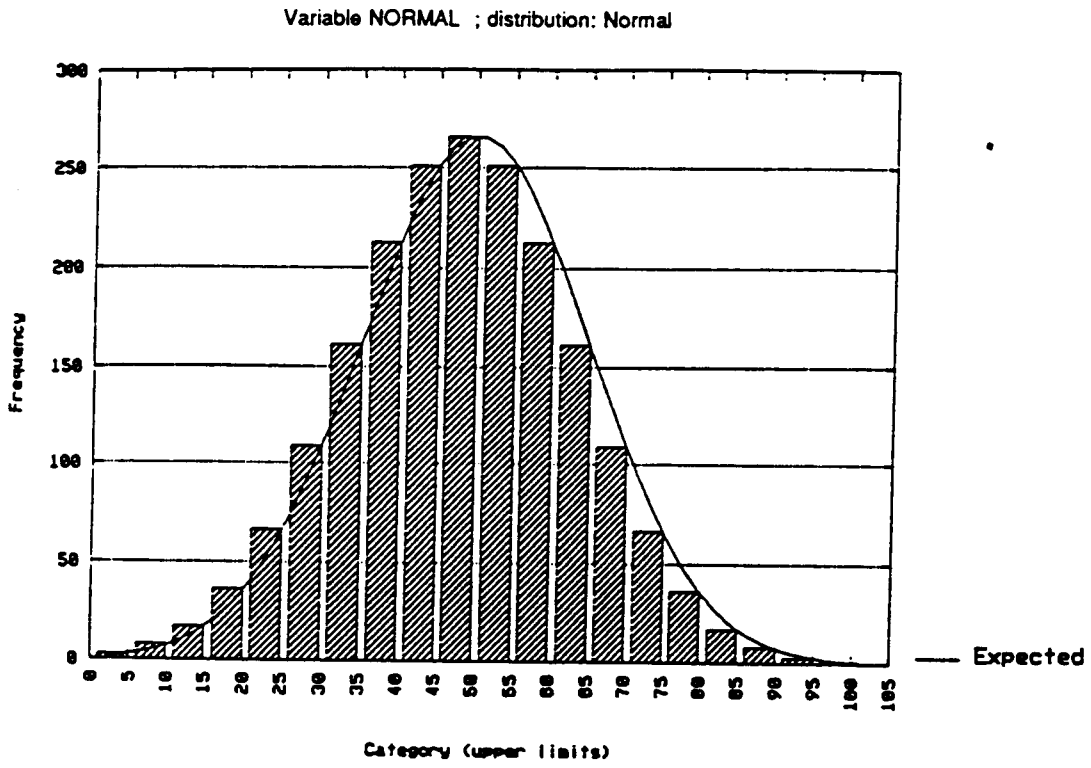


Figure 7-2. Normal vs. Lognormal Distributions.

In this study it was determined that the bulk properties of wood such as ultimate and proximate, BTU value carbon, hydrogen, oxygen analysis followed a normal distribution, whereas the properties associated with contaminants such as metals, chlorine, sulfur, ash and moisture followed a lognormal distribution.

7.2.3 Compositing of Samples

The more samples of a population, the greater the accuracy of any resulting statistical calculations; however, it is not always possible or cost effective to analyze many samples especially when dealing with a very large population. This problem is further compounded when very small sample quantities are analyzed and small particles of contaminant can result in large analytical differences. To alleviate the cost of analyzing every sample taken while still generating reasonable results, it was appropriate to composite samples before analysis.

In the procedures established for gathering samples, the lot or population of each facility was divided into eight segments. From each of these segments, five or more incremental samples were taken. In the case of certain metal contaminants (As, Cr, Pb, Ti, and Zn) the increment samples were analyzed individually. Other increment samples were randomly reduced in size and combined with additional increments from the same segment. This new sample was used to estimate the average characteristics of that segment. A comparison of incremental samples and their composites, for the same metals, indicated that the compositing procedure more accurately predicted fuel properties. As discussed later in this chapter, the data confirms that when additional samples are taken from a population, the resulting distribution of the data more closely fits a normal distribution. The composite samples exhibited more of a normal distribution than their corresponding increments and were more representative of their true value and of the facilities' design parameters.

7.3 General Sampling and Analysis Plan

7.3.1 Homogeneous Wood Types

Six homogeneous wood product categories were sampled and analyzed to determine the physical and chemical characteristics of common wood products.

At least one sample from each category was analyzed for ultimate/proximate, chemical composition, minerals, total metals and phenols. In cases where actual furnace ash was available it was analyzed.

1. Plywood - Scraps from a manufacturer of plywood were received along with an ash sample from the manufacturer's combustor. An approximate five-pound sample of wood was ground and analyzed.
2. Pressure-treated Lumber - Two samples of clean, unweathered pressure-treated wood and a sample of fire-treated/pressure-treated wood were ground and analyzed. A TCLP test was run on one sample of each type of treated wood.
3. Particle Board - Four samples of particle board were ground and analyzed. Each sample consisted of approximately five pounds of clean cut boards. One was a sample of southern hardwoods; the others were samples of southern pine.

4. Creosote Treated - Samples of used railroad ties and telephone poles were collected and analyzed separately. Ten railroad ties from 30 to 50 years old were sampled. The condition of the ties varied from rotting to no structural disintegration. From 10 to 15 telephones were hogged for this project. Approximately 100 pounds of chips were collected and quartered into a ten-pound sample for analysis. A complete TCLP was performed on the ground wood to determine the effects of creosote-treated woods on landfills.
5. Furniture Manufacturer Scrap - Two different samples of scrap generated during the manufacture of furniture were analyzed. The first sample consisted of birch wood sheets glued together to form a solid wood core. The second consisted of sawdust from a combination of hardwoods, laminated woods, and wood composites. An ash sample from the facility burning these materials was also analyzed.
6. Laminated Wood Panel Products - Small samples of wood and ash were received from a plant burning laminated woods. There was not enough material to run all of the analyses. An ultimate/proximate analysis and a total metals analysis were performed on the wood while minerals analysis and a total metals analysis were performed on the ash.

7.3.2 Waste Wood Processors

Six waste wood processors were sampled as part of the project. Random stockpile samples indicative of normal processing activities were taken from each facility. Also from three of the facilities, samples were taken from conveyors to obtain information on wood produced during the sampling day. The samples were taken using bulk material sampling methods previously discussed.

The analyses performed on each sample collected is described in Figure 7-3 which outlines the stock pile and conveyor sampling methods. When conveyor sampling was not possible, additional samples were taken from the stockpiles. For the analyses that required ash samples, slight variations to the sampling method had to be made. Since wood is 2 percent to 10 percent ash, a much larger sample of wood had to be collected to generate appropriate quantities of ash for analysis. It proved more feasible to collect these samples from a combination of several segments instead of one larger segment, a modification discussed in Section 7-3.

When possible a total of eight primary sampling segments were obtained from each processor, six from the stockpiles and two from the conveyors. Each primary unit is a composite of increments from one segment. For stockpile samples, a segment is defined as the volume of wood equivalent to one-half to two truckloads (or approximately 45 to 180 cubic yards). For conveyor samples, a segment is also defined as the volume of wood in one-half to two truckloads, translated into a corresponding operating time. Increments were taken every 15 minutes and composited into one primary sampling unit with portions of the increments saved for further incremental analysis.

The analysis method described as "five metals" is an elemental analysis for five selected metals. The "five metals" analyses were used to limit the number of elemental analyses and still provide a large data pool for subsequent analysis of the most important metals. The "five metals" analyses were done on 16 increments from each of five wood processors and on four increments from another. The five metals of particular interest are arsenic, lead, zinc, chromium, and titanium.

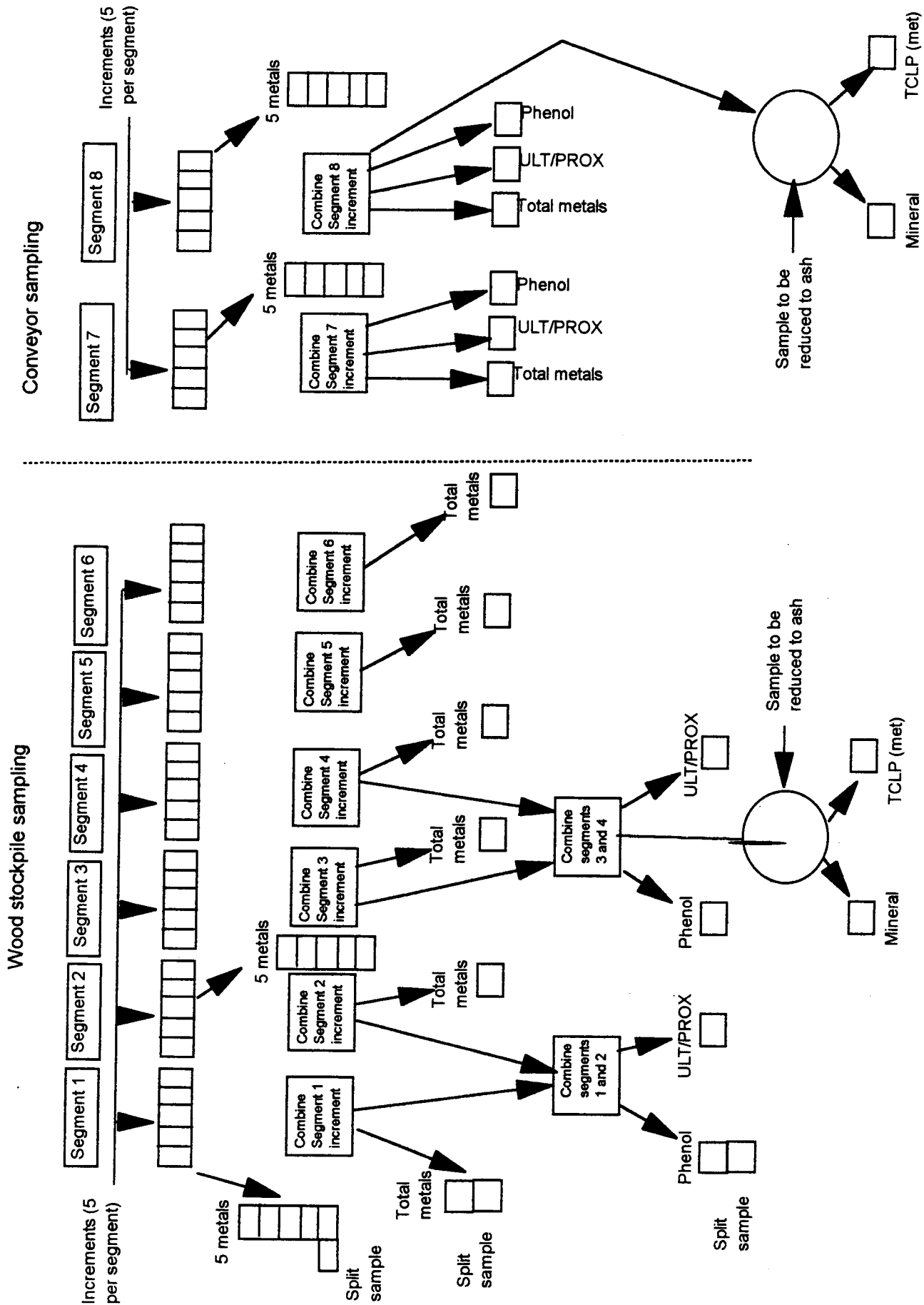


Figure 7-3. Wood stockpile sampling/conveyor sampling.

- Arsenic can be used to indicate the presence of pressure-treated wood, which is commonly impregnated with arsenical water-soluble preservatives.

Arsenic is also an indicator of biocides and herbicides used in wood treatments.

- Chromium is a prime component of water-soluble preservatives and yellow paints.
- Lead is an indicator of lead-based paint.
- Titanium is a primary component of modern paint and usually is not present in any other waste wood treatment contaminant.
- Zinc is a prime component of fire-retardation treatments and of white paints.

A total elemental analysis for 11 metals, the "five metals" and barium, cadmium, copper, mercury, nickel, and silver were also undertaken. As seen in Figure 7-3, the total number of primary sample units analyzed for "total metals" is eight. Segments 1, 2, 7, and 8 had "total metals" analyses performed on combinations of four individual increments.

As shown in Figure 7-3 four composite samples were prepared from stockpile samples to determine ultimate/proximate and phenol values. Also, four conveyor samples from each processor were analyzed for these parameters. Variability between segments is lost by this method. However, the ultimate/proximate properties were not expected to vary significantly between segments. Therefore, the variability data for these analyses was not critical and provided sufficient data for statistical analysis (e.g., to estimate variance, mean, etc.) of these properties. Also, this study was to explore whether phenol determinations could be used to characterize and identify particular waste wood properties. Very limited data was to be gathered to evaluate the use of the phenol analysis.

Stock pile and conveyor samples were also composited into samples to be laboratory ashed. Ash characteristics are more important on the scale of several "truckloads", because the volume of ash is only about 2 to 10 percent that of wood. In the early part of the program, attempts were made to collect samples to be ashed from as few segments as possible. It was later determined that combining several segments together to form composite samples better represented the site and significantly reduced sampling time. The ash generated from each sample was tested for its minerals content and metal leaching toxicity (TCLP).

7.3.3 Waste Wood Combustion Facilities

Two facilities permitted to burn waste wood were willing to allow a limited sampling program. Site 5, while permitted to burn waste wood, was not doing so at the time of the site visit. However, waste wood emissions data from this facility was obtained from prior test programs and is presented in Section 8. For comparative purposes, some sampling was performed from the feed conveyor, the bottom ash hopper, and fly ash hopper. These samples were taken concurrently every 10 minutes for a total of eight samples.

Site 8 was burning mostly waste wood. Unfortunately the bulk of the material burned at that site undergoes little if any size reduction and the feed material was too large to sample. However, samples of ash were collected at the end of each day over a seven-day period. Two types of ash were collected

from this site: bottom ash consisting of material dropping off the end of the grate, and sifting, consisting of ash that fell in between the grates. There was no flue gas particulate collection system so fly ash samples were not obtained.

Figure 7-4 shows the distribution of analyses performed on both the wood and ash samples collected. To determine sample variance, two random samples from each half of the sampling period were analyzed for "five metals". All the increments from each half of the sampling period were combined and analyzed for total metals. For the ash samples, a composite of all the increments was analyzed for minerals composition and a TCLP test. For the wood samples, a composite of all the increments was analyzed for ultimate/proximate and phenols analyses.

In addition to the above testing, some additional TCLP tests were run on available ash. Often, ash is quenched at combustors before collection is possible, but in some cases ash was collected dry. To simulate the cementation process that combustion ash undergoes when wetted, distilled deionized water was added to splits of some of the dry samples. These mixtures were allowed to set until hard, ground, and tested for TCLP.

7.4 Analytical Methods

Each of the laboratory analyses performed as part of this project is described below.

7.4.1 Ultimate/Proximate Analysis

This test is a basic analysis routinely done on all types of combustion fuel. It determines the properties most important in the design of the combustion system. On a moisture and ash-free basis this test is not significantly affected by the type of waste wood and therefore, only composite samples were analyzed.

The ultimate/proximate analysis includes the following determinations:

- Heating value (Btu/lb)
- As a percent by weight:
 - Hydrogen -Ash
 - Total Carbon -Oxygen (by difference)
 - Fixed Carbon -Sulfur
 - Nitrogen -Chlorine (not usually part of ultimate analysis)
 - Volatiles -Alkalies as sodium oxide

The sulfur and chlorine content is important in terms of evaluating environmental impacts of acid gases.

The test methods used by the laboratory were ASTM methods D3176, D3173, and D2361.

7.4.2 Elemental Metals Analysis ("five metals" and "total metals")

This series of tests determines the concentrations (ppm by weight or $\mu\text{g/g}$) of each of the following elements in the sample.

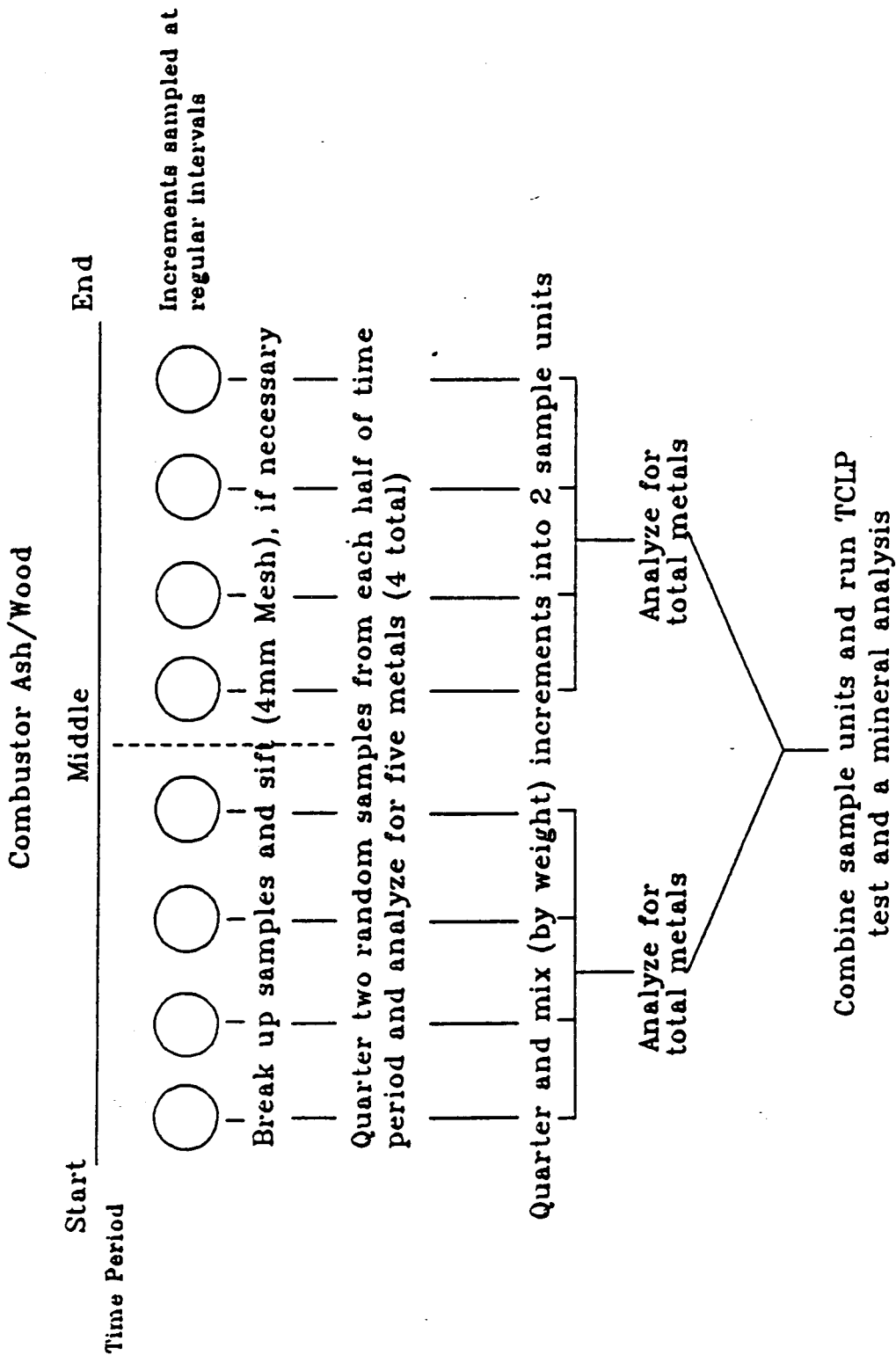


Figure 7-4. Distribution of analyses performed on wood and ash samples.

<u>Element</u>	<u>EPA Method^b</u>	<u>Element</u>	<u>EPA Method^b</u>
Arsenic ^a	7060	Mercury	7471
Barium	7081	Nickel	7520
Cadmium	7131	Silver	7961
Chromium ^a	7191	Titanium ^a	283.2 ^c
Copper	7211	Zinc [*]	7950
Lead ^a	7421		

a "five metals" analysis

b see Test Methods... in Bibliography Section

c see Methods for Chemical... in Bibliography Section

Analysis by the above methods entails digesting the sample (wood or ash) in concentrated acid (HNO₃) (EPA 3050) and then testing for each element in a graphite furnace using atomic absorption. The method usually requires only one gram of analyte to be digested. Even after blending and grinding, it was believed that this was too small an amount to test considering the heterogeneous mixtures of wood tested. Thus, the testing laboratories were requested to digest five grams of sample per test to increase data reliability. The composite samples for site 7 were tested at a different laboratory using different test methods to compare the effectiveness of test methods.

Each sample was prepared (ASTM D3683) analyzed for trace elements (barium, silver) by inductively coupled plasma emission spectroscopy. Arsenic was determined by graphite furnace atomic absorption. Mercury was determined by double gold amalgamation cold vapor atomic absorption. Titanium was determined by fusing with lithium tetraborate (ASTM D3682), cadmium, chromium, copper, lead, nickel and zinc were determined by aqua regia digestion of ash, followed by atomic absorption analysis.

7.4.2.1 Titanium Analysis

Titanium concentrations in the samples were determined by two methods. Most of the total metals and all the "five metals" analyses used EPA methods (EPA 3050, EPA 283.2). In general these methods involve the acid digestion of the sample into solution and then analyzing the extracted fluid. A second method (ASTM D 3682) was used to determine titanium concentrations for the minerals analysis. This method was also used for the site 7 total metal analyses. This method, which determines the major components of ash, involves fusing the ash with lithium tetraborate, digesting this fused material in hydrochloric acid, then analyzing the resulting fluid. The minerals analysis, by fusing ash with this other compound, ensures a complete digestion of the material. Based on a review of the data it appears that the first method may not have ensured a complete digestion. Conversations with the laboratory performing the work using this method indicated there was an insoluble white residue left in the digestion chamber.

Titanium in its elemental form is soluble in dilute acid; however, several titanium compounds such as titanium dioxide are insoluble in acids and/or somewhat soluble in sulfuric acid (CRC, 1985). Titanium dioxide, which is used in modern paints as a binder, is white. It is suspected that the undigested white material from the metals analysis was titanium dioxide.

The fact that the two methods do not correspond is apparent when looking at the results for site 1. The average value of titanium by the minerals analysis method for site 1 was about 300 ppm compared to about 50 ppm to 100 ppm averages of total metals and "five metals" respectively. Review of the data from sites 2, 4, 6 and the "five metals" analysis of site 7, show the same disparity in titanium concentrations which suggests that ASTM D 3682-87 is the

better method for determining titanium concentrations in the future. As a result, the work reported in subsequent sections uses the mineral analysis data for titanium as representative of its true value.

7.4.3 Phenols

The following list of phenol compounds were tested for in composite samples of the wood fuel.

Phenol	2-Chlorophenol
2-Nitrophenol	2,4-Dimethylphenol
2,4-Dichlorophenol	4-Chloro-3-methylphenol
2,4,6-Trichlorophenol	2,4-Dinitrophenol
4-Nitrophenol	2-Methy-4,6-dinitrophenol
Pentachlorophenol	

The method used to determine the parts per million by weight concentration of each compound was USEPA method 8270 (SW-846).

7.4.4 Laboratory Ash

In most instances it was not possible to collect waste wood and its corresponding ash samples from the same operating facilities. None of the wood processors burned waste wood. Those facilities burning waste wood from processors tested were also burning other waste wood and or waste material. Therefore, corresponding ash and waste wood samples could not be obtained. Therefore, samples were prepared in the laboratory from the waste wood fuel to determine the chemical characteristics of its wood ash. In the ashing method used, the wood sample is placed in an oven at 550°C (1,002°F) and allowed to combust slowly for several hours. This method is used to minimize volatilization of metals while still achieving complete oxidation of the combustible material. While this method is not representative of high temperature and turbulent combustion conditions of an actual boiler, it does provide an ash sample with conservative concentrations of metals and other elements. However, the oxidation level of the metal compounds and the type of compounds found probably is not representative of actual full-scale combustion parameters.

It is believed that ash prepared in this manner has a chemical concentration reasonably close to the chemical concentration of ash from a wood-fired boiler because the wood is combusted for at least one hour or longer for this method, and it is periodically weighed until a constant mass is achieved. This ensures that all combustible material is oxidized and all volatile material is driven off. However, the high temperature combinations of various compounds in the ash that could occur in boilers probably does not occur during these preparations. For example, during actual combustion arsenic may be converted to As_2O_3 while in the laboratory it could be converted to As_2O_5 . The trioxide form is much less soluble than the pentoxide form and therefore significant leaching could result. Similarly for the other metals tested, different oxidation levels and different metal salts such as chlorides, sulfates, and sulfites could be formed, resulting in widely different leaching properties for laboratory ash compared to actual combustion facility ash.

7.4.5 Mineral Analysis

This test determined the bulk composition of wood ash. For either ash generated in the laboratory or received from a combustor, samples were tested for percent metal oxides by weight of the following elements:

Silicon, Aluminum, Potassium, Sodium, Titanium, Iron, Sulfur,
Phosphorus, Calcium, Magnesium, and Undetermined

When the undetermined portion of the sample was too large, further analysis was performed. The percent by weight oxides of the following were tested for until the undetermined portion of the sample reached a reasonable level.

Lead, Zinc, Manganese, Copper, Strontium, and Barium

This analysis was performed by ASTM Method D-3682-87. The titanium oxide value was judged more representative of the amount of titanium in the wood fuel than the levels determined by the evaluated analysis Method 283.2. Therefore, this mineral analysis was used to back calculate the titanium concentration in the waste wood streams wood. These values are also reported in the tables that follow.

7.4.6 Toxicity Characteristic Leachate Procedure (TCLP)

The Environmental Protection Agency's Test Method 1311, otherwise known as the Toxicity Characteristic Leachate Procedure (TCLP), is used to determine if wastes are characteristically hazardous. Ash that fails the TCLP must be disposed of properly in authorized landfills or be specially treated. The TCLP procedure replaces the EP toxicity method. Table 7-2 lists the constituents of concern and the regulatory level that would subject the material to all RCRA Hazardous Waste requirements.

The TCLP test was performed on composite ash samples from the combustion facilities as well as laboratory-generated ash from the processors. Unburned creosote-treated samples of railroad ties and telephone poles were also tested to evaluate the effects for landfill disposal of this material.

Also, TCLP "wet" tests are defined as tests where dry ash samples were wetted and dried to allow for pozzolanic reactions. It has been proposed that the pozzolanic process fixes constituents that may otherwise leach out of the mixture. The TCLP data should be evaluated considering the previously expressed concerns about the representatives of laboratory-generated compared to actual boiler ash. TCLP test failure of laboratory ash may not be applicable to full scale boiler ash of the identical fuel type.

7.5 Test Results

This section presents the test results and evaluations of the testing performed on the wood and ash samples. Tables in this section summarize the statistical information calculated from the raw data. Tabulations of all the analyses can be found in Appendix G. Also found in this Appendix are the computer statistical computational outputs.

This section also discusses the confidence in the analytical methods used and recommends procedures for future sampling and testing programs.

While reviewing this data the reader will notice two sets of titanium values. As indicated previously, values determined as part of the "total metal" and "five metals" analysis are suspected to have low titanium levels. All discussions relating to titanium concentrations are therefore based on the results of the minerals analysis which is felt to be more accurate (see Section 7.4.2).

7.5.1 Homogeneous Wood Samples

Table 7-2. Toxicity characteristic leachate procedure (as of mid-1992).

Constituent	EPA hazardous waste (HW) number	Minimum detection Limit (MDL) ^a	Regulatory level
		mg/l	mg/l
Volatile organics			
Benzene	D018	0.01	0.5
Carbon tetrachloride	D019	0.01	0.5
Chlorobenzene	D021	0.01	100
Chloroform	D022	0.01	6.0
1,2-Dichloroethane	D028	0.01	0.5
1,1-Dichloroethylene	D029	0.01	0.7
Methyl ethyl ketone	D035	0.01	200
Tetrachloroethylene	D039	0.01	0.7
Trichloroethylene	D040	0.01	0.5
Vinyl chloride	D043	0.01	0.2
Semi-volatile organics			
Acid fraction:			
o-Cresol	D023	0.10	200
m-cresol	D024	0.10	200
p-cresol	D025	0.10	200
Pentachlorophenol	D026	0.10	200
2,4,5-Trichlorophenol	D037	0.1	100
2,4,6-Trichlorophenol	D041	0.05	400
	D042	0.05	2.0
Base neutral fraction:			
1,4 Dichlorobenzene	D027	0.025	7.5
2,4-Dinitrotoluene	D030	0.025	0.13
Hexachlorobenzene	D032	0.025	0.13
Hexachlorobutadiene	D033	0.025	0.5
Hexachloroethane	D034	0.025	3.0
Nitrobenzene	D036	0.025	2.0
Pyridine	D038	0.025	5.0
Pesticides			
Chlordane	D020	0.0005	0.03
Endrin	D012	0.0001	0.02
Heptachlor	D031	0.0001	0.008
Lindane (gamma-BHC)	D013	0.0001	0.4
Methoxychlor	D014	0.0005	10.0
Toxaphene	D015	0.005	0.5
Herbicides			
2,4-D	D016	0.005	10.0
2,4,5-TP (Silex)	D017	0.005	1.0
Metals			
Arsenic	D004	0.005	5.0
Barium	D005	0.01	100
Cadmium	D006	0.01	1.0
Chromium	D007	0.01	5.0
Lead	D008	0.08	5.0
Mercury	D009	0.0004	0.2
Selenium	D010	0.01	1.0
Silver	D011	0.01	5.0

a. Established MDLs are based on reagent grade water; achieving MDLs is matrix dependent.

The results of the homogeneous woods analysis are useful in determining possible sources of contamination in the waste wood stream. Tables 7-3 through 7-8 summarize the laboratory work performed on the samples collected for this project.

7.5.1.1 Ultimate/Proximate Analysis

One of the most outstanding features of these analysis is the consistency of the heating values for the different wood types. On a moisture-free basis these values are in a narrow range between about 8280 Btu/lb to 9430 Btu/lb. Even on a wet basis these samples were within a 1000 Btu range with the exception of the telephone pole analysis. This particular telephone pole sample had a very high moisture content of 29 percent, more than double that of any other sample. This telephone pole sample also stands out from the other samples because it had unusually high ash and chlorine content (2.41 dry weight percent ash and 0.41 dry weight percent chlorine).

From an environmental impact standpoint, sulfur, chlorine, and ash values are the most important numbers in these tables. With the exception of the creosote-treated woods, the sulfur content in all of these samples is below 0.08 dry weight percent. Thus high levels of sulfur in a waste wood stream could indicate either creosote-treated materials or non-wood contaminants such as tarpaper, shingles, and asphalt. The high chlorine values for the laminated wood may be due to either PVC coating of the wood or chlorine found in the resin. The bonding agent may also be the chlorine source in the particle board samples.

All these samples have a low ash content. Thus the higher ash contents found in C/D wastes and other waste woods may be the result of either paint, dirt or other noncombustibles in the waste wood stream (see Section 7.4.2). In theory, part of the noncombustibles can be removed using float tanks, trommels, or disk screens. Increased processing to remove fines and other dirt should reduce the ash content of waste wood streams close to that of pure wood. However, the remaining ash could contain a higher metals concentration value due to less inert dilution and thus be more toxic.

7.5.1.2 Phenols

Table 7-5 presents the results of phenols analysis for several wood types. Every value shown is at the detection limit below which the laboratory could not analyze. The absence of detectable phenols shows that these samples do not have free or leachable phenol based materials and have not been contaminated with other phenol based chemicals. It was expected that samples containing phenol based resins used as bonding agents or as treatment chemicals (plywood and pentachlorophenol materials) should have had some free phenol available for analysis. It may be that the woods tested utilized other resin combinations or that residual phenol levels were below the detection limit.

7.5.1.3 Minerals Analysis of Facility and Laboratory Ash

Table 7-6 presents the results of minerals analysis. Note the low values of silicon present in the ash. This would seem to verify the assumption that most of the silicon present in the ash of waste wood is due to dirt being processed with the wood. In most cases calcium seems to be the primary component. Titanium dioxide, an indicator of modern paints, is found in very small amounts except in the ash from the furniture manufacturer and the ash from the facility burning laminated wood. The furniture waste material was a fine sawdust so it was impossible to determine if paint was present. However, the laminated wood had visible paint pigmentations.

Carbon dioxide values are the result of calcium carbonate and magnesium carbonate compounds present in the ash.

The minerals analysis of the CCA pressure treated woods is very puzzling. The ash from the first sample sent to the laboratory was reported to have 63.85 weight percent manganese oxide content. Assuming a laboratory error had occurred, a duplicate sample of the ground material was sent for analysis. This turned out to be nearly the same at 62.83 weight percent manganese oxide. At this time no explanation can be offered for these results. A third sample of CCA pressure-treated wood was procured from another source and analyzed. Only 19.34 percent of the ash generated from this third sample consisted of compounds normally tested for in a minerals analysis. The results of the concurrent elemental metals analysis indicate that the ash is 34.5 percent oxidized chromium and 13.4 percent copper oxide. Ash from the fire-treated/pressure-treated wood sample was determined to be 80.6 percent oxidized phosphorus (P_2O_5) or 35 percent by weight phosphorus.

7.5.1.4 Elemental Metals Analysis

Table 7-7 presents the results of the elemental metals analysis. With the exception of the analysis of the laminate wood and its fly ash, CCA-treated wood and creosote-treated woods, most of the metals analyses were very near or below the detection limits. It is assumed that the metals concentrations in the laminated wood and ash result from the variety of paint pigments in the wood sample.

Of the creosote treated woods only telephone poles showed any significant contamination of metals, these being lead and zinc. It is possible that telephone poles generally located adjacent to roadways may have adsorbed vehicular engine metal particulate emissions from the atmosphere in which they existed. Additional testing of telephone poles would be required, however, to prove this theory.

As would be expected, the CCA treated (chromated copper arsenate) wood demonstrated high levels of chromium, copper, and arsenic. Industry standards show that 0.4 to 3 percent of the CCA treated wood should be CCA solution. The average fraction of the CCA metals in the two pressure treated samples was 0.43. This is within industry standards (AWP, 1988). Using this average value for arsenic, chromium, and copper it is possible to estimate the percent contamination of a waste wood stream by CCA. This assumes all of the arsenic, chromium and copper are the result contamination of CCA treated woods. This calculation was made in the following section on the heterogeneous waste wood samples to estimate possible CCA contamination levels.

7.5.1.5 Toxic Characteristic Leachate Procedure (TCLP)

In Table 7-8, the results of the leachate test on the four treated samples tested show that only the CCA pressure-treated sample may come close to being considered characteristically hazardous by the TCLP test. This sample had an arsenic level of 8 mg/L (regulatory level is 5 mg/L) and had a relatively high chromium value. The regulatory level for chromium is 5 mg/L; this sample tested at 4.10 mg/L chromium. The TCLP test allows for failure of the arsenic value for CCA wood provided no other metals or organic failures occur.

7.5.2 Waste Wood Processors

This section summarizes the analytical findings for each of the processors visited. Each subsection contains tables of averaged data and site specific conclusions that can be inferred from this data. A summary section follows where all the data collected from the processors are discussed and general

Table 7-3. Homogeneous woods ultimate and proximate analysis. Percent by weight as received.

Sample type	Volatile	Fixed carbon	Moisture	Total carbon	Hydrogen	Nitrogen	Sulfur	Ash	Oxygen (by difference)	Chlorine	Heating value (Btu/lb)
Plywood scraps	73.41	17.40	7.81	50.46	5.65	0.29	0.04	1.38	34.37	0.03	8461
Pressure treated 1	68.66	13.93	14.14	47.37	5.18	0.21	0.03	3.27	29.80	0.09	8039
Pressure treated 2	74.69	16.64	7.75	47.02	5.78	0.21	0.02	0.92	38.30	-	7702
Fire treated	63.47	27.74	7.65	46.35	5.76	1.75	0.01	1.14	37.34	-	7647
Particle board (S. hardwoods)	75.33	18.14	6.31	48.56	5.44	2.77	0.03	0.22	36.67	0.31	7790
Particle board (S. pine fine)	74.19	18.57	6.73	49.42	5.68	2.75	0.03	0.51	34.88	0.12	8247
Particle board (S. pine medium)	73.41	19.34	6.89	51.22	5.26	2.94	0.03	0.36	33.30	0.17	8357
Particle board (S. pine coarse)	74.57	18.07	6.47	50.05	5.54	3.27	0.07	0.89	33.71	0.11	8368
Telephone poles	55.80	13.51	28.98	39.52	4.28	0.31	0.40	1.71	24.80	0.29	6687
R.R. ties	72.03	13.60	13.16	48.71	5.26	0.41	0.10	1.19	31.15	0.03	8191
Birch furn. plywood	81.40	13.64	4.60	48.89	5.67	3.32	0.01	0.36	37.15	0.15	7927
Furniture waste	71.97	15.66	11.21	45.18	5.44	1.42	0.02	0.96	35.77	0.05	7484
Laminated wood	69.68	18.24	10.73	44.38	5.43	3.00	0.04	1.35	35.07	0.24	7484

Table 7-4. Homogeneous woods ultimate and proximate analysis. Percent by weight dry basis.

Sample type	Volatile	Fixed carbon	Total carbon	Hydrogen	Nitrogen	Sulfur	Ash	Oxygen, by difference	Chlorine	MAF Btu/lb	Heating value, Btu/lb	Alkaline as NaO
Plywood scraps	79.63	18.87	54.74	6.13	0.31	0.04	1.5	37.28	0.03	9318	9178	0.46
Pressure treated 1	79.97	16.22	55.17	6.03	.025	0.03	3.81	34.71	0.1	9734	9363	0.08
Pressure treated 2	80.96	18.04	50.97	6.27	0.23	0.02	1	41.51	-	8433	8349	-
Fire treated	68.73	30.04	50.19	6.24	1.89	0.01	1.23	40.44	-	8383	8280	-
Particle board (S. hardwoods)	80.4	19.36	51.83	5.81	2.96	0.03	0.24	39.13	0.33	8335	8315	0.05
Particle board (S. pine fine)	79.54	19.91	52.99	6.09	2.95	0.03	0.55	37.39	0.13	8891	8842	0.12
Particle board (S. pine medium)	78.84	20.77	55.01	5.65	3.16	0.03	0.39	35.76	0.18	9010	8975	0.07
Particle board (S. pine coarse)	79.73	19.32	53.51	5.92	3.5	0.08	0.95	36.04	0.12	9033	8947	0.1
Telephone poles	78.57	19.02	55.65	6.02	0.44	0.56	2.41	34.92	0.41	9648	9415	0.42
R.R. ties	82.96	15.67	56.11	6.06	0.47	0.12	1.37	35.87	0.04	9565	9434	0.04
Birch furn. plywood	85.32	14.3	51.25	5.94	3.48	0.01	0.38	38.94	0.16	8341	8309	0.06
Furniture waste	81.06	17.86	50.88	6.13	1.6	0.02	1.08	40.29	0.06	8521	8429	0.11
Laminated wood	78.05	20.44	49.71	6.08	3.36	0.05	1.51	39.29	0.25	8513	8384	0.09

Table 7-5. Homogeneous woods phenols and chlorophenols analysis, ug/g dry. (Negative values represent detection limits.)

Sample type	Phenol	2-Chlorophenol	2-Nitrophenol	2,4-Dimethylphenol	2,4-Dichlorophenol	4-Chloro-3-methylphenol	2,4,6-Tri-chlorophenol	2,4-dinitrophenol	4-Nitrophenol	2-Methyl-4,6-dinitrophenol	Penta-chlorophenol
Plywood scraps	-1.32	-1.32	-1.32	-1.32	-1.32	-1.32	-1.32	-6.8	-6.8	-6.8	-6.8
Pressure treated 1 particle board (S. hardwoods)	-6.6	-6.6	-6.6	-6.6	-6.6	-6.6	-6.6	-34	-34	-34	-34
Particle board (S. pine fine)	-3.3	-3.3	-3.3	-3.3	-3.3	-3.3	-3.3	-17	-17	-17	-17
Particle board (S. pine medium)	-1.98	-1.98	-1.98	-1.98	-1.98	-1.98	-1.98	-10.2	-10.2	-10.2	-10.2
Particle board (S. pine coarse)	-1.32	-1.32	-1.32	-1.32	-1.32	-1.32	-1.32	-6.8	-6.8	-6.8	-6.8
Telephone poles	-1.98	-1.98	-1.98	-1.98	-1.98	-1.98	-1.98	-10.2	-10.2	-10.2	-10.2
R.R. ties	-2.31	-2.31	-2.31	-2.31	-2.31	-2.31	-2.31	-11.9	-11.9	-11.9	-11.9
Birch furn. plywood	-2.97	-2.97	-2.97	-2.97	-2.97	-2.97	-2.97	-15.3	-15.3	-15.3	-15.3
Furniture waste	-0.33	-0.33	-0.33	-0.33	-0.33	-0.33	-0.33	-1.7	-1.7	-1.7	-1.7
	-2.31	-2.31	-2.31	-2.31	-2.31	-2.31	-2.31	-11.9	-11.9	-11.9	-11.9

Table 7-6. Homogeneous woods mineral analysis of laboratory combusted material and facility ash, % by weight of oxides in ash.

Sample type	Si	Al	Ti	Fe	Ca	Mg	K	Na	S	P	Mn	CO ₂	Cu	Sr	Ba	Undetermined	Loss on ignition
Plywood scraps	9.2	1.93	0.16	1.03	53.6	2.8	0.92	7.96	0.48	0.6	63.85					1.72	19.6
Pressure treated 1 duplicate	7.05	6.3	0.6	6.86	4	1	2.6	0.44	0.2	2.08	62.83		3.13			1.89	
Pressure treated 2	7.35	6.58	0.62	7	4	1	2.52	0.52	2.74	0.3	62.83		3.03			1.51	
Pine treated	0.86	0.4	0.03	0.7	8.26	2.16	2.06	0.65	0.8	3.02	0.48			0.04	0.06	80.48	
Particle board (S. hardwoods)	1.37	0.44	0.03	0.86	7.35	1.62	5.93	2.47	0.15	80.64	0.33			0.04	0.1	1.67	
Particle board (S. pine fine)	9.06	2.63	0.52	4	25.2	8.6	13.4	11.2	3.43	2.24	1.39	17.6				0.73	
Particle board (S. pine medium)	7	1.5	0.24	1.72	24	8	10	15.6	5.49	8	2.64	15.6				0.21	
Particle board (S. pine coarse)	10.64	2.07	0.32	3.25	26	9.2	8.56	12.56	4.39	6.2	2.11	14				0.7	
Telephone poles	25.61	4.9	0.52	3.74	27.6	6	9.12	4.04	10.29	2.8	2.04	2.2				1.14	
R.R. ties	19.73	3.97	0.36	22.64	8	3.6	2.42	16	20.44	0.3	0.62	1.1				2.54	
Birch furn. plywood	33.08	7.14	0.52	21.16	20.8	3.6	2.08	1.62	6.58	0.8	0.62					0.9	
Furniture waste	4.02	0.75	0.48	18.4	18.4	7.52	18.4	2.88	4.93	10	0.62					9.31	
Laminated wood	12.37	15.03	28	6.54	14.6	2.24	6	4.83	0.1	2.2	1.07					0.93	
	18.45	9.49	25.65	2.46	26.57	3.68	2.87	1.57	3.28	1.89						2.1	

Table 7-7. Homogeneous woods elemental metals analysis, ppm dry basis. Negative values are detection limits.

Sample type	Arsenic	Barium	Cadmium	Chromium	Copper	Lead	Mercury	Titanium ^a	Nickel	Zinc	Silver
Plywood scraps	7.2	11.1	-0.05	8.5	2.5	7.5	-0.25	1.19	-5	8.5	-0.05
Pressure treated 1	2050	6	-0.5	1740	1040	13	-0.25	-1	-5	20	0.09
Pressure treated 2	290	3	0.2	2357	1073	2.16	0.11	18	0.73	3.67	-0.1
Fire treated	10	17	0.3	31.7	64.5	1.2	0.03	17.22	0.85	11.84	20.1
Particle board (S. hardwoods)	-0.25	27.4	-0.05	-5	-2.5	6.5	-0.25	-0.25	-5	7.5	-0.05
Particle board (S. pine fine)	-0.25	10.9	-0.05	-5	-2.5	-5	-0.25	-0.25	-5	10.5	-0.05
Particle board (S. pine medium)	-0.25	9.1	-0.05	-5	-2.5	-5	-0.25	-0.25	-5	11.5	-0.05
Particle board (S. pine coarse)	0.38	25.4	0.1	-5	-2.5	-5	-0.25	0.87	-5	8	-0.05
Telephone poles	0.75	14.5	0.14	-5	8.5	39.5	-0.25	2.52	-5	91.5	-0.05
R.R. ties	1.5	25.2	0.1	-5	4	8	-0.25	2.91	-5	8	-0.05
Birch furn. plywood	-1	1.2	0.1	0.3	1.1	0.7	0.16	0.2	0.5	7	-0.1
Furniture waste	-0.25	10	-0.5	-5	2.5	-5	-0.25	2.9	-5	7	-0.05
Laminated wood ^b	3.3	70	0.08	21	3	85	-0.25	2.8	-5	16	0.6

a. Values are suspect, see text in Section 7.4.

b. Metals analysis performed on actual facility ash burning laminated wood.

Table 7-8. Homogeneous woods TCLP - metals only, mg/l. Negative values are detection limits.

Sample type	Arsenic	Barium	Cadmium	Chromium	Lead	Selenium	Silver	Mercury
Pressure treated 2	8	-1	-0.2	4.1	-2	-0.5	-0.1	-0.1
Fire treated	-1	-1	-0.2	0.4	-2	-0.5	-0.1	-0.1
Telephone poles	-0.005	0.076	-0.001	0.010	0.042	-0.001	-0.005	0.084
R.R. ties	0.018	0.140	-0.001	-0.005	0.010	-0.001	-0.005	0.031
Regulatory limits ^a	5	100	1	5	5	1	5	0.2

a. As of mid-1992.

conclusions about waste wood are made. Appendix G contains all the individual data sets for each of the sites.

7.5.2.1 Processor - Site 1

This processor sells most of its product to licensed combustion facilities and does not limit the wood types used in its product. Any wood shipped to the facility is processed. The facility also buries some of its C/D wastes for a period of time until paper and other similar types of contaminants are removed by natural decay. As a result, some of the materials produced at this site have a high dirt content. All the available processed wood fuel and fine grade wood chips (used for landscaping) were included in the sampling program. Additionally, samples were taken directly from both the fines and wood fuel process conveyors.

Tables 7-9 through 7-12 present the results of the sampling at Site 1. As expected, the variance in ultimate/proximate analyses is quite low. The greatest variation occurs in the moisture and ash content of the wood. Variation in moisture content is not unusual and is not normally a parameter of environmental concern. High ash and sulfur contents, however, generally indicate the presence of non-wood contaminants in the fuel. Pure wood typically contains 1 percent to 2 percent ash and less than 0.10 percent by weight sulfur. The percent ash at site 1 averaged 5.16 percent by weight and the average sulfur content was 0.12 percent by weight. The ash content is consistent with that found at the other facilities. The sulfur content suggests the presence of sulfur-containing materials such as creosote and pentantachlorophenol treated wood or asphalt, tarpaper, or wallboard. Chlorine was also detected in small amounts and would suggest the presence of PVC plastics or treated/glued woods containing chlorine materials (particle board, and laminated wood, etc.).

Of the phenol compounds tested, only phenol was detected in small amounts. Three of the four samples showed the presence of phenol in the wood. The sample that was measured below detection limits for phenol was reanalyzed and again proved to be less than the detection limit. The small amount of phenol in these samples may indicate the presence of particle board or plywood with some free phenols or the presence of some chemical contaminants; however, the extremely low phenol values would not be of any environmental concern.

The results of the minerals analyses indicate that silicon and calcium are the two principal components of the ash which is generally typical of wood fuel, with the silicon mainly attributed to soil and dirt processed with the wood stream. The minerals analysis of the fines material produced at the site shows a much higher silicon content than the coarse material. The silicon content of the fines materials ash was 53.1 percent compared to the silicon contents of 35.70 percent and 35.28 percent in the coarse material ash. The results are not surprising since some of the feedstock processed was buried on the site and dug up. Also the separation of the fines material from the waste wood stream concentrates loose soil into the fine product.

Metals analysis of the wood from this site indicated a wide variation of metals concentration. Of the 11 metals tested, three (cadmium, mercury, and silver) were below detection limits. Only one sample had a nickel content above detection limits and that result could not be duplicated when the sample was reanalyzed. The other seven metals were detected in relatively large quantities. Arsenic, chromium, lead, zinc, and barium levels were all significantly higher than the average of all the other facilities sampled in the program. This again is not surprising since this facility does not limit the types of C/D materials being accepted.

Table 7-9. Processor Site 1.

Wood ultimate analysis					
	Average	Standard deviation	Minimum	Maximum	Number of samples
As received					
% moisture	19.40	3.77	15.37	23.17	4
Btu/lb	6637	276	6300	6915	4
Dry basis					
% carbon	50.28	1.58	48.77	52.34	4
% hydrogen	5.92	0.20	5.68	6.11	4
% nitrogen	0.46	0.09	0.36	0.58	4
% sulfur	0.12	0.03	0.08	0.14	4
% ash	5.16	2.91	1.84	7.64	4
% oxygen (difference)	38.07	1.23	36.73	39.22	4
% chlorine	0.08	0.03	0.06	0.12	4
% volatile	79.59	2.07	77.23	81.91	4
% fixed carbon	15.25	1.07	13.80	16.25	4
Btu/lb	8238	222	8034	8503	4

Phenols in wood					
	Average µg/g	Standard deviation	Minimum µg/g	Maximum µg/g	Number of samples
Phenol ^a	0.90	0.51	0.33	1.60	5
Pentachlorophenol	<3.06	-	<1.70	<5.10	5
2-chlorophenol	<0.60	-	<0.33	<0.99	5
2-nitrophenol	<0.60	-	<0.33	<0.99	5
2,4-dimethylphenol	<0.60	-	<0.33	<0.99	5
2,4-dichlorophenol	<0.60	-	<0.33	<0.99	5
4-chloro-3-methylphenol	<0.60	-	<0.33	<0.99	5
2,4,6-trichlorophenol	<0.60	-	<0.33	<0.99	5
2,4-dinitrophenol	<3.06	-	<1.70	<5.10	5
4-nitrophenol	<3.06	-	<1.70	<5.10	5
2-methyl-4,6-dinitrophenol	<3.06	-	<1.70	<5.10	5

Mineral analysis of laboratory ash.					
	Average % by wt.	Standard deviation	Minimum % by wt.	Maximum % by wt.	Number of samples
Silicon dioxide	41.36	8.30	35.28	53.10	3
Aluminum oxide	7.58	0.72	6.73	8.49	3
Titanium dioxide	1.18	0.27	0.84	1.50	3
Iron oxide	8.67	0.85	7.83	9.83	3
Calcium oxide	15.44	4.20	9.52	18.80	3
Magnesium oxide	3.97	1.31	2.24	5.40	3
Potassium oxide	3.47	0.62	2.60	3.92	3
Sodium oxide	3.21	0.61	2.50	3.99	3
Sulfur trioxide	8.56	1.60	6.32	9.96	3
Phosphorus pentoxide	0.95	0.25	0.60	1.16	3
Lead oxide	0.46	0.13	0.32	0.64	3
Zinc oxide	0.68	0.15	0.52	0.88	3
Manganese oxide	-	-	-	-	-

a. Analyses below detection limit were assumed to be 1/2 the detection limit for calculation purposes.

Table 7-10. Summary data from Processor Site 1.

Total metals analysis, ppm in dry wood.											
Metal	Number of samples	Arithmetic average	Standard deviation	Minimum detected ^a	90 th percentile	85 th percentile	Maximum detected	Median	Upper confidence median ^b	Geometric mean	Lognormal MVU mean ^c
Arsenic	8	68.73	85.82	3	262.5	262.5	262.5	43	86.77	29.89	81.13
Chromium	8	104.44	79.54	10	233	233	233	92	145.77	74.03	123.50
Lead	8	266.19	93.19	127	405	405	405	264.5	324.61	250.47	267.30
Titanium ^d	8	49.51	59.37	11	191.75	191.75	191.75	29.4	59.51	32.77	45.79
Titanium ^e	8	279.6	131.36	132	385	385	385	-	-	-	-
Zinc	8	176.63	91.90	66	366	366	366	158.5	222.48	157.65	176.72
Barium	8	435.63	153.89	240	630	630	630	485	531.58	409.21	437.23
Cadmium ^f	8	1.50	-	1.5	1.5	1.5	1.5	1.5	1.50	1.50	1.50
Copper	8	44.00	35.50	17	125	125	125	30.5	54.87	35.83	42.63
Mercury ^f	8	0.025	-	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Nickel	8	7.69	7.60	26.5	26.5	26.5	26.5	5	9.14	6.16	7.15
Silver ^f	8	2.500	-	2.5	2.5	2.5	2.5	2.5	2.50	2.50	2.50

Five metals analysis, ppm in dry wood.

Metal	Number of samples	Arithmetic average	Standard deviation	Minimum detected ^a	90 th percentile	85 th percentile	Maximum detected	Median	Upper confidence median ^b	Geometric mean	Lognormal MVU mean ^c
Arsenic	16	112.83	181.37	0.7	328	662	662	23	64.22	22.36	178.96
Chromium	16	126.75	149.27	4	453	475	475	71	118.30	60.04	149.57
Lead	16	430.44	514.60	84	709	2250	2250	283.5	437.94	304.99	399.19
Titanium ^d	16	116.08	158.54	2.6	443	537	537	42.45	98.61	50.12	124.38
Zinc	16	500.25	657.39	44	1920	2100	2100	235	447.63	262.88	466.07

- a. In cases where samples registered below the detection limit, one-half of the detection limit was used.
- b. Level for which there is 95% confidence that the median of any similar random sampling will show a lower value.
- c. The Minimum Variance Unbiased (MVU) estimator of the true median for a lognormal distribution (Gilbert, 1987).
- d. Values are suspect, see text in section 7.4.
- e. Calculated from minerals analysis.
- f. Meaningless, since most of the data are below detection limit.

Table 7-11. Processor Site 1 average incremental versus composite metals analysis.

Segment 1				
	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	17.6-662	297.5	262.5	13.3
Chromium	46-475	249.3	211.5	17.9
Lead	182-292	240.3	220.5	9.0
Titanium ^b	59.1-443	217.3	191.8	13.3
Zinc	107-1900	442.8	213	107.9

Segment 2				
	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	21-119	59	68	-13.2
Chromium	61-115	80.5	86	-6.4
Lead	210-561	336.3	249	35.1
Titanium ^b	18- 45.8	28.9	19.5	48.2
Zinc	105-405	236.3	140	68.8

Segment 7				
	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	1.1-25	12	3.3	263.6
Chromium	11-80	58.3	41	42.2
Lead	141-2250	838	344	143.6
Titanium ^b	39.1-537	203.3	56.1	262.4
Zinc	216-2100	1122.5	177	534.2

Segment 8				
	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	0.7-328	82.8	26	218.5
Chromium	4-453	119	106	12.3
Lead	84-709	307.3	280	9.8
Titanium ^b	2.6- 31.4	14.9	11	35.5
Zinc	44-480	199.5	120	66.3

- a. Arithmetic mean based on 4 samples.
 b. Titanium values are suspect. See text.

The highest concentration of any one metal found in the composite samples (total metals test) was 630 ppm of barium. This metal is found naturally in wood and is not normally indicative of non-wood contamination of fuel. However, the mean value of 437 ppm is at least five times greater than levels in clean wood and about three times greater than the mean of all the tested facilities. No explanation for such high levels of barium is evident. It is interesting to note that the two highest values detected for barium were from samples of fines material. In fact, the highest concentrations of each metal were found in the fines samples (segments 1 and 7).

Lead, titanium, and zinc are components in waste wood suspected to originate from the inclusion of painted woods in the fuel. For this site these elements had a geometric mean concentration of 250, 35 and 160 ppm by weight, respectively in the waste wood.

Table 7-12. Processor Site 1 Toxic Characteristic Leachate Procedure (TCLP) in laboratory ash (heavy metals), mg/l.

Metal	Average value ^a	Maximum	Detection limit	U.S. EPA limit	Number of samples
Arsenic	ND	ND	0.5	5	3
Barium	ND	ND	1	100	3
Cadmium	ND	ND	0.2	1	3
Chromium	30.93	46	0.2	5	3
Lead	5.33	14	2	5	3
Selenium	ND	ND	0.5	1	3
Silver	ND	ND	0.1	5	3
Mercury	ND	ND	0.1	0.2	3

^a Analyses below detection limit were assumed to be 1/2 the detection limit for calculation purposes.

The high values of arsenic, copper, and chromium indicate that some portion of the processed wood contains CCA pressure-treated wood. By conservatively assuming that 100 percent of these elements are the result of CCA contamination and using representative values from the analysis of pure pressure-treated wood, it is possible to estimate what percent of the waste wood is CCA treated. The resulting values range from 0.03 percent to 28.9 percent CCA treated wood in the composite samples with an average of 6.1 percent. However, by removing the influence of segment 1, the average calculated CCA contamination drops to 3.6 percent, whereas the average for segment 1 alone is 14.9 percent.

Comparing the minimum and maximum values for each of the metals in the "five metals" versus the "total metals" analyses, the "five metals" results vary over a much greater range. The "total metals" analyses are performed on composited samples whereas the "five metals" analyses are performed on non-composited samples. Also in most instances the averages and geometric means of the composited samples were less than the non-composited values for the same metals. It is presumed that the thorough compositing of the segment samples diminished the effects of any outliers from contaminated wood and, in effect, produced a median result.

The results of the TCLP tests on laboratory ash for this facility show failures for chromium and lead. Chromium levels in the leachate were as high as 46 mg/L averaging 30.93 mg/L while lead levels were as high as 14 mg/L averaging 5.33 mg/L. The USEPA regulatory limit for both these metals is 5 mg/L.

7.5.2.2 Processor - Site 2

Site 2 solely produced wood chip fuel to be sent to a licensed combustor. The facility has no restrictions on the wood it accepts and processes a significant amount of telephone poles and C/D wood waste. Cross sections of all the available processed wood product were sampled as well as sampling directly from the process conveyor.

Tables 7-13 through 7-16 present the results of the sampling at site 2. Similar to site 1, the variance in the ultimate/ proximate analyses is low and the greatest variation occurs in the moisture and ash contents. Moisture, as previously stated, is not usually considered a parameter of environmental concern. The ash content for wood from this site varies dramatically from 2 percent to 21 percent dry weight, averaging 7.38 percent, which indicates the presence of non-wood contaminants is not evenly distributed in the fuel. However, the low sulfur (0.06 percent) and chlorine (0.03 percent) values suggest that materials such as asphalt, tarpaper, wallboard and PVC plastics are being separated out of the processed waste wood fuel.

Pentachlorophenol was the only phenol compound detected in all four samples. This is an indicator of penta-treated wood in the fuel, possibly from telephone poles and railroad ties being hogged at the site for disposal. The absence of other detectable phenols suggests an absence of phenol-based chemical contamination of the wood.

The results of the minerals analysis show very high levels of silicon dioxide compared to the average of the facilities which suggests that a sizable amount of dirt is being processed with the wood. This facility is equipped with disk screens and a shaker tower which apparently are not removing enough of the entrained dirt.

The metals analysis for this site indicates a high level of metals contamination. Of the eleven metals tested, only mercury was below detection. The lowest values detected for arsenic and lead in the composite samples are greater than the upper confidence limit of the median calculated for all six processors. The maximum detected levels for lead, titanium, zinc, cadmium, and copper are the highest of all six processors. The average value of copper is four times that of all six processors. Arsenic, lead, and zinc values are twice as high. All these values indicate a heavy contamination of paints with titanium, lead and zinc compounds and of CCA and penta-treated woods.

Using representative values from the analysis of CCA treated wood, estimates of CCA contamination were calculated for this site. Assuming 100 percent of the copper, chromium, and arsenic are the result of CCA treated wood, the wood from this facility ranges between 0.60 percent and 13.4 percent CCA averaging 4.83 percent and excluding an outlying value of 312.3 percent, actually a lesser amount of CCA than seen at site 1.

Judging from the results of not only the "five metals" incremental analysis but also the composite analysis as well, it can be seen that the fuel mix at this site is extremely heterogeneous. Even though the composite analyses vary over a wide range, it is still more narrow than the range of the incremental analyses which again suggests that the compositing of samples is a more accurate means of determining facility averages.

The results of the TCLP tests on laboratory ash from this facility show failure for chromium. Chromium levels in the leachate were as high as 11 mg/L averaging 7.65 mg/L. It is unknown why this ash demonstrated no leaching of lead even though lead levels were twice as high as site 1 which failed the TCLP for lead.

Table 7-13. Processor Site 2.

Wood ultimate analysis

	Average	Standard deviation	Minimum	Maximum	Number of samples
As received					
% moisture	19.84	4.71	15.47	25.38	4
Btu/lb	6889	331.75	6434	7145	4
Dry basis					
% carbon	50.55	2.28	47.49	52.67	4
% hydrogen	5.95	0.36	5.42	6.20	4
% nitrogen	0.53	0.02	0.51	0.56	4
% sulfur	0.06	0.01	0.06	0.07	4
% ash	7.38	9.26	1.97	21.17	4
% oxygen (difference)	35.54	6.84	25.30	39.53	4
% chlorine	0.03	0.02	0.02	0.06	4
% volatile	80.53	2.26	77.80	82.51	4
% fixed carbon	12.09	7.38	1.03	16.13	4
Btu/lb	8599	147.47	8453	8794	4

Phenols in wood

	Average µg/g	Standard deviation	Minimum µg/g	Maximum µg/g	Number of samples
Phenol ^a	<1.4	-	<0.99	<1.98	4
Pentachlorophenol	25.85	15.35	6.40	43.00	4
2-chlorophenol	<1.4	-	<0.99	<1.98	4
2-nitrophenol	<1.4	-	<0.99	<1.98	4
2,4-dimethylphenol	<1.4	-	<0.99	<1.98	4
2,4-dichlorophenol	<1.4	-	<0.99	<1.98	4
4-chloro-3-methylphenol	<1.4	-	<0.99	<1.98	4
2,4,6-trichlorophenol	<1.4	-	<0.99	<1.98	4
2,4-dinitrophenol	<7.22	-	<5.10	<10.20	4
4-nitrophenol	<7.22	-	<5.10	<10.20	4
2-methyl-4,6-dinitrophenol	<7.22	-	<5.10	<10.20	4

Mineral analysis of laboratory ash.

	Average % by wt.	Standard deviation	Minimum % by wt.	Maximum % by wt.	Number of samples
Silicon dioxide	63.24	3.16	61.00	65.47	2
Aluminum oxide	10.31	0.01	10.30	10.31	2
Titanium dioxide	1.24	0.57	0.84	1.64	2
Iron oxide	5.46	0.61	5.03	5.89	2
Calcium oxide	7.26	1.05	6.52	8.00	2
Magnesium oxide	1.46	0.31	1.24	1.68	2
Potassium oxide	2.98	0.01	2.97	2.99	2
Sodium oxide	2.29	0.02	2.27	2.30	2
Sulfur trioxide	3.80	0.25	3.62	3.97	2
Phosphorus pentoxide	0.38	0.04	0.35	0.40	2
Lead oxide	1.03	0.97	0.34	1.71	2
Zinc oxide	-	-	-	-	-
Manganese oxide	-	-	-	-	-

a. Analyses below detection limit were assumed to be 1/2 the detection limit for calculation purposes.

Table 7-14. Summary data from Processor Site 2.

Total metals analysis, ppm in dry wood.											
Metal	Number of samples	Arithmetic average	Standard deviation	Minimum detected ^a	90 th percent-tile	85 th percent-tile	Maximum detected	Median	Upper confidence median ^b	Geometric mean	Lognormal MVU mean ^c
Arsenic	8	78.64	53.57	19.1	157.3	157.3	157.3	65.25	104.66	61.28	80.37
Chromium	8	49.44	32.35	12.5	89.5	89.5	89.5	38.5	65.56	39.35	50.39
Lead	8	572	318.94	248.5	1300	1300	1300	526.75	708.50	512.63	567.07
Titanium ^d	8	24.73	17.65	8.7	63.7	63.7	63.7	23.1	31.71	20.31	24.55
Titanium ^e	8	633.7	281.6	202	1066	1066	1066	-	-	-	-
Zinc	8	283.5	220.89	103	800	800	800	212.5	353.75	234.76	275.76
Barium	8	117.25	57.75	45	226	226	226	108	147.73	105.25	117.57
Cadmium	8	0.87	0.53	0.25	2	2	2	0.7	1.12	0.74	0.87
Copper	8	455.75	1149.38	25	3300	3300	3300	50.5	223.51	79.23	204.86
Mercury	8	0.125	-	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Nickel	8	5.63	6.89	2.5	22	22	22	2.5	6.57	3.79	5.04
Silver	8	0.302	0.24	0.025	0.65	0.65	0.65	0.285	0.42	0.19	0.34

Five metals analysis, ppm in dry wood.

Metal	Number of samples	Arithmetic average	Standard deviation	Minimum detected ^a	90 th percent-tile	85 th percent-tile	Maximum detected	Median	Upper confidence median ^b	Geometric mean	Lognormal MVU mean ^c
Arsenic	16	118.01	114.63	0.125	280.45	360.6	360.6	59.75	122.87	45.50	293.38
Chromium	16	56.47	49.64	2.5	144	146.5	146.5	37.5	60.48	35.41	63.18
Lead	16	594.89	502.69	141	1315	1970	1970	428.875	642.20	448.66	584.53
Titanium ^d	16	17.28	11.63	5.7	40.3	42.8	42.8	13.75	19.20	14.37	17.10
Zinc	16	217.25	118.58	86	440	455	455	174.5	244.38	190.57	216.64

- In cases where samples registered below the detection limit, one-half of the detection limit was used.
- Level for which there is 95% confidence that the median of any similar random sampling will show a lower value.
- The Minimum Variance Unbiased (MVU) estimator of the true median for a lognormal distribution (Gilbert, 1987).
- Values are suspect, see text in section 7.4.
- Calculated from minerals analysis.
- Meaningless, since most of the data are below detection limit.

Table 7-15. Processor Site 2 average incremental versus composite metals analysis.

Segment 1

	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	219.1-360.6	271.7	154	76.4
Chromium	86.5-146.5	126.5	91.25	38.6
Lead	187.5-444	323.1	334.75	-3.5
Titanium ^b	7.8- 14.5	10.9	13.9	-21.6
Zinc	124 -190	151.8	223	-31.9

Segment 2

	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	44.1- 198.5	102.9	81.1	26.9
Chromium	21.5- 51.5	38.4	45	-14.7
Lead	260.5-1315	715.4	575.5	24.3
Titanium ^b	12.5- 40.3	24.8	26.4	-6.1
Zinc	162 - 380	270.5	240	12.7

Segment 7

	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	0.25- 222.4	77.7	43.2	79.9
Chromium	5.0 - 108	44.1	30	47.0
Lead	244 - 830	476.6	486.5	-2.0
Titanium ^b	7.1 - 42.8	20.1	13.7	46.7
Zinc	92 - 455	228	159	43.4

Segment 8

	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	1.65- 39.2	19.7	19.1	3.1
Chromium	7.5 - 29	16.9	12.5	35.2
Lead	244 -830	476.6	456	4.5
Titanium ^b	5.7 - 18.3	13.2	30.1	-56.1
Zinc	86 -440	218.8	265	-17.4

a. Arithmetic mean based on 4 samples.

B. Titanium values are suspect. See text.

7.5.2.3 Processor - Site 3

Site 3 generally accepts all forms of wood waste except creosote- treated woods. Workers at the facility hand pick wood from the dumping floor which then goes through a picking station to further remove unwanted materials from the fuel. Access to this site was very limited. As a result, only one stockpile segment could be sampled.

Tables 7-17 through 7-19 present the limited results of the sampling at site 3. The results of the ultimate/proximate analysis appear consistent with those from the other facilities. The one exception is the high chlorine value of 0.16 percent dry weight, the highest value of all the processors. This

Table 7-16. Processor Site 2 Toxic Characteristic Leachate Procedure (TCLP) in laboratory ash (heavy metals), mg/l.

Metal	Average value ^a	Maximum	Detection limit	U.S. EPA limit	Number of samples
Arsenic	ND	ND	0.5	5	2
Barium	ND	ND	1	100	2
Cadmium	ND	ND	0.2	1	2
Chromium	7.65	11	0.2	5	2
Lead	ND	ND	2	5	2
Selenium	ND	ND	0.5	1	2
Silver	ND	ND	0.1	5	2
Mercury	ND	ND	0.1	0.2	2

a. Analyses below detection limit were assumed to be 1/2 the detection limit for calculation purposes.

suggests the presence of PVC plastics or treated/glued woods containing chlorine. Also, sulfur and ash contents, when compared to facility averages, are low, suggesting a fairly clean product.

No phenol compounds were detected above detection limits in the wood analyzed. The detection limits, however, were the highest of all the facilities tested. The minerals analysis of laboratory-prepared ash from this wood showed average levels of silicon dioxide and calcium oxide. These were the principal components of the ash.

The metals analysis of the wood shows levels relative to and slightly lower than the amount seen at other facilities. The composite sample for this site measured the smallest amount of zinc detected for all the sites. However, this site also measured the highest level of nickel (53 ppm) and the second highest level of cadmium (1.7 ppm) of all the facilities tested.

The consistency of the fuel at this site is variable and can be seen in the results of the incremental analyses. Also these samples were taken from a small cross-section of the processed wood on site.

The results of the TCLP test on laboratory ash for this facility show failure levels for chromium and a high level of arsenic leaching. This is somewhat puzzling considering the reasonably low levels of arsenic and chromium found in the wood.

7.5.2.4 Processor - Site 4

The primary product of site 4 is mulch for landscaping. The facility also produces wood fuel as a secondary product. The facility refuses to accept treated woods (creosote, CCA) but will accept some painted woods. Since the facility's main product is mulch no effort is made to remove soil from the wood. All samples taken from this site were from wood piles of a size grading appropriate for wood fuel.

Table 7-17. Summary data from Processor Site 3.

Wood ultimate analysis

	Average	Standard deviation	Minimum	Maximum	Number of samples
As received					
% moisture	5.19	-	-	-	1
Btu/lb	8339	-	-	-	1
Dry basis					
% carbon	52.9	-	-	-	1
% hydrogen	5.85	-	-	-	1
% nitrogen	0.51	-	-	-	1
% sulfur	0.08	-	-	-	1
% ash	3.87	-	-	-	1
% oxygen (difference)	36.79	-	-	-	1
% chlorine	0.16	-	-	-	1
% volatile	78.52	-	-	-	1
% fixed carbon	17.61	-	-	-	1
Btu/lb	8795	-	-	-	1

Phenols in wood

	Average µg/g	Standard deviation	Minimum µg/g	Maximum µg/g	Number of samples
Phenol ^a	<2.64	-	-	-	1
Pentachlorophenol	<13.60	-	-	-	1
2-chlorophenol	<2.64	-	-	-	1
2-nitrophenol	<2.64	-	-	-	1
2,4-dimethylphenol	<2.64	-	-	-	1
2,4-dichlorophenol	<2.64	-	-	-	1
4-chloro-3-methylphenol	<2.64	-	-	-	1
2,4,6-trichlorophenol	<2.64	-	-	-	1
2,4-dinitrophenol	<13.64	-	-	-	1
4-nitrophenol	<13.64	-	-	-	1
2-methyl-4,6-dinitrophenol	<13.64	-	-	-	1

Mineral analysis of laboratory ash.

	Average % by wt.	Standard deviation	Minimum % by wt.	Maximum % by wt.	Number of samples
Silicon dioxide	36.55	-	-	-	1
Aluminum oxide	7.14	-	-	-	1
Titanium dioxide	1.64	-	-	-	1
Iron oxide	4.78	-	-	-	1
Calcium oxide	22.4	-	-	-	1
Magnesium oxide	3.92	-	-	-	1
Potassium oxide	5.6	-	-	-	1
Sodium oxide	4.62	-	-	-	1
Sulfur trioxide	9.46	-	-	-	1
Phosphorus pentoxide	2.04	-	-	-	1
Lead oxide	-	-	-	-	1
Zinc oxide	-	-	-	-	1
Manganese oxide	-	-	-	-	1

a. Analyses below detection limit were assumed to be ½ the detection limit for calculation purposes.

Table 7-18. Summary data from Processor Site 3 elemental metals analysis (ppm in dry wood). Negative values represent detection limits.

Description	As	Cr	Pb	Ti	Zn	Ba	Cd	Cu	Hg	Ni	Ag
Increment	20.9	16.5	259.5	8.7	350						
Increment	53.3	15.5	105.6	18.05	250						
Increment	112.9	35.5	88	13.68	88						
Increment	1.66	-5	25	2.58	2						
Combination	7.22	17	59.5	8.1	2.5	72.8	1.7	37	-0.25	53	0.075

Table 7-19. Processor Site 3 Toxic Characteristic Leachate Procedure (TCLP) in laboratory ash (heavy metals), mg/l.

Metal	Average value ^a	Detection limit	U.S. EPA limit	Number of samples
Arsenic	3.7	0.5	5	1
Barium	ND	1	100	1
Cadmium	ND	0.2	1	1
Chromium	20	0.2	5	1
Lead	ND	2	5	1
Selenium	ND	0.5	1	1
Silver	ND	0.1	5	1
Mercury	ND	0.1	0.2	1

^a Analyses below detection limit were assumed to be 1/2 the detection limit for calculation purposes.

Table 7-20 through 7-23 present the results of the sampling at site 4. The ultimate/proximate analyses indicate a high ash content of 16 percent dry weight in the wood. This high ash, coupled with a moisture content of 20 percent, significantly lowers the value of this wood as a fuel (6033 Btu/lb). The wood at this site is regularly wetted and mixed to promote decay. Wood portions sold as fuel are the remains from this process.

Low sulfur and chlorine levels for this site suggested that the facility is successful in either preventing or removing contaminants such as tarpaper and PVC plastics from the waste stream.

Of the phenol compounds tested, only one sample showed the presence of pentachlorophenol at 31 ppm. This one value suggests that some penta-treated wood was delivered to the site and escaped detection. Wood piles are not mixed together at the site but are instead kept separate to keep track of aging.

The results of the two minerals analyses are remarkably alike, with no significant variation between the samples. The principal component of the ash

Table 7-20. Processor Site 4.

Wood ultimate analysis					
	Average	Standard deviation	Minimum	Maximum	Number of samples
As received					
% moisture	20.01	2.87	15.96	22.63	4
Btu/lb	6033	406.23	5440	6362	4
Dry basis					
% carbon	45.38	3.23	42.04	49.19	4
% hydrogen	5.17	0.71	4.17	5.79	4
% nitrogen	0.73	0.12	0.58	0.83	4
% sulfur	0.05	0.03	0.02	0.08	4
% ash	15.99	11.21	5.61	31.26	4
% oxygen (difference)	32.69	7.70	21.64	38.81	4
% chlorine	0.06	0.00	0.05	0.06	4
% volatile	68.47	7.80	59.47	76.49	4
% fixed carbon	15.55	4.24	9.27	18.31	4
Btu/lb	7542.75	460.57	7031	8076	4

Phenols in wood					
	Average µg/g	Standard deviation	Minimum µg/g	Maximum µg/g	Number of samples
Phenol ^a	<1.74	-	<0.99	<2.64	4
Pentachlorophenol	10.51	13.70	2.55	31.00	4
2-chlorophenol	<1.74	-	<0.99	<2.64	4
2-nitrophenol	<1.74	-	<0.99	<2.64	4
2,4-dimethylphenol	<1.74	-	<0.99	<2.64	4
2,4-dichlorophenol	<1.74	-	<0.99	<2.64	4
4-chloro-3-methylphenol	<1.74	-	<0.99	<2.64	4
2,4,6-trichlorophenol	<1.74	-	<0.99	<2.64	4
2,4-dinitrophenol	<8.92	-	<5.10	<13.60	4
4-nitrophenol	<8.92	-	<5.10	<13.60	4
2-methyl-4,6-dinitrophenol	<8.92	-	<5.10	<13.60	4

Mineral analysis of laboratory ash.					
	Average % by wt.	Standard deviation	Minimum % by wt.	Maximum % by wt.	Number of samples
Silicon dioxide	64.32	0.20	64.18	64.46	2
Aluminum oxide	10.86	0.48	10.52	11.20	2
Titanium dioxide	0.63	0.04	0.60	0.66	2
Iron oxide	6.13	0.33	5.89	6.36	2
Calcium oxide	6.46	0.08	6.40	6.51	2
Magnesium oxide	2.54	0.08	2.48	2.60	2
Potassium oxide	3.47	0.09	3.40	3.53	2
Sodium oxide	2.38	0.00	2.38	2.38	2
Sulfur trioxide	0.71	0.16	0.60	0.82	2
Phosphorus pentoxide	1.00	0.00	1.00	1.00	2
Lead oxide	0.24	0.04	0.21	0.26	2
Zinc oxide	-	-	-	-	-
Manganese oxide	-	-	-	-	-

a. Analyses below detection limit were assumed to be ½ the detection limit for calculation purposes.

Table 7-21. Summary data from Processor Site 4.

Total metals analysis, ppm in dry wood.											
Metal	Number of samples	Arithmetic average	Standard deviation	Minimum detected ^a	90 th percentile	85 th percentile	Maximum detected	Median	Upper confidence median ^b	Geometric mean	Lognormal MVU mean ^c
Arsenic	8	6.95	4.87	1.11	15.7	15.7	15.7	6.4	9.74	5.02	7.56
Chromium	8	1.13	6.59	5	23.5	23.5	23.5	12.75	16.97	11.49	13.30
Lead	8	93.50	41.09	43	159.5	159.5	159.5	96.75	116.93	85.23	93.86
Titanium ^d	8	37.44	15.74	16.9	69.6	69.6	69.6	38.45	46.14	34.65	37.51
Titanium ^e	8	530.5	208.4	398	663	663	663	-	-	-	-
Zinc	8	129.38	46.20	80	215	215	215	126.5	155.15	122.50	129.31
Barium	8	75.94	22.63	33.5	107	107	107	77	91.02	72.26	76.47
Cadmium	8	0.41	0.23	0.25	0.75	0.75	0.75	0.25	0.52	0.36	0.41
Copper	8	15.69	8.11	6	31	31	31	15.75	20.12	13.79	15.82
Mercury	8	0.125	-	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Nickel	8	13.00	8.34	2.5	26	26	26	12.75	18.05	9.84	13.90
Silver	8	0.108	0.09	0.025	0.3	0.3	0.3	0.075	0.14	0.09	0.11

Five metals analysis, ppm in dry wood.

Metal	Number of samples	Arithmetic average	Standard deviation	Minimum detected ^a	90 th percentile	85 th percentile	Maximum detected	Median	Upper confidence median ^b	Geometric mean	Lognormal MVU mean ^c
Arsenic	15	7.75	9.58	0.28	14.9	37.4	37.4	5.7	7.29	3.58	9.09
Chromium	15	15.83	10.43	2.5	30.5	32	32	16	18.25	11.51	17.23
Lead	15	119.77	81.01	29	237.5	286	286	110.5	135.91	94.23	121.89
Titanium ^d	15	43.73	43.58	10.5	76.6	176.5	176.5	27	46.32	30.97	42.22
Zinc	15	200.47	276.28	63	210	1180	1180	132	198.94	138.29	178.24

- a. In cases where samples registered below the detection limit, one-half of the detection limit was used.
 b. Level for which there is 95% confidence that the median of any similar random sampling will show a lower value.
 c. The Minimum Variance Unbiased (MVU) estimator of the true median for a lognormal distribution (Gilbert, 1987).
 d. Values are suspect, see text in section 7.4.
 e. Calculated from minerals analysis.
 f. Meaningless, since most of the data are below detection limit.

Table 7-22. Processor Site 4 average incremental vs. Composite metals analysis.

Segment 1

	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	0.28- 37.4	9.7	1.115	770
Chromium	2.5 - 23.5	8.3	5	66.0
Lead	29 - 63	41.875	43	-2.6
Titanium ^b	11.5 - 17.2	14.5	22.1	-34.4
Zinc	63 -120	80.3	95	-15.5

Segment 2

	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	2.47- 12.1	5.98	8.3	-28.0
Chromium	16 - 27	20.4	17.5	16.6
Lead	110.5 - 180.5	140.3	159.5	-12.0
Titanium ^b	23.1 - 176.5	79.9	16.9	372.8
Zinc	169 -1180	427.5	215	98.8

Segment 7

	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	6.9- 14.9	11.3	7.1	59.2
Chromium	10 - 32	24.4	18.5	31.9
Lead	107.5-286	213	128	66.4
Titanium ^b	32.8- 76.6	55	37.1	48.2
Zinc	81 -210	146.8	154	-4.7

Segment 8

	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	0.77- 5.7	2.73	15.7	-82.6
Chromium	5 - 11.5	8.5	14.5	-41.4
Lead	44.5 -114.5	72	110	-34.5
Titanium ^b	10.5 - 27	19.5	39.8	-51.0
Zinc	63 -132	96.3	158	-39.1

a. Arithmetic mean based on 4 samples.

B. Titanium values are suspect. See text.

is silicon at a level of 64 percent. This strongly suggests that the bulk of the high ash content is the result of soil mixed in the wood.

Metal analysis at this site indicated a very low variance between sample values. This is even true with the incremental analysis. Upon further examination, the composite data from this site is seen to follow a normal rather than lognormal distribution. The medians and arithmetic averages are almost identical for each metal including most of the incremental analysis. This case demonstrates very well how compositing samples will most accurately characterize bulky waste. Over the months the wood piles are allowed to decompose they are repeatedly mixed. This compositing results in the normal distribution seen in even the incremental samples.

When compared to the median values for all six facilities, the metals content in this facility's wood is somewhat lower in all cases except titanium. However, considering the unusually high ash content of this wood, the lb/MMBtu of metals emissions from a boiler could be somewhat higher even though the metals concentrations in ash will be very dilute.

Using representative values from the analysis of CCA treated wood, estimates of CCA contamination were calculated for this site. Assuming that 100 percent of the chromium, copper, and arsenic found in this fuel is the result of CCA treated wood, the wood from this facility ranges from 0.1 percent to 2.9 percent CCA and averages 0.8 percent, lowest of all the sites and indicative that CCA can adequately be removed from the waste fuel stream if the processors desires to do so.

The results of the TCLP tests on laboratory ash show some leaching of barium, chromium, and silver, but none of these exceed regulatory levels.

Table 7-23. Processor Site 4 Toxic Characteristic Leachate Procedure (TCLP) in laboratory ash (heavy metals), mg/l.

Metal	Average value ^a	Maximum	Detection limit	U.S. EPA limit	Number of samples
Arsenic	ND	ND	0.5	5	2
Barium	0.8	1.1	1	100	2
Cadmium	ND	ND	0.2	1	2
Chromium	1.1	1.4	0.2	5	2
Lead	ND	ND	2	5	2
Selenium	ND	ND	0.5	1	2
Silver	0.13	0.2	0.1	5	2
Mercury	ND	ND	0.1	0.2	2

^a Analyses below detection limit were assumed to be 1/2 the detection limit for calculation purposes.

7.5.2.5 Processor - Site 6

Site 6 accepts all forms of wood waste; however, treated woods are sorted out before processing the wood into a fuel product. The fuel is processed using a shaker screen, float tank, picking station, and trommel screen. Samples were collected from cross sections of all of the available processed wood fuel and from both process lines.

Tables 24 through 27 present the results of the sampling at site 6. The results of the ultimate/proximate analysis are similar to those of the other sites and vary little except for moisture and ash content. Moisture content ranged between 15.9 and 35.2 weight percent, averaging 23.75 percent while ash content ranged between 2.94 and 8.58 dry weight percent. The ash content is somewhat lower than the average of the facilities but is still much higher than clean wood, which indicates the presence of non-wood contaminants in the fuel. Percent sulfur varied over a broader range than seen at other sites and averaged at 0.15 percent, the highest average sulfur content of all the sites visited. This suggests the

Table 7-24. Processor Site 6.

Wood ultimate analysis					
	Average	Standard deviation	Minimum	Maximum	Number of samples
As received					
% moisture	23.75	8.15	15.91	35.21	4
Btu/lb	6375	756	5346	7162	4
Dry basis					
% carbon	50.11	0.82	48.93	50.81	4
% hydrogen	5.87	0.17	5.71	6.08	4
% nitrogen	0.52	0.08	0.42	0.59	4
% sulfur	0.15	0.07	0.10	0.24	4
% ash	5.15	2.41	2.94	8.58	4
% oxygen (difference)	38.20	1.75	35.95	40.11	4
% chlorine	0.03	0.01	0.02	0.04	4
% volatile	78.53	1.72	76.37	80.35	4
% fixed carbon	16.33	1.04	15.05	17.50	4
Btu/lb	8352	131	8243	8517	4

Phenols in wood					
	Average µg/g	Standard deviation	Minimum µg/g	Maximum µg/g	Number of samples
Phenol ^a	<1.56	-	<0.99	<2.64	4
Pentachlorophenol	<8.08	-	<5.10	<13.6	4
2-chlorophenol	<1.56	-	<0.99	<2.64	4
2-nitrophenol	<1.56	-	<0.99	<2.64	4
2,4-dimethylphenol	<1.56	-	<0.99	<2.64	4
2,4-dichlorophenol	<1.56	-	<0.99	<2.64	4
4-chloro-3-methylphenol	<1.56	-	<0.99	<2.64	4
2,4,6-trichlorophenol	<1.56	-	<0.99	<2.64	4
2,4-dinitrophenol	<8.08	-	<5.10	<13.6	4
4-nitrophenol	<8.08	-	<5.10	<13.6	4
2-methyl-4,6-dinitrophenol	<8.08	-	<5.10	<13.6	4

Mineral analysis of laboratory ash.					
	Average % by wt.	Standard deviation	Minimum % by wt.	Maximum % by wt.	Number of samples
Silicon dioxide	52.67	1.22	51.80	53.53	2
Aluminum oxide	10.76	0.34	10.52	11.00	2
Titanium dioxide	1.78	0.11	1.70	1.86	2
Iron oxide	6.69	0.16	6.58	6.80	2
Calcium oxide	11.00	0.85	10.40	11.60	2
Magnesium oxide	2.91	0.13	2.82	3.00	2
Potassium oxide	2.67	0.09	2.60	2.73	2
Sodium oxide	2.57	0.18	2.44	2.70	2
Sulfur trioxide	7.05	0.26	6.86	7.23	2
Phosphorus pentoxide	0.60	0.00	0.60	0.60	2
Lead oxide	0.36	0.18	0.23	0.48	2
Zinc oxide	-	-	-	-	-
Manganese oxide	-	-	-	-	-

a. Analyses below detection limit were assumed to be ½ the detection limit for calculation purposes.

Table 7-25. Summary data from Processor Site 6.

Total metals analysis, ppm in dry wood.

Metal	Number of samples	Arithmetic average	Standard deviation	Minimum detected ^a	90 th percent-tile	85 th percent-tile	Maximum detected	Median	Upper confidence median ^b	Geometric mean	Lognormal MVU mean ^c
Arsenic	8	10.23	9.73	0.46	26.5	26.5	26.5	6.55	14.11	5.20	12.61
Chromium	8	12.34	7.53	2.5	22.5	22.5	22.5	10.75	16.57	9.98	12.74
Lead	8	121.81	45.09	59.5	190.5	190.5	190.5	112.75	148.30	114.32	122.06
Titanium ^d	8	24.05	9.82	14	41	41	41	20.6	29.27	22.41	24.01
Titanium ^e	8	542.6	246.6	498	587	587	587	-	-	-	-
Zinc	8	143.69	58.10	70	260	260	260	151.5	175.50	133.94	143.74
Barium	8	86.56	70.03	25	214	214	214	53	111.56	65.14	85.66
Cadmium	8	0.50	0.47	0.25	1.6	1.6	1.6	0.25	0.61	0.39	0.47
Copper	8	16.20	11.50	4	30.5	30.5	30.5	10.75	21.33	12.68	16.39
Mercury	8	0.125	-	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Nickel	8	6.84	4.27	2.5	13.5	13.5	13.5	6.875	9.00	5.59	6.94
Silver	8	0.092	0.08	0.025	0.27	0.27	0.27	0.0787	0.12	0.07	0.09

Five metals analysis, ppm in dry wood.

Metal	Number of samples	Arithmetic average	Standard deviation	Minimum detected ^a	90 th percent-tile	85 th percent-tile	Maximum detected	Median	Upper confidence median ^b	Geometric mean	Lognormal MVU mean ^c
Arsenic	16	2.46	2.92	0.125	6.93	9.79	9.79	1.255	2.29	1.24	2.63
Chromium	16	7.38	4.90	2.5	17.5	19	19	6.25	8.26	6.09	7.38
Lead	16	135.50	109.38	27	329.5	378	378	95	147.25	102.43	134.29
Titanium ^d	16	58.58	48.19	13.3	109	196	196	36.75	63.62	44.96	57.62
Zinc	16	154.28	111.34	48	345	420	420	101	170.02	125.87	151.72

- a. In cases where samples registered below the detection limit, one-half of the detection limit was used.
- b. Level for which there is 95% confidence that the median of any similar random sampling will show a lower value.
- c. The Minimum Variance Unbiased (MVU) estimator of the true median for a lognormal distribution (Gilbert, 1987).
- d. Values are suspect, see text in section 7.4.
- e. Calculated from minerals analysis.
- f. Meaningless, since most of the data are below detection limit.

Table 7-26. Processor Site 6 average incremental versus composite metals analysis.

Segment 1

	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	0.67- 1.26	1.00	0.8	25.0
Chromium	5 - 10	5.4	6.25	-13.6
Lead	43.5 -260.5	132.9	84.5	57.3
Titanium ^b	34.8 -196	110	30.7	258.3
Zinc	63 -204	125.6	97.5	28.8

Segment 2

	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	0.6- 6.93	2.71	7.3	-62.9
Chromium	5.5- 6.5	6	6.5	-7.7
Lead	68.5-104	90.6	108	-16.1
Titanium ^b	23.9- 38.4	30.5	14	117.9
Zinc	82 -101	93.8	100	-6.2

Segment 7

	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	1.87- 9.79	5.78	20	-71.1
Chromium	7.5 - 19	13.6	22.5	-39.6
Lead	27 -378	127	148	-14.2
Titanium ^b	23.3 -100.6	44.3	14.4	207.6
Zinc	48 -345	138	160	-13.8

Segment 8

	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	0.25- 0.75	0.4	5.8	-93.1
Chromium	5 - 7	5	13	-61.5
Lead	68 -329.5	191.5	190.5	0.5
Titanium ^b	13.3 - 80.2	49.6	41	21.0
Zinc	152 -420	260	260	-0.1

- a. Arithmetic mean based on 4 samples.
- B. Titanium values are suspect. See text.

presence of sulfur-containing materials such as asphalt, telephone poles, railroad ties, tarpaper, or wallboard.

Very little chlorine was detected in the sampled wood, suggesting adequate removal of PVC plastics and relatively little processing of chlorine-containing wood types. Observing the processor operation, it was noted that the float tanks removed all the plastics seen entering the system. All the phenols compounds tested were below detection limits and therefore the presence of phenol contaminants was minimal.

The results of the minerals analyses show that the two principal components of the ash are silicon dioxide and calcium oxide. This is consistent with most of the data from the other facilities. This bulk ash mixture is

characteristic of wood fuel in general with the high silicon mainly attributed to soil mixed in the wood.

Metals analysis at this site indicated similar results to those of site 4. Distribution curves of the data from the composite samples indicate a normal distribution in most cases with a few outliers. The results of the incremental analysis still follow the predicted lognormal distribution but to a lesser extent. Mercury was not detected above detection limits and the cadmium and the silver levels, when detected, were very low. Median and arithmetic averages for each of the metals tested except titanium and nickel were below the median and average of all the processors. Nickel values, when detected, were somewhat higher than most of the other facilities (not the highest).

This facility had two separate process lines. Comparing the ultimate analyses of samples from segment 7 and segment 8 (process line 1 and process line 2) the most obvious difference is the ash content.

Table 7-27. Processor Site 6 Toxic Characteristic Leachate Procedure (TCLP) in laboratory ash (heavy metals), mg/l.

Metal	Average value ^a	Maximum	Detection limit	U.S. EPA limit	Number of samples
Arsenic	ND	ND	0.5	5	2
Barium	ND	ND	1	100	2
Cadmium	ND	ND	0.2	1	2
Chromium	1.15	1.2	0.2	5	2
Lead	ND	ND	2	5	2
Selenium	ND	ND	0.5	1	2
Silver	ND	ND	0.1	5	2
Mercury	ND	ND	0.1	0.2	2

^a Analyses below detection limit were assumed to be 1/4 the detection limit for calculation purposes.

Process line 1 without a trommel has a much higher ash content than process line 2 which has a trommel. Percent ash values were 8.58 dry weight percent for line 1 and 2.94 dry weight percent for line 2. Another difference in the samples taken from the process lines is the results of the metals analyses. Process line 1 has much higher levels of arsenic, chromium, copper, and nickel than line 2 which suggests that process line 1, which deals with smaller sized wood waste, is seeing larger amounts of CCA treated woods. Even so, the calculated CCA contamination for the entire site ranged only from 0.2 to 2.9 percent CCA treated wood, averaging 0.9 percent.

The results of the TCLP tests on laboratory ash for this facility indicate some leaching of chromium within regulatory limits. The average leachate level for chromium was 1.15 mg/L and the regulatory level is 5 mg/L.

7.5.2.6 Processor - Site 7

Site 7 accepts and processes mostly construction wood waste and some demolition wood into hogged wood. Some manual effort is made to remove non-wood contaminants, and loads that are too contaminated are rejected. Conveyor samples could not be taken at this site and the amounts of processed wood were limited. Two of the eight samples are cross section combinations of the other segments.

Tables 7-28 through 7-31 present the results of the sampling at site 7. The ultimate/proximate analysis at this site is consistent with that at the other sites. The moisture content of this wood is very low, averaging about 5.4 weight percent. Visual inspection confirms that very little of this wood is "clean" unprocessed wood. Ash concentrations vary dramatically from 0.24 percent to 12.58 percent dry weight, averaging 6.4 percent.

Average sulfur content is fairly high at 0.1 percent suggesting that contaminants such as asphalt and tarpaper are present. Visual inspection of the samples confirmed these contaminants. Average chlorine levels of 0.05 percent suggest some contamination of chlorine-containing material. Visual inspection indicated the presence of plastics and particle board mixed with the processed wood.

The results of the minerals analysis show very low levels of silicon dioxide in the laboratory wood ash compared to previous results which strongly suggests that the nonwood components of the processed wood at this site are the result of paints or treatments on the wood rather than soil contamination.

To evaluate the accuracy of these results, metals analysis on composite samples was performed at a different test laboratory using different methods than the analysis of the other sites. With the exception of titanium, these results are similar to those of the other facilities. Incremental analysis was still performed using the previous laboratory and these results were consistent with the work of the new laboratory.

The consistently high levels of titanium suggest that the waste wood stream contained a lot of painted wood. The lower levels of lead than those seen at other sites suggest that only a small portion of the painted wood is contaminated with lead-based paints. These results, coupled with very low moisture content of the wood, suggest that most of the wood collected by this site comes from manufacturing and construction sources rather than demolition and land-clearing sources.

Most of the metals concentrations are significantly lower than those at other sites, especially lead, zinc and barium. Since this facility basically does not remove contaminated materials from the waste stream, it would appear that this facility is controlling its waste wood fuel quality by limiting the type of waste wood it receives.

Assuming 100 percent of the arsenic, chromium, and copper present in the wood is the result of CCA treatment, the estimated level of CCA treated wood at this site was calculated. The resulting values range from 0.2 to 8.0 percent CCA wood and averaged 1.0 percent.

The results of the TCLP tests on laboratory ash for this facility show failure for chromium. Chromium levels in the leachate were 12 mg/L and 6.2 mg/L while the USEPA regulatory level is 5 mg/L.

7.5.2.7 **Combination of Six Processors**

Table 7-28. Processor Site 7.

Wood ultimate analysis					
	Average	Standard deviation	Minimum	Maximum	Number of samples
As received					
% moisture	5.37	0.30	5.06	5.75	4
Btu/lb	7984	263	7620	8244	4
Dry basis					
% carbon	50.45	2.31	47.26	52.52	4
% hydrogen	5.86	0.18	5.62	6.03	4
% nitrogen	0.62	0.04	0.59	0.68	4
% sulfur	0.1	0.03	0.06	0.14	4
% ash	6.4	5.28	0.24	12.58	4
% oxygen (difference)	36.57	3	33.79	40.54	4
% chlorine	0.05	0.01	0.04	0.05	4
% volatile	77.24	2.82	73.26	79.24	4
% fixed carbon	16.36	6.41	8.18	22.29	4
Btu/lb	8437	289.25	8040	8718	4

Phenols in wood					
	Average µg/g	Standard deviation	Minimum µg/g	Maximum µg/g	Number of samples
Phenol ^a	<1.98	-	<1.65	<2.31	4
Pentachlorophenol	<10.20	-	<8.50	<11.90	4
2-chlorophenol	<1.98	-	<1.65	<2.31	4
2-nitrophenol	<1.98	-	<1.65	<2.31	4
2,4-dimethylphenol	<1.98	-	<1.65	<2.31	4
2,4-dichlorophenol	<1.98	-	<1.65	<2.31	4
4-chloro-3-methylphenol	<1.98	-	<1.65	<2.31	4
2,4,6-trichlorophenol	<1.98	-	<1.65	<2.31	4
2,4-dinitrophenol	<10.20	-	<8.50	<11.90	4
4-nitrophenol	,10.20	-	<8.50	<11.90	4
2-methyl-4,6-dinitrophenol	<10.20	-	<8.50	<11.90	4

Mineral analysis of laboratory ash.					
	Average % by wt.	Standard deviation	Minimum % by wt.	Maximum % by wt.	Number of samples
Silicon dioxide	29.46	4.12	26.54	32.37	2
Aluminum oxide	4.42	0.13	4.32	4.51	2
Titanium dioxide	0.91	0.04	0.88	0.94	2
Iron oxide	4.99	1.85	3.68	6.29	2
Calcium oxide	32.84	3.34	30.48	35.2	2
Magnesium oxide	6.34	0.37	6.08	6.6	2
Potassium oxide	4.55	0.07	4.5	4.6	2
Sodium oxide	3.25	0.18	3.12	3.38	2
Sulfur trioxide	5.46	1.01	4.74	6.17	2
Phosphorus pentoxide	0.6	0	0.6	0.6	2
Lead oxide	-	-	-	-	-
Zinc oxide	-	-	-	-	-
Manganese oxide	-	-	-	-	-

a. Analyses below detection limit were assumed to be ½ the detection limit for calculation purposes.

Table 7-29. Summary data from Processor Site 7.

Total metals analysis, ppm in dry wood.											
Metal	Number of samples	Arithmetic average	Standard deviation	Minimum detected ^a	90 th percentile	85 th percentile	Maximum detected	Median	Upper confidence median ^b	Geometric mean	Lognormal MVU mean ^c
Arsenic	8	4.75	1.83	1	6	6	6	5.5	6.39	4.2	4.97
Chromium	8	15.4	3.62	11.5	21.8	21.8	21.8	14.7	169.76	15.05	838.13
Lead	8	50.3	15.72	22.9	67.5	67.5	67.5	51.3	61.13	47.66	50.61
Titanium ^d	8	342.4	49.57	307.2	460.8	460.8	460.8	323.2	370.46	339.71	342.20
Titanium ^e	2	353	176.9	226	480	480	480	-	-	-	-
Zinc	8	59.8	19.61	41.0	93.2	93.2	93.2	51.2	70.50	57.26	59.72
Barium	8	50.3	27.18	15	97	97	97	50.5	65.44	43.21	50.96
Cadmium	8	0.90	0.51	0.38	1.6	1.6	1.6	0.736	1.15	0.78	0.90
Copper	8	22.5	25.34	9.4	84.7	84.7	84.7	14.2	26.68	16.68	20.58
Mercury	8	0.073	0.026	0.04	0.1	0.1	0.1	0.075	0.088	0.068	0.073
Nickel	8	4.2	0.65	3.2	5.12	5.12	5.12	4.416	4.66	4.19	4.23
Silver	8	0.113	0.04	0.1	0.2	0.2	0.2	0.1	0.13	0.11	0.11

Five metals analysis, ppm in dry wood.

Metal	Number of samples	Arithmetic average	Standard deviation	Minimum detected ^a	90 th percentile	85 th percentile	Maximum detected	Median	Upper confidence median ^b	Geometric mean	Lognormal MVU mean ^c
Arsenic	16	8.30	11.28	0.41	27	39.2	39.2	3.875	6.99	3.72	8.16
Chromium	16	10.63	9.01	2.5	28	31.5	31.5	8.75	11.44	7.51	10.79
Lead	16	39.22	26.73	6.5	64	123.5	123.5	36.5	44.32	32.46	39.65
Titanium ^d	16	14.26	9.43	3.5	25.29	37.68	37.68	14.08	16.08	11.28	14.60
Zinc	16	38.06	16.91	18	52.5	88	88	33.25	42.58	35.15	37.94

- In cases where samples registered below the detection limit, one-half of the detection limit was used.
- Level for which there is 95% confidence that the median of any similar random sampling will show a lower value.
- The Minimum Variance Unbiased (MVU) estimator of the true median for a lognormal distribution (Gilbert, 1987).
- Values are suspect, see text in section 7.4.
- Calculated from minerals analysis.
- Meaningless, since most of the data are below detection limit.

Table 7-30. Processor Site 7 average incremental versus composite metals analysis.

Segment 1

	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	1 - 5.21	2.2725	5	-54.6
Chromium	5 -11.5	5.5	14.1	-61.0
Lead	23 -64	41.375	46.464	-11.0
Titanium ^b	6.77-15.24	12.535	460.8	-97.3
Zinc	31.5 -45	38.5	43.52	-11.5

Segment 2

	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	1.08-39.2	11.8175	6	97.0
Chromium	5 -28	11.625	17.6	-33.9
Lead	6.5 -42.5	23.75	67.52	-64.9
Titanium ^b	3.87-19.48	8.985	320	-97.2
Zinc	18.5 -40.5	30.625	71.04	-56.9

Segment 7

	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	0.41-27	8.185	6	36.4
Chromium	5 -31.5	11.25	18.5	-39.2
Lead	23 -43.5	28.375	51.392	-44.8
Titanium ^b	3.5 -14.99	8.9075	320	-97.2
Zinc	18 -29	24.625	51.2	-51.9

Segment 8

	Incremental range, ppm	Incremental average ^a , ppm	Combine segment, ppm	Percent difference
Arsenic	4.15- 20.2	10.925	5	118.5
Chromium	10.5 - 18	14.125	12.5	13.0
Lead	35 -123.5	63.375	64	-1.0
Titanium ^b	21.46- 37.68	26.605	326.4	-91.8
Zinc	44.5 - 88	58.5	45.696	28.0

a. Arithmetic mean based on 4 samples.

B. Titanium values are suspect. See text.

Tables 7-32 through 7-34 summarize results of the sampling at all six processor sites. The following subsections discuss these results, variations in the data, and conclusions that can be made of processed wood as a whole.

7.5.2.7.1 Ultimate/Proximate Analysis

A total of 21 composite samples from six processors were analyzed for ultimate/proximate properties. Reviewing the data as a whole, four of these results vary the most, the weight percent analyses of moisture, sulfur, ash, and chlorine found in the wood. The other results do not vary significantly.

The overall heating value for this wood averaged 8260 Btu/lb dry wood which is somewhat lower than typical values available in the literature and may be

Table 7-31. Processor Site 7 Toxic Characteristic Leachate Procedure (TCLP) in laboratory ash (heavy metals), mg/l.

Metal	Average value ^a	Maximum	Detection limit	U.S. EPA limit	Number of samples
Arsenic	ND	ND	0.5	5	2
Barium	ND	ND	1	100	2
Cadmium	ND	ND	0.2	1	2
Chromium	9.1	12	0.2	5	2
Lead	ND	ND	2	5	2
Selenium	ND	ND	0.5	1	2
Silver	ND	ND	0.1	5	2
Mercury	ND	ND	0.1	0.2	2

^a Analyses below detection limit were assumed to be 1/2 the detection limit for calculation purposes.

attributed to the higher ash content in processed waste wood compared to "clean" wood.

Moisture and ash concentrations varied the most in this program. Moisture is not normally an environmental concern but is important for maintaining stable operating conditions in a boiler. Moisture content varies too much even in pure wood products to be used as anything but a general indicator as to the source and quality of the fuel. In general, high moisture contents indicate larger silvicultural portions in waste fuel, while low moisture may indicate larger portions of construction and processed woods.

High ash contents indicate contamination of the wood from two sources. The primary source of ash seems to be the inclusion of dirt in the wood characterized by high levels of silicon in the ash. Ash of this sort is not too environmentally important except for the possibility of over-taxing particulate control devices and increasing particulate emissions. Screening the waste wood product during various processing stages significantly limits dirt from the final product. Another source of ash is the inclusion of nonwood materials such as asphalt, tarpaper, insulation, and metals as well as a variety of paints and coatings. This source of ash is the most important environmentally. Ferrous metals in the form of nails, staples, or fixtures are fairly easy to remove with magnetic separators and constitute a valuable by-product of scrap metal. Metals, tar paper, insulation and plastics can be removed from wood quite easily using float tanks. As observed during the site visits, when float tanks and metals removal systems were properly functioning there was very little solid contamination in the waste wood product. However, the removal of "treated" woods is more difficult and is best accomplished by limiting the type of wood a facility will accept. Otherwise, if a facility accepts all types of wood, the wood product quality is controlled by the types of "treated" woods hand picked from the fuel stream. This requires a high level of attention and control in inspecting and enforcing the manual picking operations.

Asphalt and tarpaper or shingles contamination can be inferred somewhat from sulfur concentrations in the fuel. Unfortunately certain wood types such as

Table 7-32. Combination of six processors.

Wood ultimate analysis					
	Average	Standard deviation	Minimum	Maximum	Number of samples
As received					
% moisture	17.08	8.02	5.06	35.21	21
Btu/lb	6858	839	5346	8339	21
Dry basis					
% carbon	49.52	2.86	42.04	52.9	21
% hydrogen	5.76	0.44	4.17	6.2	21
% nitrogen	0.57	0.12	0.36	0.83	21
% sulfur	0.094	0.049	0.02	0.24	21
% ash	7.82	7.45	0.24	31.26	21
% oxygen (difference)	36.24	4.69	21.64	40.54	21
% chlorine	0.054	0.033	0.02	0.16	21
% volatile	76.95	5.58	59.47	82.51	21
% fixed carbon	15.23	4.49	1.03	22.29	21
Btu/lb	8261	453.7	7031	8795	21

Phenols in wood					
	Average µg/g	Standard deviation	Minimum µg/g	Maximum µg/g	Number of samples
Phenol ^a	0.87	0.34	0.33	1.60	22
Pentachlorophenol	8.93	11.69	0.85	43.00	22
2-chlorophenol	<1.47	-	<0.33	<2.64	22
2-nitrophenol	<1.47	-	<0.33	<2.64	22
2,4-dimethylphenol	<1.47	-	<0.33	<2.64	22
2,4-dichlorophenol	<1.47	-	<0.33	<2.64	22
4-chloro-3-methylphenol	<1.47	-	<0.33	<2.64	22
2,4,6-trichlorophenol	<1.47	-	<0.33	<2.64	22
2,4-dinitrophenol	<7.572	-	<1.7	<13.6	22
4-nitrophenol	<7.572	-	<1.7	<13.6	22
2-methyl-4,6-dinitrophenol	<7.572	-	<1.7	<13.6	22

Mineral analysis of laboratory ash.					
	Average % by wt.	Standard deviation	Minimum % by wt.	Maximum % by wt.	Number of samples
Silicon dioxide	48.33	14.22	26.54	65.47	12
Aluminum oxide	8.55	2.48	4.32	11.2	12
Titanium dioxide	1.19	0.45	0.6	1.86	12
Iron oxide	6.44	1.66	3.68	9.83	12
Calcium oxide	15.32	9.79	6.4	35.2	12
Magnesium oxide	3.53	1.74	1.24	6.6	12
Potassium oxide	3.61	0.93	2.6	5.6	12
Sodium oxide	2.94	0.75	2.27	4.62	12
Sulfur trioxide	5.76	3.14	0.6	9.96	12
Phosphorus pentoxide	0.84	0.46	0.35	2.04	12
Lead oxide	0.51	0.47	0.21	1.71	9
Zinc oxide	0.68	0.18	0.52	0.88	3
Manganese oxide	0.28	-	0.28	0.28	2

a. Analyses below detection limit were assumed to be 1/2 the detection limit for calculation purposes.

Table 7-33. Summary data from six wood processors.

Total metals analysis, ppm in dry wood.

Metal	Number of samples	Arithmetic average	Standard deviation	Minimum detected ^a	90 th percent-tile	85 th percent-tile	Maximum detected	Median	Upper confidence median ^b	Geometric mean	Lognormal MVU mean ^c
Arsenic	41	33.13	53.66	0.46	105.00	142.40	262.50	7.30	17.96	11.36	35.43
Chromium	41	38.46	50.91	2.50	91.25	106.00	233.00	17.60	29.49	21.76	36.15
Lead	41	218.93	238.88	22.91	486.50	575.50	1300.00	127.00	186.00	140.91	215.54
Titanium ^d	41	93.61	129.00	8.10	320.00	332.80	460.80	32.60	61.28	43.20	84.42
Titanium ^e	12	444.92	249.96	132.00	663.00	1066.00	1066.00	391.50	526.63	386.81	446.83
Zinc	41	155.94	130.76	2.50	260.00	340.00	800.00	134.00	152.15	117.23	170.60
Barium	41	151.79	162.16	15.00	450.00	550.00	630.00	87.00	128.36	97.39	148.28
Cadmium	41	0.86	0.56	0.25	1.60	1.60	2.00	0.70	0.84	0.67	44.26
Copper	41	109.14	511.40	4.00	65.50	84.67	3300.00	22.00	33.99	24.48	(d)
Mercury	41	0.10	0.04	0.03	0.13	0.13	0.13	0.13	(d)	(d)	7.82
Nickel	41	8.31	9.43	2.00	19.00	22.00	53.00	5.00	7.23	5.69	0.55
Silver	41	0.61	0.95	0.03	2.50	2.50	2.50	0.10	0.30	0.19	

Five metals analysis, ppm in dry wood.

Metal	Number of samples	Arithmetic average	Standard deviation	Minimum detected ^a	90 th percent-tile	85 th percent-tile	Maximum detected	Median	Upper confidence median ^b	Geometric mean	Lognormal MVU mean ^c
Arsenic	83	50.25	106.43	0.13	219.10	262.00	662.00	6.46	11.63	7.45	66.84
Chromium	83	42.45	81.22	0.75	108.00	146.50	475.00	15.50	20.94	15.72	39.81
Lead	83	258.74	378.31	6.50	561.00	830.00	2250.00	141.00	168.16	131.69	259.16
Titanium ^d	83	48.17	82.42	2.58	102.00	176.50	537.00	23.00	30.59	24.37	43.75
Zinc	83	219.93	347.40	2.00	405.00	480.00	2100.00	116.00	151.29	120.86	214.09

- a. In cases where samples registered below the detection limit, one-half of the detection limit was used.
- b. Level for which there is 95% confidence that the median of any similar random sampling will show a lower value.
- c. The Minimum Variance Unbiased (MVU) estimator of the true median for a lognormal distribution (Gilbert, 1987).
- d. Values are suspect, see text in section 7.4.
- e. Calculated from minerals analysis.
- f. Meaningless, since most of the data are below detection limit.

Table 7-34. Combination of six processors Toxic Characteristic Leachate Procedure (TCLP) in laboratory ash (heavy metals), mg/l.

Metal	Average value ^a	Maximum	Detection limit	U.S. EPA limit	Number of samples
Arsenic	0.532	0.5	0.5	5	12
Barium	0.55	1.1	1	100	12
Cadmium	0.1	0.1	0.2	1	12
Chromium	12.57	46	0.2	5	12
Lead	2.083	14	2	5	12
Selenium	0.25	0.25	0.5	1	12
Silver	0.0625	0.2	0.1	5	12
Mercury	0.05	0.05	0.1	0.2	12

^a Analyses below detection limit were assumed to be 1/2 the detection limit for calculation purposes.

telephone poles and railroad ties contain high levels of sulfur as well. Visually those sites using float tanks showed no sign of asphalt or tarpaper in the product. Many of these sites also process telephone poles which increase the sulfur content of the waste wood. Of all the sites the lowest levels of sulfur were found at site 4. This site refuses any shipments containing either asphalt or creosote-treated woods.

High chlorine values in wood fuel have been thought to be the result of PVC plastics in the wood waste. However, from the analysis of pure woods, telephone poles and woods using resins as binding agents also contain higher levels of chlorine. These waste wood types in addition to PVC would be a major source of chlorine contaminants. Chlorine values ranged from 0.02 percent to 0.16 percent dry weight but averaged only 0.054 percent.

Figures 7-5 through 7-8 represent histograms of the data from all the facilities for moisture, ash, sulfur, and chlorine. Moisture content did not follow a distribution curve. Ash and chlorine levels both follow a distinctly lognormal curve. Sulfur values almost conform to a normal distribution except for one outlying value of 0.24 percent dry weight.

7.5.2.7.2 Phenols Analysis

In this project the only phenol compounds detected were phenol and pentachlorophenol. The detected values were at very low levels, the maximums being 1.6 ppm phenol and 43 ppm pentachlorophenol. The phenols tests were included in the study to determine:

- if any of the wood types which have phenols derivatives such as plywoods, or pentachlorophenol treated wood have leachable organics; and
- as an indicator of pesticides, herbicides or other chlorinated organics which could be present with waste woods.

Since the sampling of plywoods and pentachlorophenol-treated woods did not

Variable MOISTURE; distribution: Normal
 Kolmogorov-Smirnov d = .1544198, p = n.s.
 Chi-Square: 4.956679, df = 2, p = .0838985

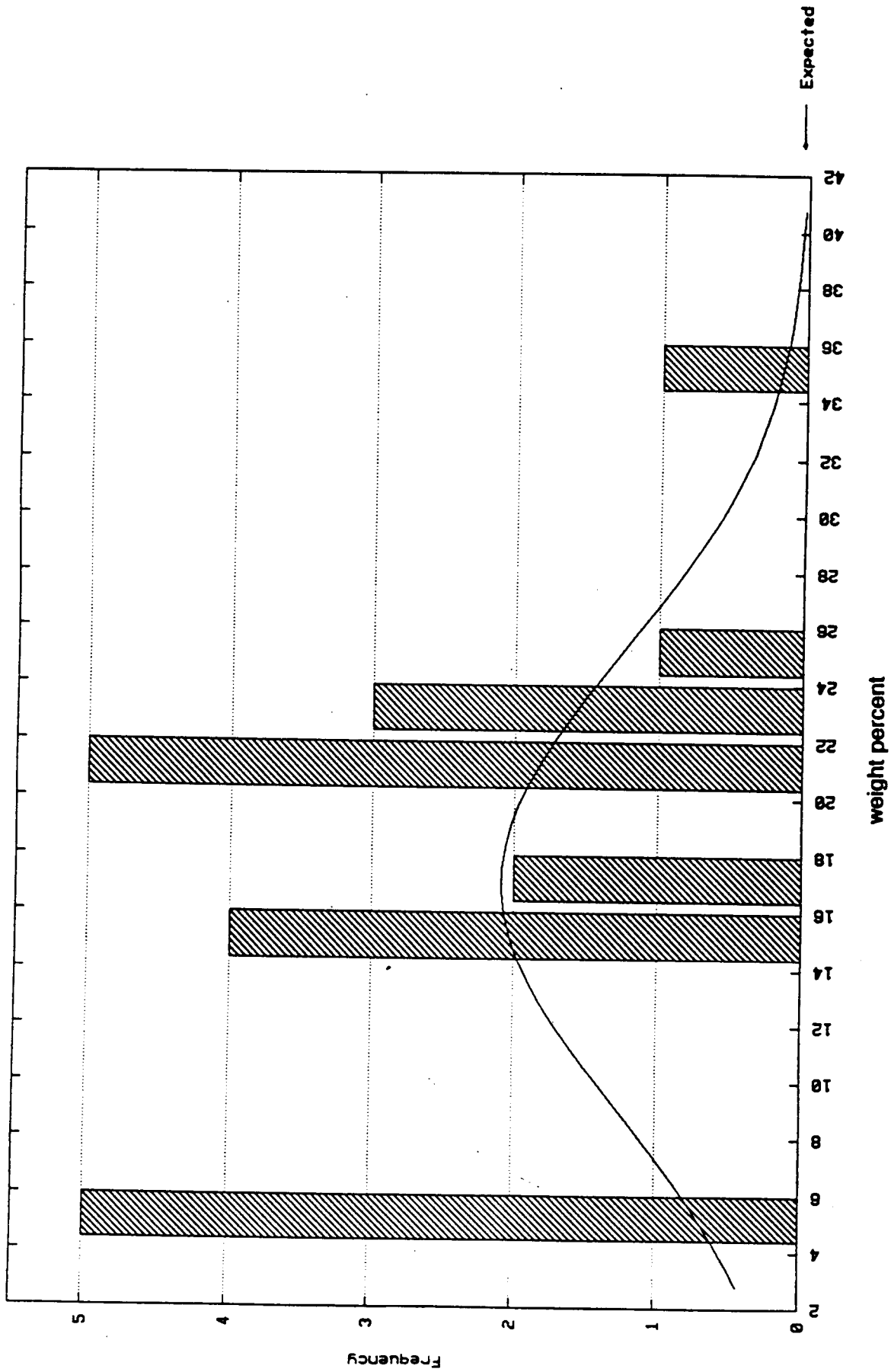


Figure 7-5. Histogram of moisture content for 6 processors.

Variable ASH ; distribution: Lognormal
 Kolmogorov-Smirnov d = .0702272, p = n.s.
 Chi-Square: 1.283269, df = 2, p = .5264380

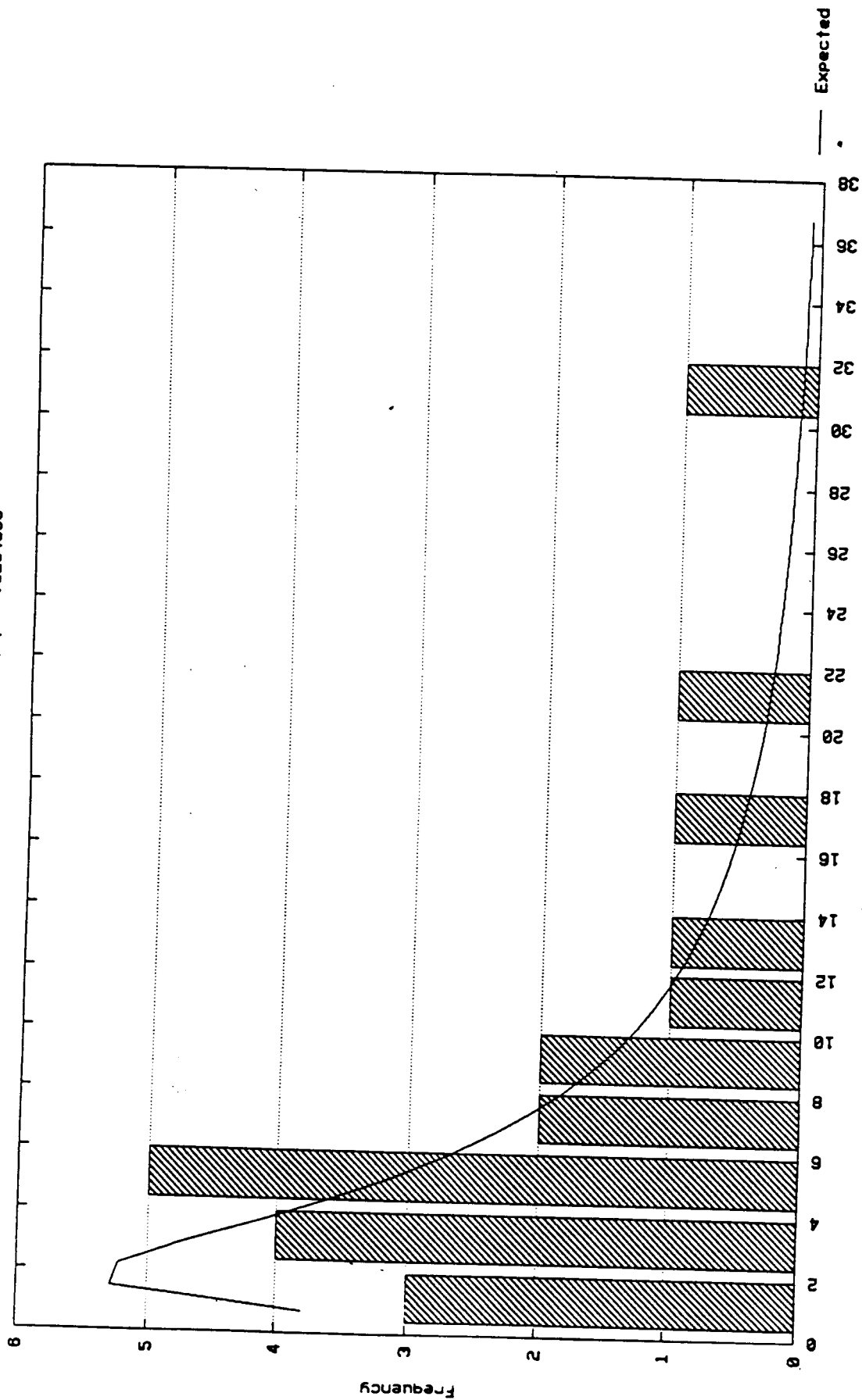


Figure 7-6. Histogram of ash content for 6 processors.

Variable CHLORINE; distribution: Lognormal
 Kolmogorov-Smirnov d = .1388418, P = n.s.
 Chi-Square: 3.142382, df = 2, P = .2078135

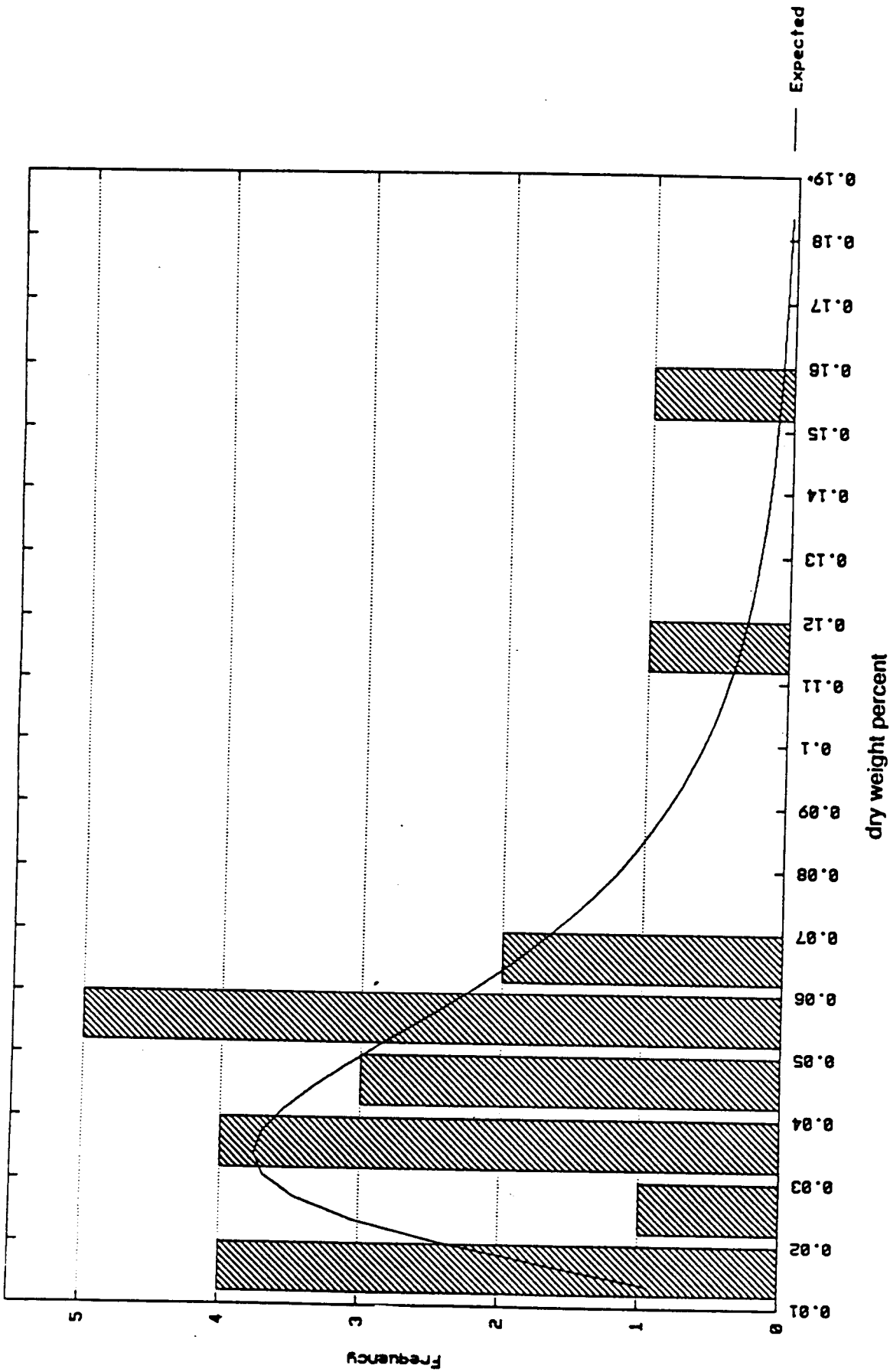


Figure 7-7. Histogram of chlorine content for 6 processors.

Variable SULFER 1 distribution: Normal
 Kolmogorov-Smirnov d = .1838372, p = n.s.
 Chi-Square: 2.881082, df = 2, p = .2368174

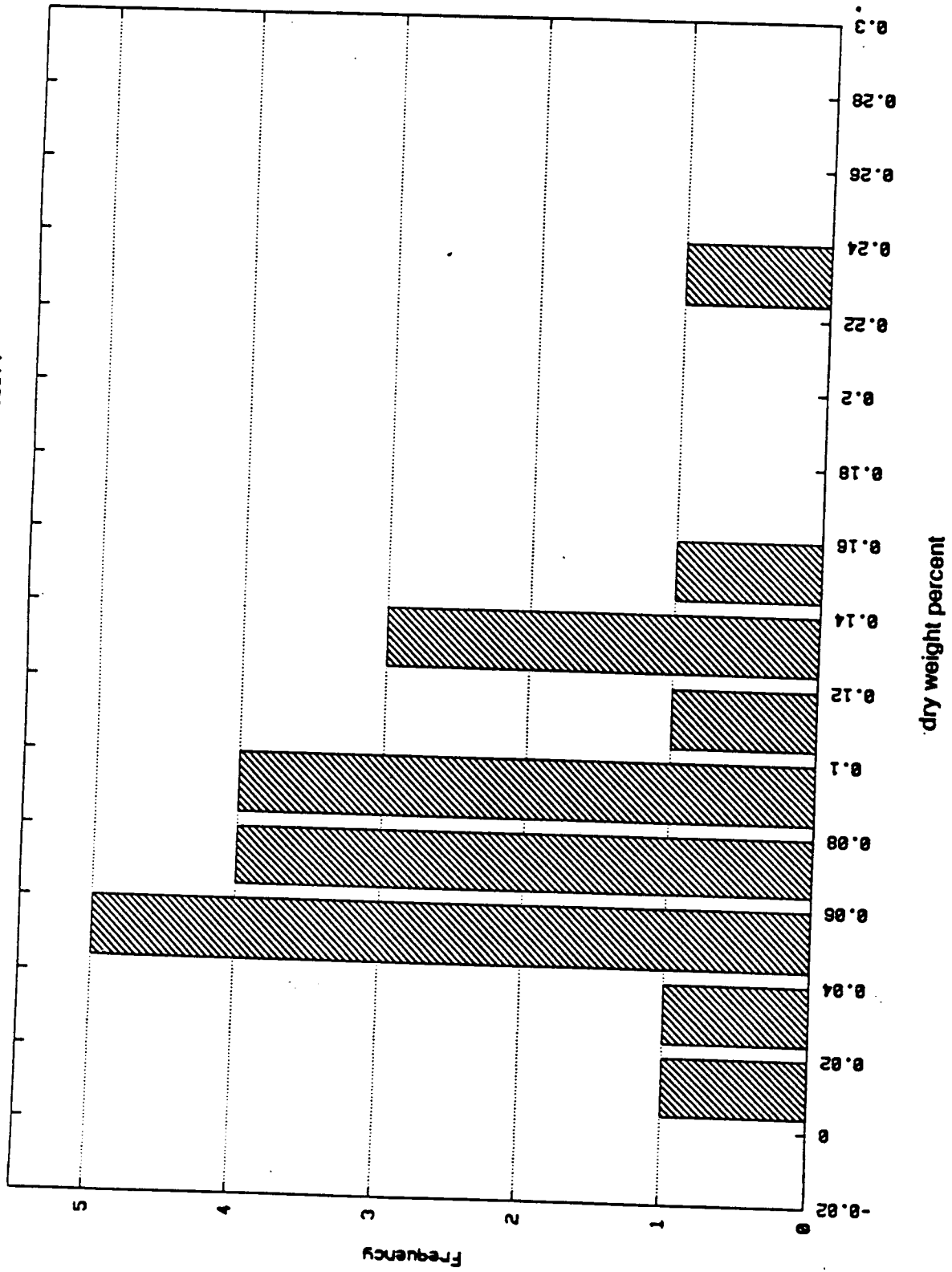


Figure 7-8. Histogram of sulfur content for 6 processors.

exhibit leachable phenol derivatives and phenols were detected only at very low levels in the waste wood stream, it can be concluded that waste wood in general has very little if any leachable phenol-based organic chemical contaminants. Therefore, as previously suspected, organic contamination should not be a major concern.

7.5.2.7.3 Minerals Analysis

The principle components of waste wood ash are silicon dioxide and calcium oxide. Relatively large amounts of calcium are normally found in wood ash as seen in the homogeneous woods analyses and prior experience with "clean" wood. In waste wood ash calcium levels are diluted significantly by the amount of silicon dioxide present. Silicon dioxide ash concentrations from wood boilers are not normally as high as those seen in the ash from waste wood processors. This processing requires removing wood from a mixed waste stream, and the high levels of silicon dioxide are the results of sand, dirt and rock mixed in with the wood. Samples showing high concentrations of silicon dioxide in the ash also tended to have high ash concentrations in the wood. Some of the highest values for ash in wood and silicon dioxide in ash were found at site 4. Site 4 is a facility mainly producing mulch for landscaping which purposely does not try to remove dirt from its product. At sites 1, 3 and 7 both ash and silicon levels are lower than the other sites. These facilities use screening techniques to limit dirt in the fuel and it is apparent that they are quite capable of reducing soil contamination. Any processor wishing to control the ash content of its product can do so by the proper application of shaking and screening techniques.

Front end removal of noncombustibles from the fuel would result in less boiler ash; however, the removal of soil may affect the quality of the remaining ash. Using silicon dioxide as an indicator of the presence of dirt, some strong correlations were discovered. As silicon levels decreased so did aluminum levels. Iron levels also dropped somewhat with silicon but not consistently. Titanium levels increased somewhat with decreases in silicon but not in such a way to provide a strong correlation. Decreases in silicon and aluminum in wood ash strongly increase calcium and magnesium levels while marginally increasing potassium, sodium, sulfur, zinc and phosphorus. These elements are from wood not soil.

Generally, the minerals analyses at each site were nearly identical which strongly suggests that bulk ash characteristics are a function of processing techniques.

From a boiler fuel standpoint it is desirable to limit the quantity of dirt within the fuel, and in turn limit the quantity of boiler ash that must be disposed of. The data indicates that a number of facilities, through appropriate fuel processing techniques, are able to accomplish lower fuel ash levels. However, facilities with reduced fuel ash levels may have higher concentration levels of toxic metals in the ash. If a facility is handling a large amount of painted wood, or CCA-treated wood or other wood types with metal contaminants, the concentration of the contaminant metal will be higher at reduced ash levels.

7.5.2.7.4 Metals Analysis

The purpose of the metals analysis for this project was twofold:

- to show variation in the processed wood from site to site as well as within the sites; and

- to determine accurate estimates of levels of these metals found in waste wood as fuel for use in predicting the environmental properties of this material.

All the available metals data from the six processors has undergone a series of statistical manipulations. Table 7-33, previously discussed, presents a summary of the most relevant points. Figures 7-9 through 7-18 present histograms of the concentration distributions of each metal. Appendix G contains all the output tables from Statsoft's CSS/3 statistical program.

The histograms indicate that all the data conforms to lognormal distributions with most of the analysis showing low levels of each element (as predicted). Each case has a few outlying values that are much higher than the rest. These values raise the arithmetic averages significantly above the median levels. Thus the standard deviation of the data becomes very large and misleading.

These histograms also quite clearly demonstrate the effectiveness of compositing the samples. Compare the histograms of composite samples vs. incremental samples. The comparative number of outlying values and how far afield these values are is definitely lessened in the composite samples. While the composite distributions do not conform to normal distributions, they do begin to approach them.

Comparing the summary data of the "total metals" data versus the "five metals" data listed in Table 7-33 also demonstrates the value of composite sampling of bulk fuels. The composite samples generally have lower average and 95th percentile values than the incremental analyses. Conversely, median, geometric mean, and upper confidence levels for the median are lower for the incremental "five metals" analysis.

Despite compositing, the variations in the data are still quite large. Care should be taken in how these numbers are used when characterizing possible plant emissions. As demonstrated by the distributions of the incremental analyses, most of the samples have much lower concentrations of metals than the arithmetic average of all the data. Compositing of samples normalizes the distribution of data, more closely representing a large population of wood fuel. Theoretically, compositing of a greater number of samples for analysis will generate a normal curve when median and mean values are equal.

For permitting and engineering analysis calculations, extremely conservative metals emissions rates can be calculated using 95th percentile values with and without additional safety factors. Considering the nature of the data presented above this practice seems far too stringent. These analyses suggest that the geometric means within a reasonable confidence interval may better characterize large populations of waste wood fuel because each of these samples represents a small glimpse of the wood fuels from a particular facility. Even collecting a number of samples at a single site is an indication of only several hours of full scale feed to a facility. Therefore, the geometric mean probably is most representative of long term operation conditions and the geometric mean plus one or two standard deviations is probably more representative of short-term variations.

7.5.2.7.5 TCLP

Of the twelve TCLP tests performed on laboratory ash for this project six samples failed the TCLP test for chromium. One of those failed for lead. All the other samples had some detectable amount of chromium in the leachate, two of which are more than 80 percent of the regulatory limit. Arsenic was detected once in the leachate at a level 75 percent of the regulatory limit.

Variable ARSENIC ; distribution: Lognormal
 Kolmogorov-Smirnov d = .8427873, p = n.s.
 Chi-Square: 1.494777, df = 1, p = .2214858

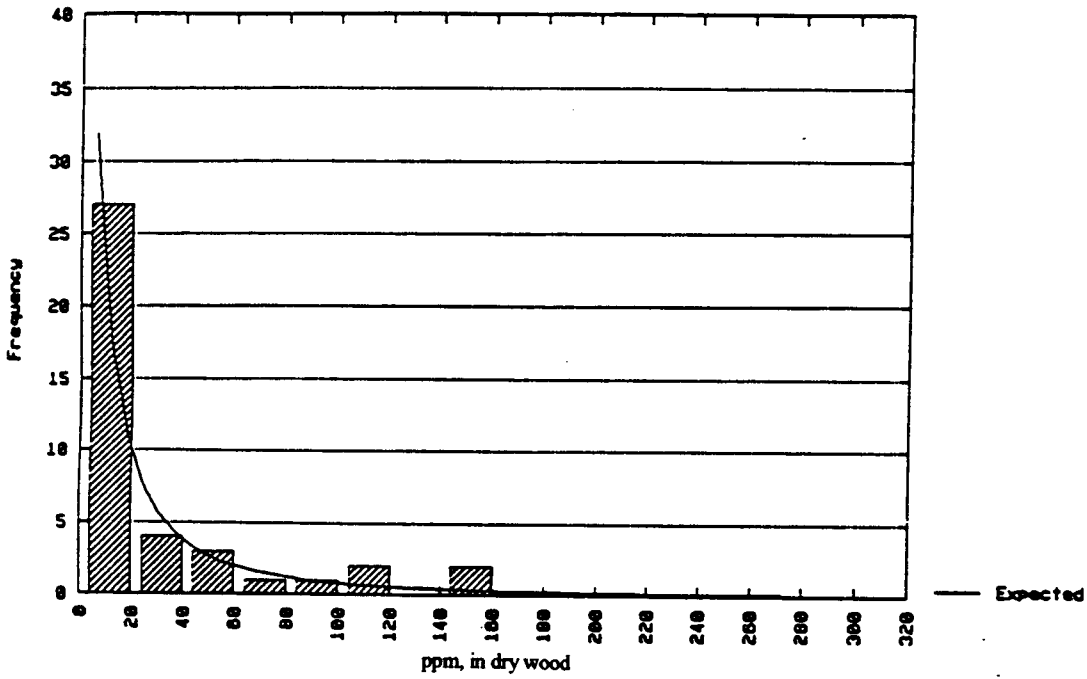


Figure 7-9A. Composite samples frequency histogram.

Variable ARSENIC ; distribution: Lognormal
 Kolmogorov-Smirnov d = .8562735, p = n.s.
 Chi-Square: 7.557817, df = 8, p = .2724198

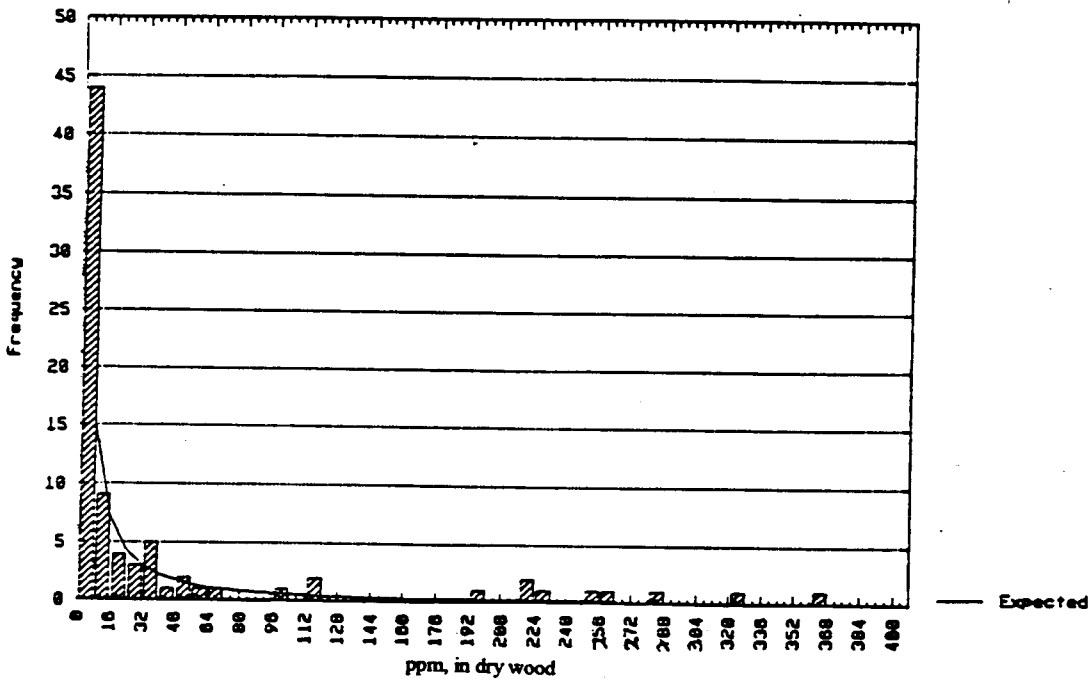


Figure 7-9B. Incremental samples frequency histogram.

Variable CHROMIUM; distribution: Lognormal
 Kolmogorov-Smirnov d = .1189173, p = n.s.
 Chi-Square: 4.365258, df = 1, p = .3437823

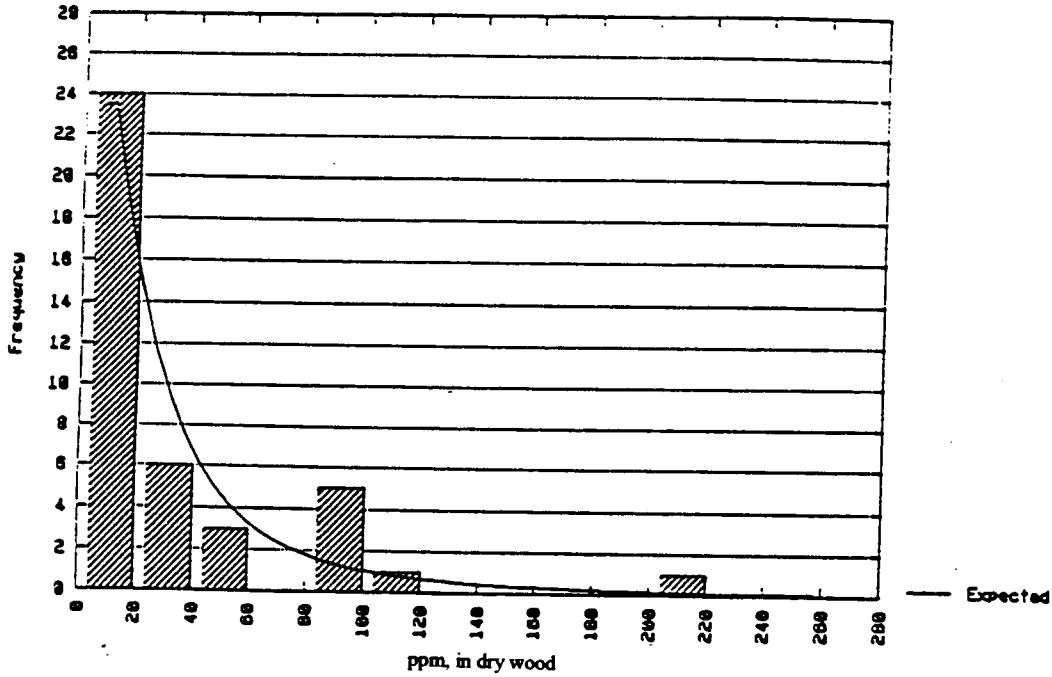


Figure 7-10A. Chromium composite samples frequency histogram.

Variable CHROMIUM; distributions: Lognormal
 Kolmogorov-Smirnov d = .8271833, p = n.s.
 Chi-Square: 1.891878, df = 2, p = .3884825

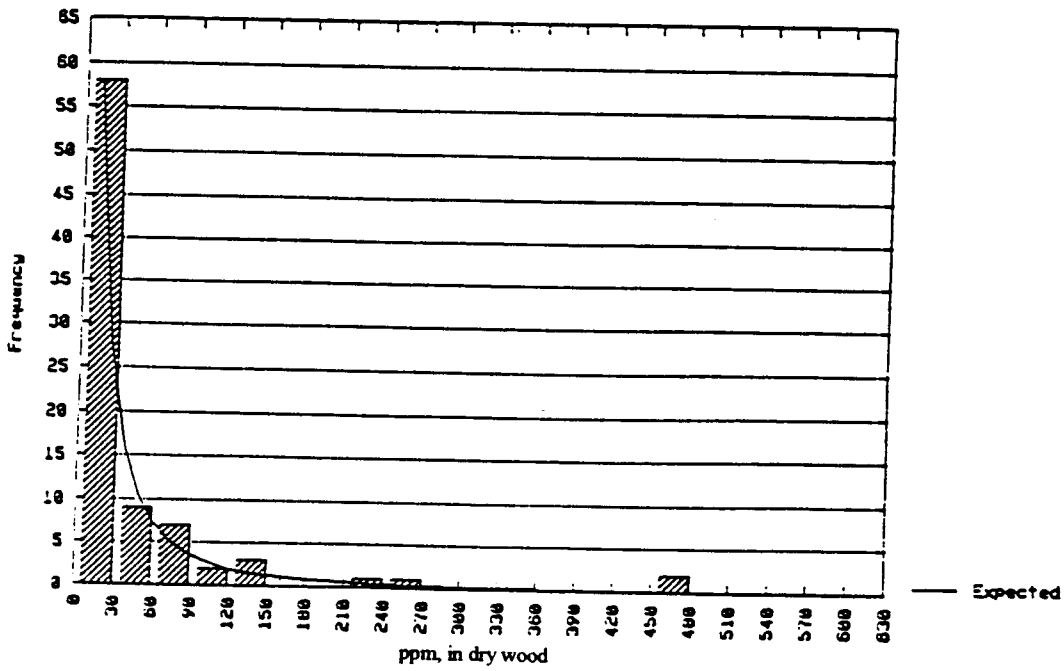


Figure 7-10B. Chromium incremental samples frequency histogram.

Variable LEAD ; distribution: Lognormal
Kolmogorov-Smirnov d = .0588418, p = n.s.
Chi-Square: 2.272528, df = 2, p = .3218383

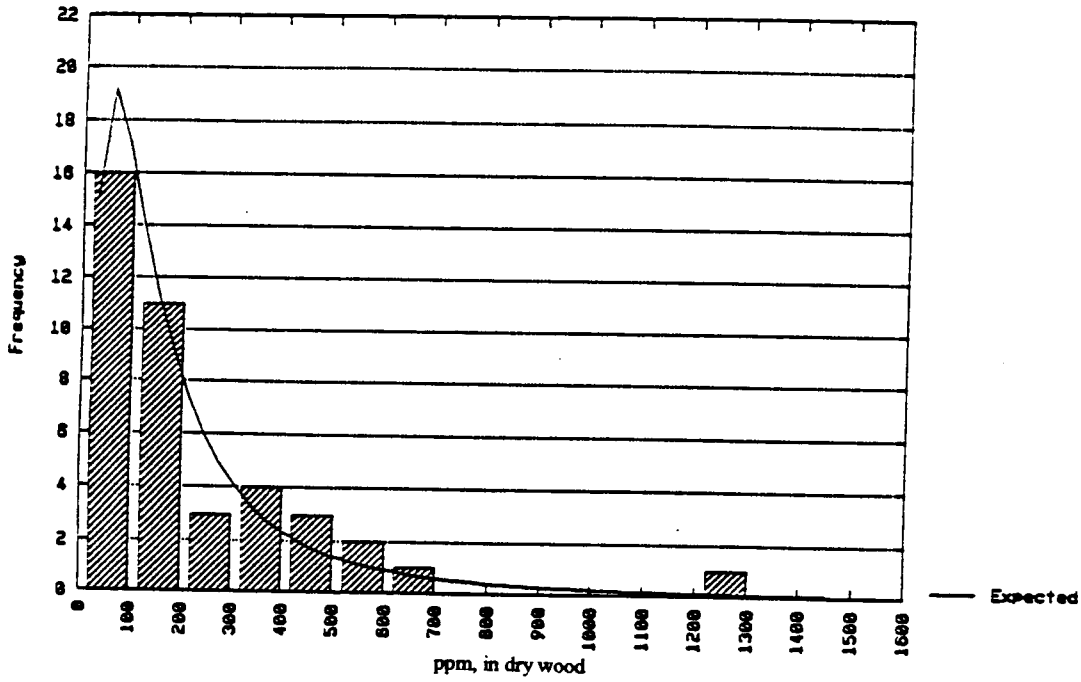


Figure 7-11A. Lead composite samples frequency histogram.

Variable LEAD ; distribution: Lognormal
Kolmogorov-Smirnov d = .0238514, p = n.s.
Chi-Square: 1.246828, df = 3, p = .7417974

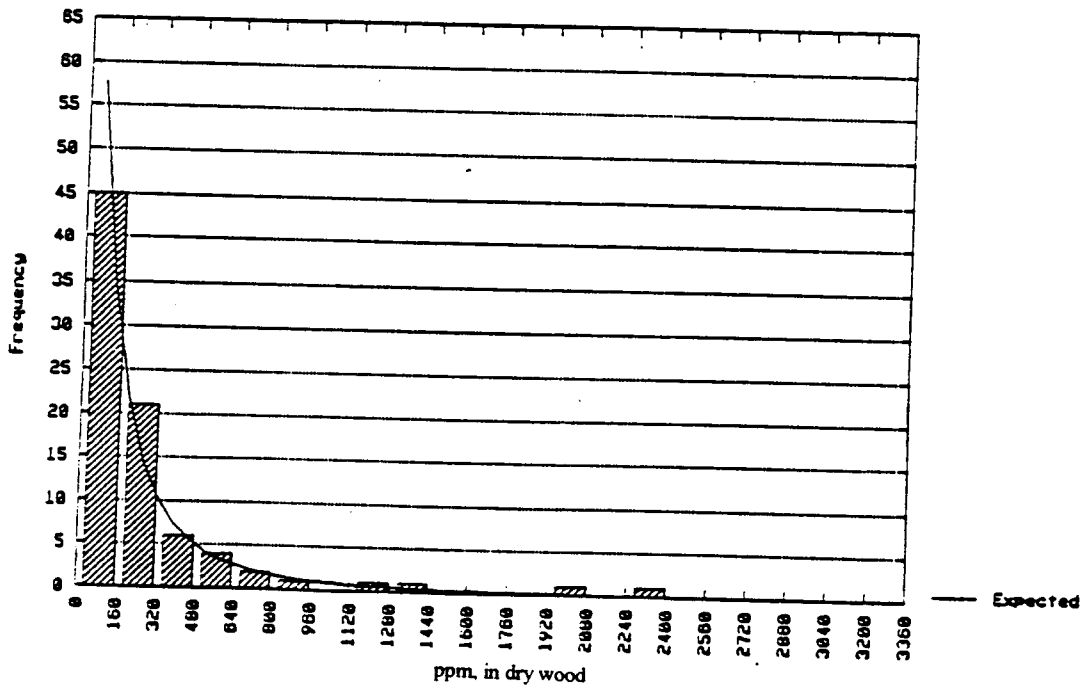


Figure 7-11B. Lead incremental samples frequency histogram.

Variable TITANIUM; distribution: Lognormal
 Kolmogorov-Smirnov d = .1579886, p = n.s.
 Chi-Square: 18.91172, df = 1, p = .0889588

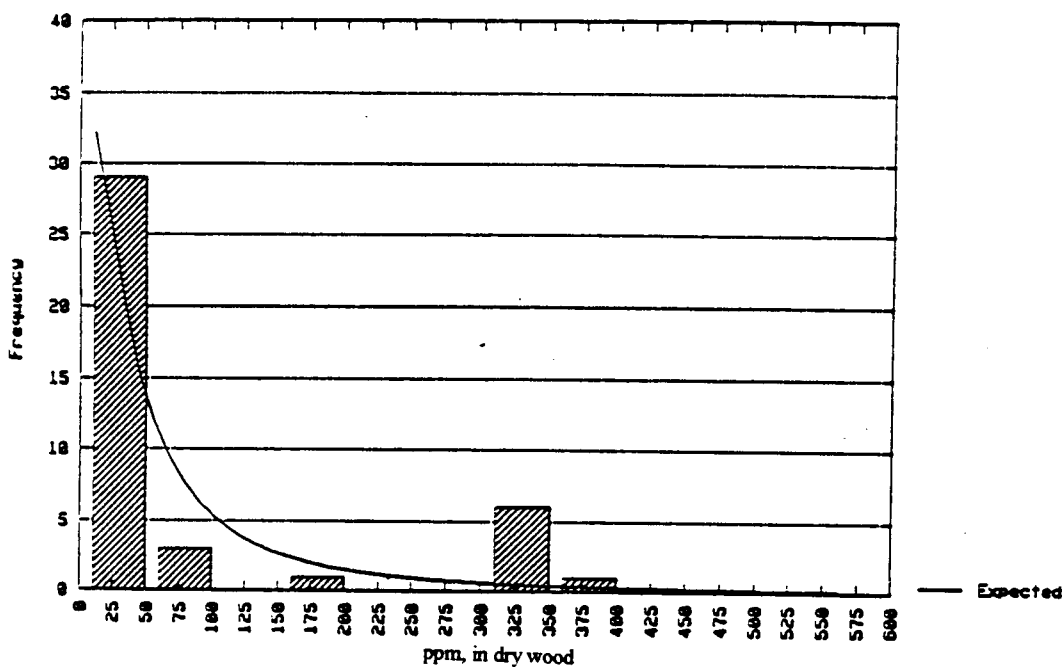


Figure 7-12A. Titanium composite samples frequency histogram.

Variable TITANIUM; distribution: Lognormal
 Kolmogorov-Smirnov d = .0509348, p = n.s.
 Chi-Square: 1.925325, df = 2, p = .3818859

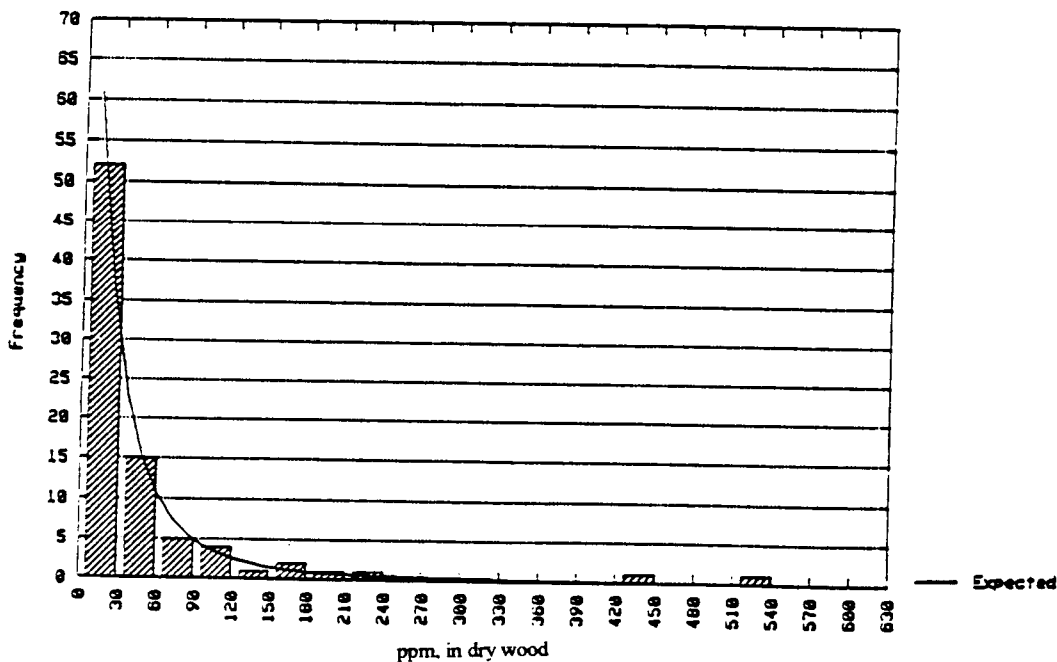


Figure 7-12B. Titanium incremental samples frequency histogram.

Variable ZINC ; distribution: Lognormal
 Kolmogorov-Smirnov d = .0730878, p = n.s.
 Chi-Square: 5.915517, df = 4, p = .2855748

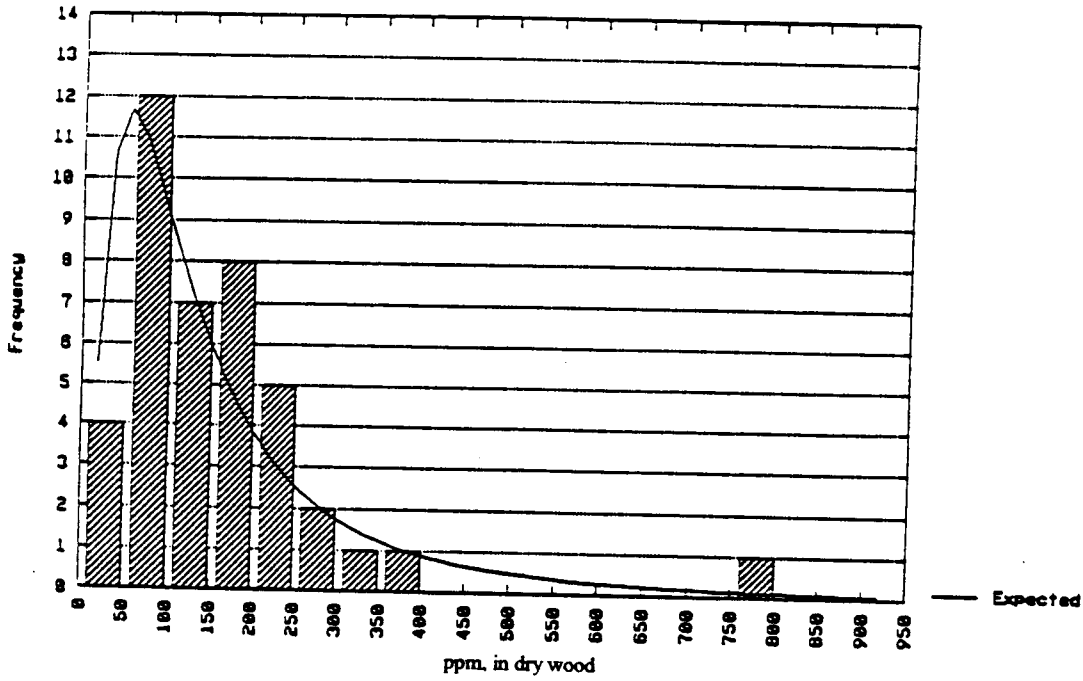


Figure 7-13A. Zinc composite samples frequency histogram.

Variable ZINC ; distribution: Lognormal
 Kolmogorov-Smirnov d = .0524982, p = n.s.
 Chi-Square: 4.938623, df = 3, p = .1785200

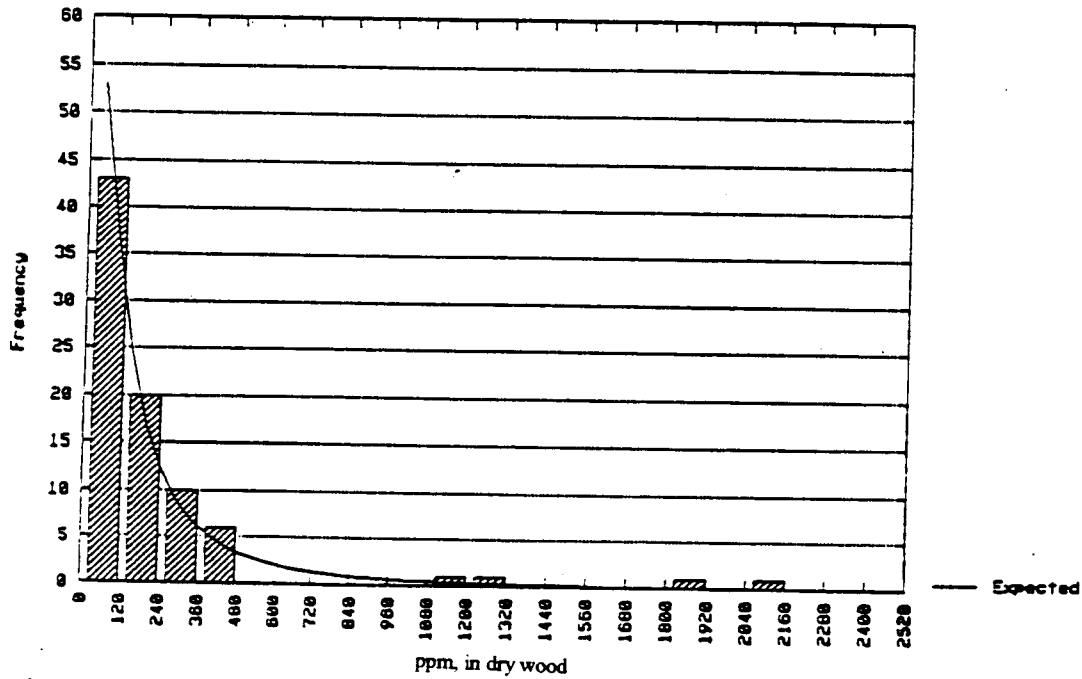


Figure 7-13B. Zinc incremental samples frequency histogram.

Variable BARIUM ; distribution: Lognormal
 Kolmogorov-Smirnov d = .0578879, p = n.s.
 Chi-Square: 2.082215, df = 3, p = .5555283

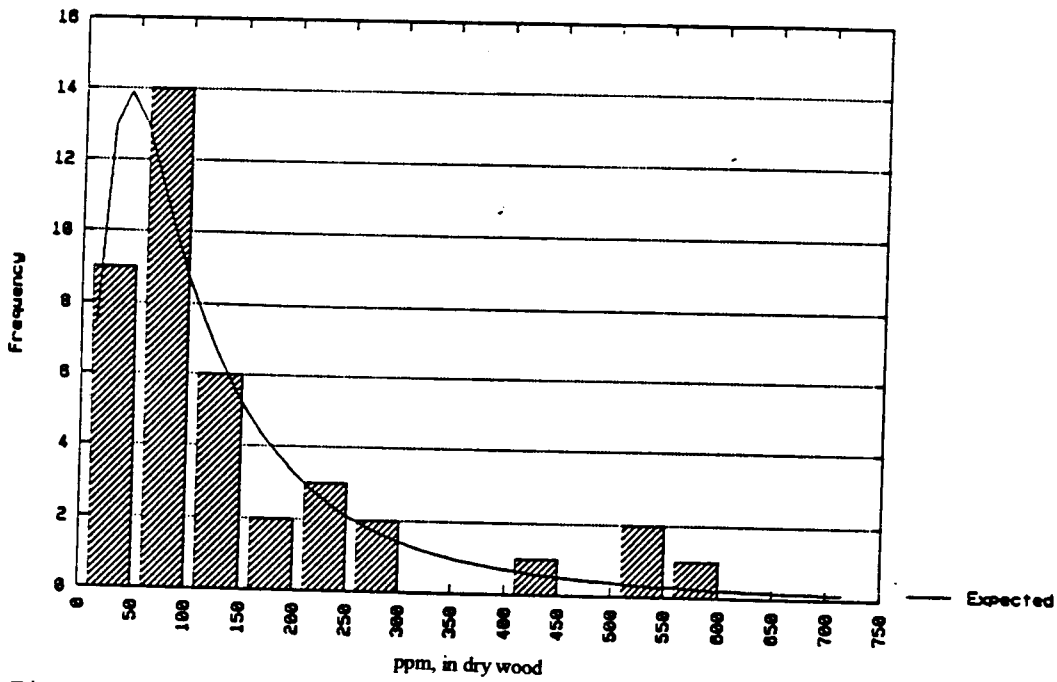


Figure 7-14. Barium composite samples frequency histogram.

Variable CADMIUM ; distribution: Lognormal
 Kolmogorov-Smirnov d = .1587235, p = n.s.
 Chi-Square: 24.52336, df = 4, p = .0000638

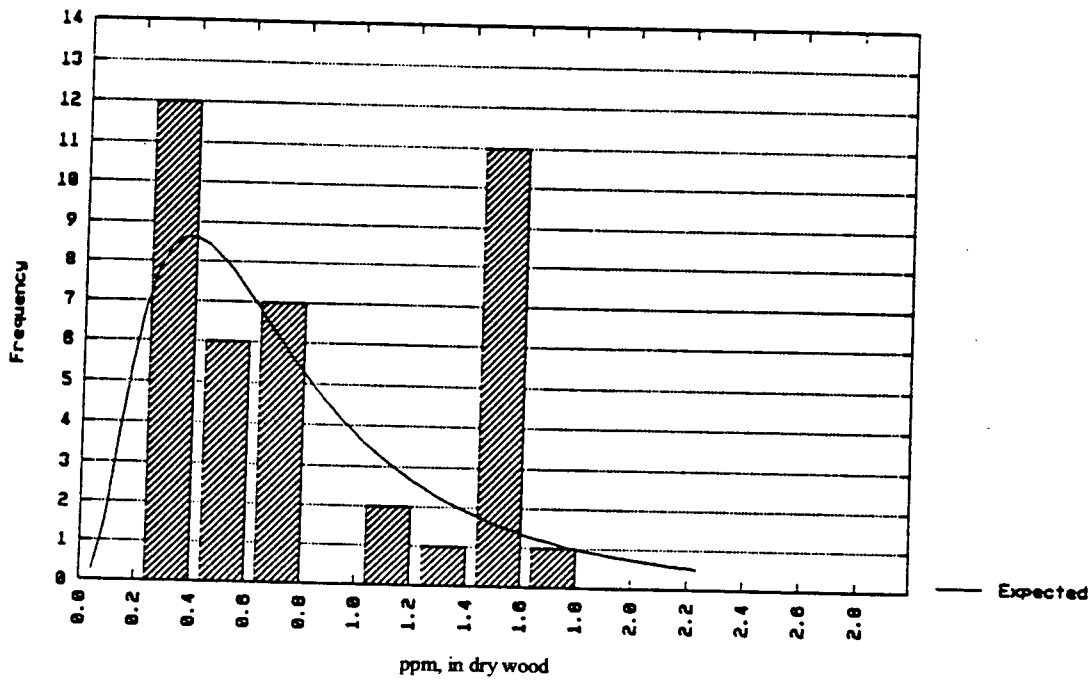


Figure 7-15. Cadmium composite samples frequency histogram.

Variable COPPER ; distribution: Lognormal
 Kolmogorov-Smirnov d = .1894471, p = n.s.
 Chi-Square: 2.677235, df = 2, p = .2622226

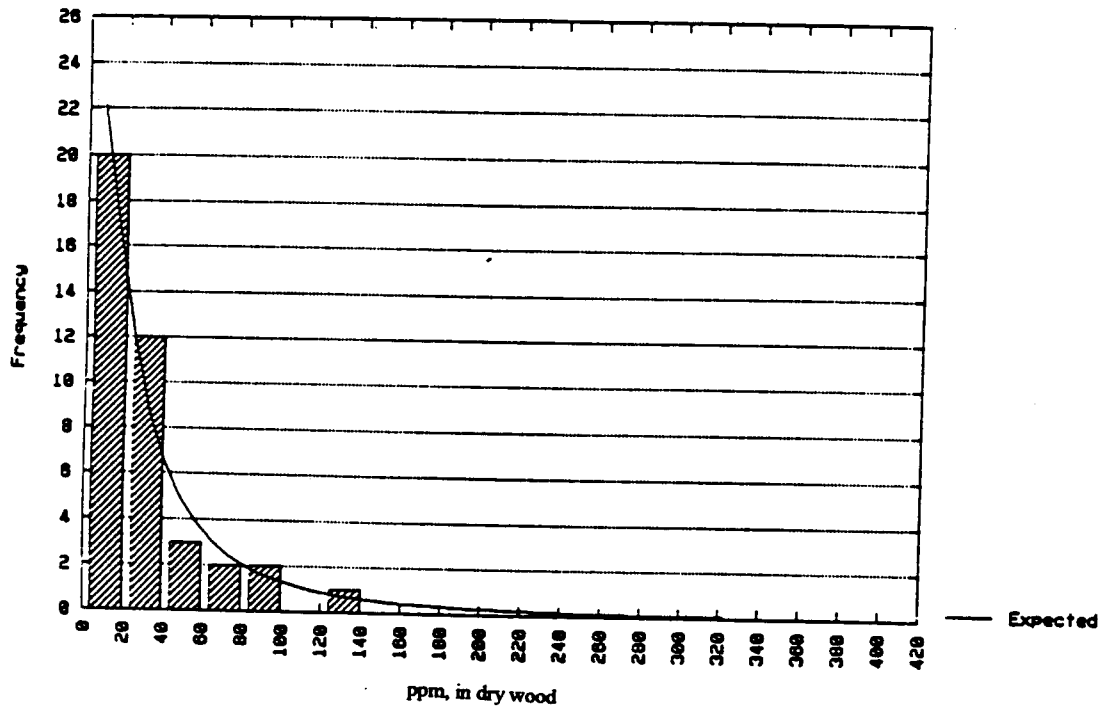


Figure 7-16. Copper composite samples frequency histogram.

Variable NICKEL ; distribution: Lognormal
 Kolmogorov-Smirnov d = .1966785, p < .10
 Chi-Square: 9.249415, df = 1, p = .0023576

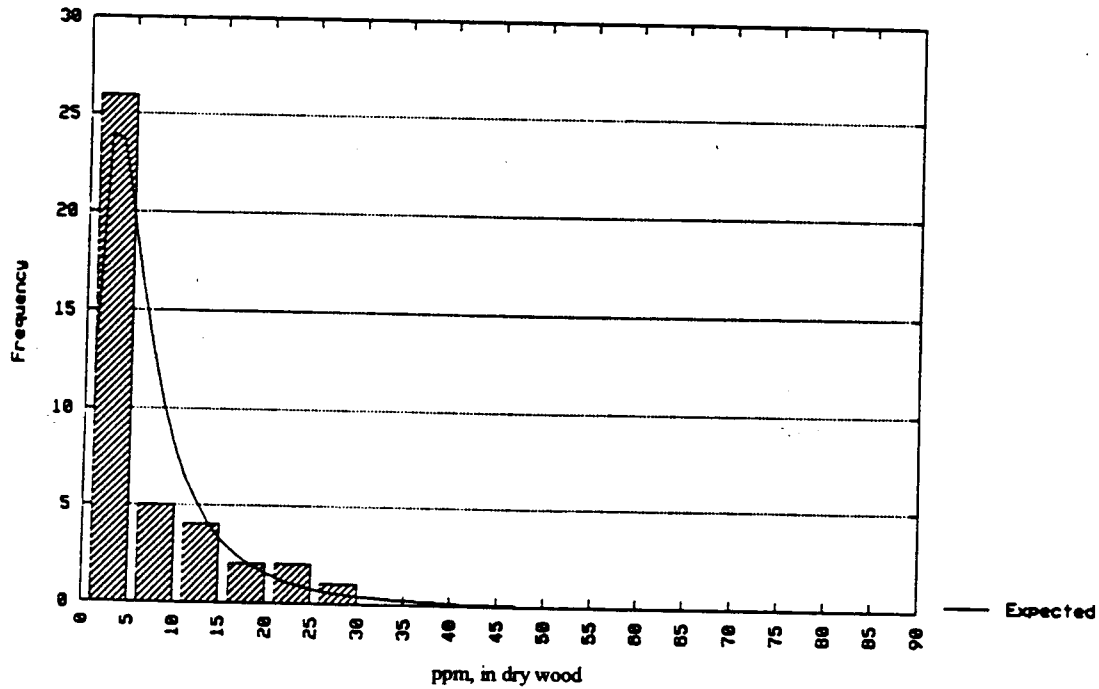


Figure 7-17. Nickel composite samples frequency histogram.

Variable SILVER ; distribution: Lognormal
 Kolmogorov-Smirnov d = .1499847, p = n.s.
 Chi-Square: 8.198877, df = 2, p = .0168572

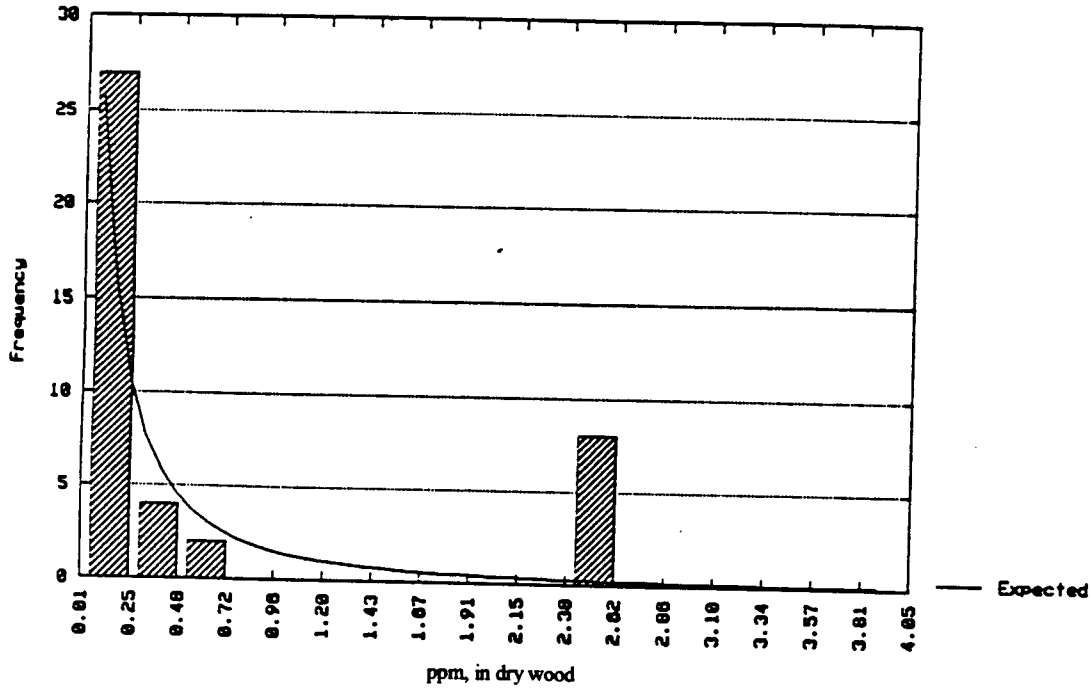


Figure 7-18. Silver composite samples frequency histogram.

Barium and silver leachate were both detected in small amounts in separate samples.

If the results of the laboratory-generated ash were representative of boiler ash, it would have to be disposed of at a facility permitted to accept hazardous waste or be treated in some way to make the ash non-hazardous.

Sites 4 and 6 were the only sites to pass the TCLP. Comparing the median values for chromium for each site, sites 4 and 6 had the lowest chromium levels in wood of 13 ppm and 10.8 ppm. The next lowest facilities however were not very far off in chromium levels. Site 3 has a median chromium level of 13 ppm and site 7 has a level of 14.7 ppm.

No correlation of elemental metal concentration with TCLP test failure could be ascertained from this data.

Unfortunately these numbers still do not indicate any concentration above which the sample will fail the TCLP test. If such a concentration exists, it will have to be the concentration of chromium in ash compared to wood since ash contents vary so much. However, it is important to again note that these ash samples are laboratory generated and probably don't have the same matrix as real ash generated in a high temperature furnace. As discussed in Section 7.3, real combustor ash may reach a fusion temperature that binds the chromium to the ash, preventing leaching.

7.6 Wood Fired Combustors

Two separate facilities burning wood as fuel were visited as part of this project. Site 5 is a combustor that is permitted to burn construction/demolition waste wood but at the time of the visit was burning only clean untreated wood chips. Site 8 is a combustor burning all sorts of waste wood including construction/demolition, landclearing, and manufacturing waste. In the following tables "clean" refers to material from site 5 and "waste" refers to material from site 8.

7.6.1 Minerals Analysis on Ash

Table 35 presents the results of the minerals analysis performed on samples from site 5 and 8. It is interesting to note that the bulk of the "clean" fuel bottom ash is silicon dioxide. A large portion of the soil contamination included in this fuel stream is a result of outdoor processing and storage. The "clean" fuel fly ash breaks down more evenly into principal components of oxides of silicon, aluminum, and calcium. The fly ash appears to also contain some of the entrained soil but seems mostly to be the bulk of the wood combustion by-products. Both sulfur and potassium oxides have fairly high concentrations compared to the products of "waste" wood combustion and the summary of the processor data. Since fly ash could not be collected at site 8, we cannot confirm if sulfur generally becomes part of the fly ash stream and not the bottom ash.

With the exception of some noncombustibles, the two types of bottom ash from site 8 seem to have little variation in the principal components. Physically, the siftings ash is generally a dark grey powder with some pebbles while the hopper ash contains rocks, nails, and a somewhat darker color ash. Bulk materials such as nails and rocks could not be processed and were therefore removed using a 4mm sieve.

Calcium oxide levels found in both types of "waste" bottom ash more closely resemble the "clean" fuel fly ash. This is more than likely a function of the combustor-burning technologies involved. Site 5 utilizes a large portion of undergrate air and has a turbulent bed while site 8 has no forced undergrate air and a feed ram operating at seven-minute intervals pushing burning fuel down the combustion ramp.

7.6.2 TCLP

Table 36 presents the results of the metals portion of the TCLP tests performed on ash from sites 5 and 8. Full TCLPs were run on each of the samples except for the "clean" fuel bottom ash which was mostly rock. Of the components tested for in the full TCLP test no organics were found in the leachate. As described earlier in the chapter, two of the ash samples were split then treated with distilled water to initiate a pozzolanic process. It was hoped that this process would bind the material and prevent leaching. Quite unexpectedly, the result of this ash preparation on the "clean" fuel fly ash seems to liberate many of the metals. Arsenic, cadmium, lead, and silver, all below detection limits in the untreated fly ash leachate, increased to above detection levels in the treated ash with cadmium approaching the regulatory limit. Leachate values for chromium and selenium also increased with selenium reaching a level of 0.98 mg/L. The regulatory level is 1.0 mg/L for selenium. The results of the treating of the "waste" fuel grate siftings ash leachate were mixed. Chromium levels increased in the treated ash leachate while barium and lead levels decreased.

7.6.3 Elemental Metals Analysis

Table 7-35. Mineral analysis on ash from two wood fired combustors, percent by weight of oxide of element.

Sample type	Number of samples	Si	Al	Ti	Fe	Ca	Mg	K	Na	S	P	Mn	Pb	Zn	Sr	Ba	Undetermined
"Clean" fuel fly ash	1	38.25	11.28	0.62	5.92	21.43	4.56	8	1.52	3.89	2.4	0.81	-	-	-	0.15	1.03
"Clean" fuel bottom ash	1	76.95	8.72	0.47	4.09	3.96	1.72	1.78	1.68	0.03	0.39	0.19	-	-	0.14	0	0
"Waste" fuel siftings ash	1	38.43	8.67	2.66	8.71	29.36	5.03	2.28	3.59	0.09	0.54	0.07	0	0	0.03	0.47	0
"Waste" fuel hopper ash	1	39.23	10.29	2.95	10.76	25.35	4.33	1.98	3.45	0.18	0.5	0.06	0	0	0.12	0.79	0

Table 7-36. Toxicity characteristic Leaching Procedure (TCLP) on ash from two wood fired combustors, mg/l. Negative values represent detection limits.

	Number of samples	Arsenic As	Barium Ba	Cadmium Cd	Chromium Cr	Lead Pb	Selenium Se	Silver Ag	Mercury Hg
"Clean" fuel fly ash	1	-0.005	1.75	-0.001	0.009	-0.005	0.015	-0.001	-0.0005
"Clean" fuel fly ash ^a	1	0.124	0.94	0.7	0.047	1.41	0.98	0.002	-0.0005
"Clean" fuel bottom ash	1	-0.5	1.1	-0.2	-0.2	-2	-0.5	-0.1	-0.1
"Waste" fuel grate siftings	1	-0.005	2.4	-0.001	0.42	0.42	-0.005	-0.001	-0.0005
"Waste" fuel grate siftings ^a	1	-0.005	1.5	-0.001	0.006	0.006	-0.005	-0.001	-0.0005
"Waste" fuel hopper ash	1	-0.005	1.42	-0.001	0.017	0.017	-0.005	-0.001	-0.0005
US EPA Regulatory limits (as of mid-1992)		5	100	1	5	5	1	5	0.2

a. Sample was wetted with distilled water and allowed to harden before it was sent to the laboratory for analysis.

Table 7-37. Metals in wood combustor fuel or ash, ppm.

"Clean" wood combustor wood fuel						
Element	Number of samples	Average	Minimum	Maximum	Standard deviation	
Arsenic	6	0.26	0.125	0.44	0.15	
Chromium	6	2.50	2.5	2.5	0.00	
Lead	6	4.33	2.5	9	2.91	
Titanium ^a	6	45.47	27.4	58.1	11.03	
Zinc	6	13.50	11	14.5	1.45	
Barium	2	72.75	67	78.5	8.13	
Cadmium	2	0.05	0.05	0.05	0.00	
Copper	2	4.75	4	5.5	1.06	
Mercury	2	0.13	0.125	0.125	0.00	
Nickel	2	4.25	2.5	6	2.47	
Silver	2	0.03	0.025	0.025	0.00	

"Clean" wood combustor fly ash						
Element	Number of samples	Predicted ^b	Average	Minimum	Maximum	Standard deviation
Arsenic	6	8.82	27.67	16	38.2	9.42
Chromium	6	86.21	61.17	42	76	12.94
Lead	6	149.43	72.17	31	111	31.44
Titanium ^a	6	1567.82	164.17	133	209	28.18
Zinc	6	465.52	491.25	147.5	800	246.49
Barium	2	2508.62	1055	915	1195	197.99
Cadmium	2	1.72	4.065	0.63	7.5	4.66
Copper	2	163.79	107.75	61	154.5	66.11
Mercury	2	4.31	0.3875	0.125	0.65	0.37
Nickel	2	146.55	48.75	42	56.5	9.55
Silver	2	0.86	1.075	0.35	1.8	1.03

"Waste" wood combustor bottom ash						
Element	Number of samples	Predicted ^c	Average	Minimum	Maximum	Standard deviation
Arsenic	12	74.22	48.3	28.5	78.8	14.34
Chromium	12	240.63	133.5	82	209	32.43
Lead	12	785.94	191.08	86	438	93.12
Titanium ^a	12	5350	1765.25	250	4790	1539.23
Zinc	12	934.36	469.17	280	850	190.57
Barium	4	785.94	1236.25	875	1465	278.22
Cadmium	4	14.06	0.07	0.21	0.025	0.09
Copper	4	351.56	614.5	258	1050	327.17
Mercury	4	1.14	0.125	0.125	0.125	0.00
Nickel	4	65.63	54.125	45.5	61.5	6.57
Silver	4	1.77	0.875	0.31	2.35	0.99

a. Titanium values are suspect. See text.

b. Calculated from "Clean" wood analysis using 2.9% ash in wood.

c. Predicted from Site 7 summary total metals analysis, titanium values from Site 7 appear valid.

Table 37 presents the results of the elemental metals analysis on wood and ash samples from the clean wood combustor (site 5) and the waste wood combustor (site 8).

Metals concentrations in the "clean" wood fuel are, in most cases, much lower than median concentrations from the construction/demolition wood processors. Only barium, and nickel levels approach C/D levels, 84 percent and 85 percent respectively of median C/D values. Mercury values were below detection and nickel values were at or about detection throughout the program. Barium is an element found naturally in virgin wood.

From the ultimate/proximate analysis performed on the clean wood (see appendices) the fuel is 2.9 percent ash. Assuming 100 percent of the metals go to ash, predicted values of metals concentrations in the ash were calculated. Comparing these values with the average of the actual fly ash analysis shows higher concentrations of arsenic, cadmium, zinc and silver in the actual fly ash which suggests that these metals became enriched in the fly ash. The other metals which have actual fly ash metals concentrations lower than predicted indicate that these metals either tended to enrich the bottom ash or escape collection. Without bottom ash analyses which would allow mass balance calculations, no definitive conclusion can be drawn.

7.7 Sample Accuracy and Reproducibility

7.7.1 Laboratory Variability

The results of any test plan can only be as accurate as the analysis reports provided by the laboratories doing the analysis. Therefore, several split or duplicate samples were sent to the laboratories to verify results. Split samples were always taken after the material had been size reduced. These samples were also labeled so that the laboratories did not know these were split samples. However, it is not always necessary to analyze split samples to see variation in laboratory results. Minimum detection limits (MDLs) varied significantly from sample to sample for the same analysis. Two laboratories following the same protocol (EPA Method 1311, TCLP, November, 1990) showed drastically different detection limits. In an effort to explain these variations, a review of available protocols and methods was made and discussed at length with laboratory personnel. The following subsections detail our findings.

7.7.2 Split or Duplicate Analysis

Of the tests performed on wood samples, the elemental metals, phenols and minerals in ash analyses were verified using split samples. The TCLP test required too much wood to generate ash and was too expensive to run repeatedly. The ultimate/proximate test was not expected to vary significantly. Four "five metals" analysis, four "total metals", one phenols, and one minerals analysis were split.

The results of the duplicate metals analysis showed that the sampling procedures provided reasonably representative results. Some interesting trends were also noted. Analysis of split samples demonstrated relatively good repeatability for the metals; arsenic, chromium, and copper. These metals, as discussed throughout this report, are commonly found in CCA pressure-treated lumber. The distribution of the metals in impregnated wood should be fairly even. Since all the split samples were first ground and mixed thoroughly before splitting, CCA treated wood particles in the samples would be evenly distributed as well. Metals commonly found in surface treatments of wood, such as lead, titanium, and zinc, fluctuated more widely, but in most cases varied by a factor of three or less. Only a small fraction

of the overall wood volume is ever touched by surface treatment. While sample preparation methods attempted to create as homogenous a mixture as possible, the analysis and averaging of multiple samples, as performed for this project, seems necessary to characterize these metals in wood.

Many of the other metals sampled for were rarely above detection limits. In the cases of cadmium and silver, when detected, the repeatability of the data was very good (example: cadmium 1.00 ppm and 1.05 ppm). Mercury was never detected.

Only one duplicate phenol test sample was run. These analyses are expensive and for the most part showed no detection. In this one case phenol was detected in one analysis but not in the split. All the other compounds remained undetected but the minimum detection limits differed by a factor of two. The concentration of phenol was measured at 1.10 ug/g while the detection limit of the split was 0.66 ug/g. The phenols test requires a relatively large sample (300 to 400 grams) which, coupled with the heterogeneous nature of the wood and the proximity to the detection limits should account for this discrepancy.

The minerals analysis of the first pressure-treated wood sample was repeated since it seemed highly unlikely that there would be 63.85 percent manganese in the ash. The duplicate, however, showed a level of 62.83 percent manganese. In fact the values of all twelve compounds sampled for were within ± 2 percent of each other. This demonstrates that the ash from wood combustion is by far a much more homogeneous mixture than the wood fuel.

7.7.3 Minimum Detection Limits (MDL)

A minimum detection limit (MDL) is the value below which a laboratory cannot accurately evaluate the concentration present in the sample. Thus a laboratory may state something similar to no detection above MDL. This does not mean that the compound tested for is not present but that the equipment used cannot quantify how much, if any, is present. For conservative purposes, values equal to one half the detection limits were used for unbiased statistical calculations (Gilbert, 1981).

Since detection limits were varying from test to test, it was of concern. The testing laboratories were contacted to determine why this was occurring.

Each test is subject to influences of the matrix of the analyte, i.e., the chemical and physical makeup of the analyte. In some cases, compounds found in the matrix, other than those being tested for, will react with chemical reagents or test equipment. The effects of these interferences vary. In the case of metals analysis by acid digestion, the extraction fluid at times would bubble out of the container when processed. In these cases samples would be diluted with some non-reactive solution until they could be processed. The greater the dilution, the higher the MDL rises. Another case of matrix interference occurs when the matrix prevents further concentrating of extraction solutions. As part of some analyses, a certain weight of analyte is mixed with an extraction solution. The extraction solution is then siphoned off and evaporated to concentrate the solution. While the extraction solution is normally evaporated down to a standard volume, this is not always possible. Compounds available in the matrix of the analyte (such as salt in the water) may prevent or significantly slow evaporation.

7.8 Suggestions for Future Analysis

In reviewing the results of the laboratory testing for this project, certain tests have proven to be adequate while others have been less than sufficient

for characterizing wood and ash. The following methods for characterizing wood and ash are suggested for future work:

- The use of ultimate/proximate analyses of wood fuel is a consistent and reliable method for determining the basic fuel properties. Since variations among samples analyzed are low, the testing of composite samples is justified.
- Testing of phenol compounds yielded little in determining the amount of phenol and phenol-formaldehyde compounds in the waste wood stream. Future testing should evaluate the possibility of testing for formaldehyde since this is a compound found in both phenol-formaldehyde and urea-formaldehyde resins. Also, the lack of phenol compounds did indicate that certain types of organic contamination were not occurring and should no longer concern future investigations.
- The use of graphite furnace atomic adsorption appears to be a reliable and repeatable method for determining arsenic, chromium, and copper in waste wood. However, future testing for metals contamination should be performed on ash samples when available. The analysis of ash is an extension of the compositing performed in this project. As suggested earlier in this report, composite samples demonstrate a more uniform distribution of the data more closely approximating a median value and representative of the long-term combustion of wood fuel. By combusting wood into ash, this not only composites a large quantity of wood but also concentrates it so that metals such as cadmium, nickel and silver might be more easily detected. The construction/demolition fuel tested during this project had an average ash content of 7.8 percent dry weight. A sample of ash, therefore, should have approximately 12 times higher concentrations of metals than the wood it came from. Also the use of ash samples would alleviate the size reduction and sample dissolving problems associated with wood sample analysis.
- The use of the Toxic Characteristic Leachate Procedure (TCLP) should be limited to actual facility ash instead of ash generated in the laboratory. Under actual high temperature combustion conditions, the ash reaches fusion temperature and potentially leachable materials may become bonded within the ash. Insufficient data is available at this time to prove or disprove this theory. However, in other pilot and full scale studies, similar types of waste wood fuels did not exhibit the same type of metals leaching that occurred with the laboratory-generated ashes in this project.
- For the next project phase it is recommended that testing of various types of waste wood (both "treated" and "clean") be conducted on fullscale boilers. This testing should take place on boilers ranging in size from 50 to 300 million BTU/hr. The combustion systems should have appropriate particulate controls. The testing should include a number of days of continuous operation where numerous fuel, bottom ash, fly ash and uncontrolled particulate emissions samples are collected at least every hour. A material balance should be performed about the system to determine how the metals are distributed in the various ash fractions.

7.9 Bibliography - Chapter 7

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8.0 ENVIRONMENTAL IMPACTS OF WASTE WOOD COMBUSTION - AIR

8.1 Introduction

Emissions of trace metals, sulfur and chloride from the combustion of waste wood in boilers can be approximated using wood and ash concentration data such as those presented in Chapter 7.0. These data, in conjunction with conservative assumptions about the partitioning of these compounds between bottom and fly ash or the reaction with components of the ash (in the case of sulfur and chloride), can be used to estimate air emissions. Worst-case assumptions about the partitioning (e.g. 100 percent of metals are contained in the fly ash) can be used to obtain overestimates of emission rates; however, emissions of organic compounds can not be estimated from wood and ash composition data. Therefore, actual emissions data from the testing of existing wood boilers have been compiled to supplement the wood and ash concentration data obtained for this project. Although emissions data for criteria pollutants (i.e. particulate matter, nitrogen oxides, carbon monoxide, sulfur dioxide and total hydrocarbons) were obtained in the course of compiling these data, the focus of this study was on non-criteria pollutants such as metals and various organic compounds that are regulated as hazardous air pollutants (HAPs) by most state agencies.

In the absence of HAP emissions data for wood boilers, regulators have used test data from residential wood combustion appliances to quantify emissions. Although these data may be useful in identifying the types of pollutants that may be formed from wood combustion, the emission rates from industrial wood-fired boilers, as will be seen in this chapter, are significantly lower due to the differences in combustor design, combustion efficiencies and operating conditions. The overall objective of compiling emissions data for this project, therefore, was to summarize available HAP emissions data that are more applicable to commercial or industrial wood boiler facilities. The specific objectives of this task were:

- To identify pollutants that could be emitted from combustion of various waste woods;
- To compile available test data on emissions from different wood boiler designs firing different types of waste wood fuels;
- To summarize the test data in consistent units of measure and reference;
- To identify and evaluate operating variables that affect the levels of pollutants formed and emitted;
- To compare emission factors from commercial/industrial wood boilers to those from residential wood combustion appliances; and
- To evaluate the capability of different boiler designs and waste wood fuels to meet regulatory standards.

8.1.1 Key Findings

- Criteria and non-criteria pollutant emissions data from over 100 wood combustors have been located and summarized into consistent units for convenient evaluation. Overall, the data should be useful in characterizing emissions from wood combustors. However, the statistical summaries should be used with caution due to the

wide variation in boiler designs, sizes, fuel sources and combustion controls represented by the many data sources.

- Relatively few sources of emissions data were found on combustion of C/D, railroad ties, telephone poles or other "treated" wood. Comparison of these data with those from "clean" wood combustion at the same sources indicates that organic emissions are generally not increased from combustion of "treated" wood. While metals emission data from these sources were very limited, the data indicate only slightly higher levels for "treated" wood combustion.
- Organic compounds regulated as hazardous air pollutants that have been measured in detectable amounts in wood combustor flue gas include aldehydes, benzene, phenol, and polynuclear aromatic hydrocarbons (PAH). These compounds are formed as products of incomplete combustion and do not appear to be a function of wood composition or source. Instead, they appear to be correlated to emissions of carbon monoxide and total hydrocarbons, which are also indicative of combustion inefficiency. "Good" combustion conditions appear to minimize organic emissions.
- Metals usually found in wood combustor particulate include arsenic, chromium, copper, lead, zinc, aluminum, titanium, iron, and manganese. Emissions estimated from wood and ash composition data summarized in Chapter 7 indicate that C/D wood samples obtained for this research probably contained higher concentrations of metals than wood fuel usually combusted at existing facilities for which emissions data were found.
- Particulate emissions vary according to the type of particulate control device (electrostatic precipitators and baghouses perform the best, followed by wet scrubbers and mechanical cyclones).
- Metals control efficiency appears to be roughly equivalent to total particulate control efficiency with the exception of mercury.
- Chlorinated organic compounds, such as dioxins, furans, polychlorinated biphenyls, chlorinated phenols and chlor-benzenes are usually measured at extremely low concentrations or were reported to be less than minimum detection limits.
- Combustion of wood fuel with high levels of C/D or "treated" wood, particularly CCA wood, may result in exceedance of state guideline concentrations. Predicted exceedances of arsenic and chromium guidelines imply that the amount of CCA-treated wood in a fuel stream may need to be reduced by good processing practices to insure compliance with state air toxics guidelines.

Section 8.2 provides an overview of the types of pollutants that may be emitted from combustion of various waste wood fuels. Section 8.3 summarizes the sources of test data used to compile the data. The major sources of test data are described in some detail; all other sources are summarized in tabular form indicating the types of boilers, fuels and pollutants tested. Section 8.4 describes the methods and assumptions used to compile the data. A summary and evaluation of the test data are presented in Sections 8.5 and 8.6. Finally, an evaluation of the compliance potential of various facility configurations, controls, and fuel types to meet regulatory criteria is discussed in Section 8.7.

8.2 Identification of Pollutants from Waste Wood Combustion

As with any combustion process, all the criteria pollutants will be formed from wood combustion. Carbon monoxide (CO) and total gaseous nonmethane hydrocarbons (TGNMHC) will be formed due to combustion inefficiencies. Even the most efficient boilers could have up to several hundred parts per million (ppm) of CO and a few ppm of TGNMHC. Nitrogen oxides (NO_x) emissions are inversely proportional to CO and TGNMHC emissions; e.g., the higher combustion temperatures needed to achieve low CO and TGNMHC emissions usually result in higher levels of nitrogen in the combustion air being oxidized to NO_x. In addition, a component of total NO_x emissions is directly proportional to the nitrogen content of the fuel. Emissions of particulate matter (PM) are a function of boiler design, fuel ash content, and effectiveness of particulate control systems. Sulfur dioxide (SO₂) is formed via oxidation of sulfur in the fuel and appears to be also a function of the alkalinity of the fuel and ash. More than 90 percent of the sulfur in the fuel reacts with alkalinity in the wood and remains in the ash from the boiler (Oglesby and Blosser, 1980).

Non-criteria air pollutants that may be emitted from wood-fired boilers and are typically regulated as HAPs consist primarily of metals and various organic compounds. Metals may be emitted as a result of their natural presence in wood and from the non-wood portion of various waste wood fuels. For example, as seen in Chapter 7, relatively small concentrations of arsenic, barium, cadmium, chromium, copper, lead and zinc are found in clean wood fuel obtained from silvicultural activities. The source of metals may also be soil that is brought into the boiler as a contaminant. Significantly higher levels of arsenic, copper, chromium, lead and mercury are associated with waste wood containing various treated or coated products. For example, combustion of arsenic, copper and chromium contained in pressure-treated wood products would result in emissions of these metals. Pigments in paint, which could also result in emissions of metals when burning waste wood from building demolition, include relatively high concentrations of lead, titanium, mercury and aluminum.

Organics are usually emitted from any combustion process as products of incomplete combustion (PICs). Organic HAPs of potential concern from wood combustion include formaldehyde and other aldehydes, benzene, phenol, and polynuclear aromatic hydrocarbons (PAH). Some of these compounds, particularly formaldehyde and benzene, both carcinogens, have been measured at relatively high levels from residential wood combustion appliances. As a result, the general public and some regulators have assumed that these compounds are also emitted from commercial and industrial wood boilers even though the combustion design and efficiency of the latter would be expected to result in significantly lower PIC emissions. Other PICs of regulatory and health concern associated with combustion of solid wastes include halogenated compounds such as dioxins and furans, chlorophenols and chlorobenzenes. Presumably, these compounds could only be formed if there were sufficient chlorine in the combustion air or chlorinated compounds in the fuel and inefficient combustion conditions. As will be seen later in this chapter, limited stack testing of wood boilers has indicated non-detectable or insignificant levels of these compounds are emitted.

8.3 Sources of Emissions Data

Most of the emissions test data on HAPs located for this research were found in reports and papers that have been written in the 1991-92 time period and were available only in draft form. The bulk of the data were found in a relatively small number of reports on rather comprehensive test programs. A data base of wood-fired boiler emissions compiled in 1990 by Concord

Scientific Corporation for Environment Canada included relatively few entries on HAPs using the normal literature search procedures (CSC, 1990). Most of the data collected in that effort were on criteria pollutant emissions. The process used to obtain data for the current research primarily involved contacting state and federal agencies and associations involved in regulating or operating wood fired boilers. The majority of data were obtained from states in which a large number of wood boilers are currently operating. The sources which contained the most comprehensive and useful data on HAPs are summarized in this section. Each summary contains a brief description of the type of combustor(s), fuel type(s), test program objectives and pollutants tested. Table 8-1 summarizes all emission sources used to compile data for this study, including those from which only criteria pollutant data were obtained. (Editors note: Since publication of the original report in 1992, most of the draft references have been published. The following text and the Bibliography have been updated to reflect these changes.)

- Sassenrath, 1991 - "Air Toxic Emissions From Wood Fired Boilers" - for the Timber Association of California (2²) - Under sponsorship of the Timber Association of California, operators of wood boilers formed a pooled test program to consolidate emissions testing efforts required to comply with California's Air Toxic "Hot Spots" law (AB 25888). The reference summarizes the results of the program. In addition, data summaries from all test runs at all eleven facilities were obtained directly from the Timber Association of California. Eleven different source tests were conducted representing approximately 85 wood-fired boilers operating in northern California. The eleven boilers included two fuel cells, two dutch ovens, five spreader stokers, one air injection and one fluidized bed. Emission control systems included mechanical cyclones, wet scrubbers and electrostatic precipitators (ESPs). The HAPs evaluated in the testing program included toxic metals, benzene, aldehydes, phenolics, PAHs, dioxins and dibenzofurans. The primary conclusions from the test program were as follows:
 - Toxic metals are significantly reduced by high- efficiency particulate collection devices required on new facilities.
 - Aldehydes and benzene were measured as high as one part per million. Concentrations vary widely depending on the type of boiler. Emissions are slightly lower for fuel cells and dutch ovens than for spreader stokers, probably due to the large area of hot refractive surface relative to the furnace combustion zone.
 - Volatile organic concentrations in the stack rise with an increase in carbon monoxide concentrations in some boilers, but no similar combustion efficiency relationship could be established between boiler types.
 - PAH emissions from properly operated wood-fired boilers are very low.
- California Air Resources Board (CARB), 1990 - "Evaluation Test on a Wood Waste Fired Incinerator at Pacific Oroville Power Inc." (5) - CARB conducted an evaluation test of the Pacific Oroville

² Refers to reference number in Table 8-1 and in Bibliography.

Table 8-1. Plant information for emissions data sources.

ID	Plant name	State	Boiler	MMBtu/hr	Fuel	Particulate controls	Other emission controls	Ref. No.	Pollutants tested for
001	Afton Generating Station	WY	NR	165		MC WS	CC	1	Permits, criteria
002	Collins Pine Co.	CA	NR	56		MC ESP	CC	1	Permits
003	Co-Gen, Inc.	ID	NR	63		ESP	CC	1	Permits
004	Hay Fork Co-Gen	CA	NR	236		MC ESP	CC	1	Permits, criteria
005	McNeil Generating Station	VT	SS	666		MC ESP	CC	1,32	Permits, criteria
006	Texas Electric Co-Op	TX	NR	35	SILV CLRE	MC		1	Permits
007	Sierra Pacific Industries	CA	SS	245		MC ESP	CC	1,2	Permits, criteria, metals, PAH, aromatics, halogenated HC, aldehydes, phenols
008	Redding Power Plants A & B	CA	SS	229	CLRE	MC ESP	CC	14	Permits, criteria
009	Hudson Lumber	CA	NR	70		MC WS	CC	1	Permits
010	Sierra Forest Products	CA	NR	140		MC ESP	CC	1	Permits
011	Yankee Energy Company	CA	FB	175		MC ESP	SNCR CC	1,2	Permits, criteria, metals, PAH, aromatics, aldehydes
012	Cal Ag Power	CA	NR	92		FF	CC SI	1	Permits
013	Gabriel Power	CA	NR	147		MC ESP	CC	1	Permits
014A	Pacific Oroville Power, Inc.	CA	SS	321	SILV			1,5	Permits, criteria, metals, aromatics, halogenated HC, dioxins, furans
014B	Pacific Oroville Power, Inc. - Urban waste	CA	SS	360	SILV CLRE CD	MC ESP	CC	5	Criteria, metals, PAH, aromatics, halogenated HC, dioxins, furans, chloro-benzenes, chlorophenols, PCB
015	Washington Water & Power	WA	NNR	560				1	Permits
016	Evergreen Forest Products	ID	NR					1	Permits
017	Gold Kist, Inc.	GA	NR					1	Permits
018	ABITIBI	NC	NR					1	Permits
019	Carolina Forest Products	SC	NR					1	Permits
020	Viking Energy	PA	NR					1	Permits
021	West Vaco Corp.	PA	NR					1	Permits
022	Louisiana Pacific	ME	SS					1	Permits
023	Port St. Joe	FL	NR					1	Permits
024	Panorama Energy Corp.	AL	NNR					1	Permits
025	Alabama Kraft	ME	NR					1	Permits
026	Stratton Power	KT	NR					1	Permits
027	Willamette Industries	CA	NR					1,26	Permits, criteria
028	Martell Power	CA	NR					1	Permits
029	Ultrapower II	CA	NR	145		MC ESP	CC	1	Permits
030	Ultrapower I	CA	NR	145		MC ESP	CC	1	Permits
031	Auberry Forest Products	CA	NR	165		MC ESP	SNCR CC SI	1	Permits
032	Energy Factors Feather River	CA	NR	247		MC ESP FF	CC	1	Permits, criteria
033	Burney Forest Products	CA	FB	167		MC WS	SNCR CC	1	Permits, criteria, metals, PAH, halogenated HC, dioxins, furans, chlorobenzenes, chlorophenols, PCB
034A	Pacific Ultrapower Chinese Station	CA	SS	370	CLRE	MC ESP	SNCR CC		

(Continued)

Table 8-1. Plant information for emissions data sources (continued).

ID	Plant name	State	Boiler	MMBtu/hr	Fuel	Particulate controls	Other emission controls	Ref. No.	Pollutants tested for
034B	Pacific Ultrapower Chinese Station (unc)	CA	NR		CLRE				Criteria, metals
035	Fairhaven Power I	CA	NR	309		MC ESP	CC	1	Permits
036	Monterey Bay - ESP	CA	NR	230		MC ESP	SNCR CC SI	1	Permits
037	Monterey Bay - PF	CA	NR	216		MC FF	SNCR CC SI	1	Permits
038	Erath Veneer	VA	NR	32		MC	CC	1	Permits
039	Burlington Industries	GA	NR	290		MC WS		1	Permits
040	Butte	CA	NR	127		MC ESP	CC	1	Permits
041	North Coast	CA	NR	309		MC ESP	CC	1	Permits
042	Placer	CA	NR	357		MC ESP	CC	1	Permits
043	Fairhaven Power II	CA	NR	226		MC ESP	CC	1	Permits
044	Co-Generation, Inc.	MI	NR	293		MC FF	CC	1	Permits
045	Louisiana Pacific Hardboard Plant	CA	CB	127	SILV CLRE	MC ESP	CC	1,3	Permits, criteria, metals, PAH, aromatics, halogenated HC, dioxins, furans, phenols, chlorobenzenes, chlorophenols, PCB
046	Wood Preservers, inc.	CA	NR	48	BM	MC	CC	1	Permits
047	Chowchilla II	CA	FB	191	SILV BM	MC FF	SNCR CC SI	1	Permits
048	El Nido	CA	FB	152	BM	MC FF	SNCR CC	1	Permits
049	Five Points	CA	NR	240	BM	MC FF	CC	1	Permits
050	Madera Capco	CA	FB	400	SILV BM	MC FF	SNCR CC SI	1	Permits
051	Delano Ennergy Company	CA	FB		SILV BM	MC FF	SNCR CC SI	1,31	Permits, criteria
052	Mendota Biomass Power, Ltd.	CA	FB	418	SILV BM	MC FF	SNCR CC SI	1,31	Permits, criteria, other inorganics
053	Sanger	CA	NR	175	BM		CC	1	Permits
054	Superior Farms	CA	NR	100	SILV BM	MC FF	CC SI	1	Permits
055	TEDCO	CA	NR	259	CLRE BM CD	MC ESP	SNCR CC SI	1	Permits
056	Ultrapower Fresno	CA	FB	402			SNCR CC	31	Permits, criteria
057	Miller Redwood Company	CA	CB	13.9		MC		2	Criteria, metals, PAH, aromatics, aldehydes
058	Big Valley Lumber Company	CA	CB	105		MC		2	Criteria, metals, PAH, aromatics, halogenated HC, aldehydes, phenols
059	Roseburg Forest Products Co.I	CA	DO	79		MC		2	Criteria, metals, PAH, aromatics, aldehydes
060	Roseburg Forest Products Co.II	CA	DO	85		WS		2	Criteria, metals, PAH, aromatics, halogenated HC, aldehydes, phenols
061	Catalyst Hudson Company	CA	SS	142		WS		2	Criteria, metals, PAH, aromatics, halogenated HC, aldehydes, phenols
062	Georgia Pacific Corp. - CA	CA	SS	215		WS		2	Criteria, metals, PAH, aromatics, aldehydes
063	Pacific Lumber Company	CA	SS	214		ESP		2	Criteria, metals, PAH, aromatics, aldehydes

(Continued)

Table 8-1. Plant information for emissions data sources (continued).

ID	Plant name	State	Boiler	MMBtu/hr	Fuel	Particulate controls	Other emission controls	Ref. No.	Pollutants tested for
064	Wheelabrator Shasta Energy Company	CA	SS	339	CLRE	MC ESP	SI	1, 2	Permits, criteria, metals, PAH, aromatics, halogenated HC, aldehydes, PCB
065	Bohemia incorporated	CA	AS SS	61		MC		2	Criteria, metals, PAH, aromatics, aldehydes
066	Site 5 (RR)				CLRE RR	MC ESP	SNCR CC	28	Criteria, metals, PAH, aromatics, halogenated HC, aldehydes, PCB
068A	Confidential	CA	FB	332	SILV BM	MC ESP	SNCR SI	4	Criteria, metals, PAH, aromatics, halogenated HC, dioxins, furans, chlorobenzenes, chlorophenols, PCB
068B	Confidential - uncontrolled	CA	FB	324	SILV BM			4	Criteria, metals, PAH, aromatics, halogenated HC, dioxins, furans, chlorobenzenes, chlorophenols, PCB
070	Pride Manufacturing	WI	SS	6.3				6	Criteria, metals, aldehydes
071	Webster Industries	WI	FB	34				6	Criteria, aldehydes
072	Kretz Lumber Company	WI	NR	8.1				6	Criteria, aldehydes
073	U.S. Stick Corporation	WI	DO	12				6	Criteria, aldehydes
074	SNE Industries	WI	NR	13				6	Criteria, aldehydes
075	Zurn - University of Idaho	ID	SS	60		MC		7	Criteria, aldehydes
076	Koppers Company	CA	CB	100		MC		8	Criteria, aldehydes, halogenated HC, dioxins, furans
078	Unknown 1		SS	450				10	Criteria, aldehydes
079	Unknown 2		SS	1200		MC GBF ESP		10	Criteria, aldehydes
080	Unknown 3		SS	840				10	Criteria, aldehydes
081	Unknown 3 - uncontrolled		SS	840				10	Criteria, aldehydes
082	Unknown 4		CB	4.7			CC	10	Criteria, aldehydes
083	Drexel Heritage Furnishings, Inc.	NC	SS	16.6		MC		11	Permits, criteria
084	Thomasville Furniture Ind. Plant C	NC	SS	15.9		MC		11	Permits, criteria
085	Craven County Wood Energy LP	NC	SS	674				11	Permits, criteria
086	Ethan Allen Company	NC	SS	9.3		MC		11	Permits, criteria
087	Thomasville Furniture Industry	NC	SS	18.3		MC		11	Permits, criteria
088	Georgia Pacific Corp. - NC	NC	NR	40		MC		11	Permits, criteria
089	Bay Front Generating Station boiler #2.	WI	SS	202	RR	MC		13	Permits, criteria, PAH, aromatics, aldehydes
090	Wood Tech, Inc.	VA	NR	29	CLRE	MC		12	Permits
091	Energy Systems KMW - wood chips.	CT	CB	12.1	SILV	MC		21	Criteria, PAH, aromatics, aldehydes, other organics
092	Energy Systems KMW - hog fuel.	CT	CB	9.5	CLRE	MC		21	Criteria, PAH, aromatics, aldehydes, other organics
093	ORTECH - tree chips.	CT	SS	0.8	SILV	MC		21	Criteria, PAH, aromatics, aldehydes, other organics

(Continued)

Table 8-1. Plant information for emissions data sources (continued).

ID	Plant name	State	Boiler	MMBtu/hr	Fuel	Particulate controls	Other emission controls	Ref. No.	Pollutants tested for
094	ORTECH - hog fuel'	CN	SS	0.7					
095	Site 1	CN	NR	417	SILV	MC ESP		21	Criteria, PAH, aromatics, aldehydes, other organics
097	NC Study site K	NC	SS	5.3				22	Criteria, PAH
098	NC Study site EA (dry)	NC	SS	16.6	CLRE	MC		20	Criteria, PAH
099	NC Study site EA (wet)	NC	SS	28	SILV	MC		20	Criteria, PAH
100	NC Study site BP	NC	SS	27	CLRE	MC		20	Criteria, PAH
101	NC Study site HH	NC	SS	5.5	CLRE	MC		20	Criteria, PAH
102	NC Study site SF	NC	SS	12.6	CLRE	MC		20	Criteria, PAH
103	NC Study site EL	NC	SS	13.2	SILV	MC		20	Criteria, PAH
104	NC Study site WW	NC	FB	17.8	SILV	MC		20	Criteria, PAH
105	P&G Port Ivory Complex	NY	SS	320	SILV CD LAM	MC WS		25	Permits, criteria
106	Long Beach	CA	SS	200	CD LAM	MC WS	SNCR	25	Permits, criteria
107	Blandin Paper Co. #5 boiler	MN	SS	180	RR			15	Criteria, metals, other inorganics, PAH, aromatics, halogenated HC, aldehydes, other organics
108	VICON Recovery Associates	MA	SS	84	CLRE			17	Criteria, other inorganics, PAH, halogenated HC, dioxins, furans, chlorobenzenes, chlorophenols, PCB
109	Northwood Pulp Mill - baseline	CN	SS	422	CLRE	MC		18	Criteria, other inorganics, halogenated HC
110	Northwood Pulp Mill - treated	CN	SS	435	CLRE OT	MC		18	Criteria, other inorganics, halogenated HC
111	Unknown Site 6		SS			ESP		10	Criteria, aldehydes
112	Unknown Site 7		SS			ESP		10	Criteria, aldehydes
113	Bio Energy Corporation	NH	SS	290	SILV	GBF	CC	29	Permits, criteria
114	Frennch island Unit 2'		FB	205	CLRE	MC GBF		23	Criteria, aromatics, aldehydes
115	Birchwood Lumber & Veneer Plant (old)	WI	SS	5.6				24	Criteria, aldehydes
116	Birchwood Lumber & Veneer Plant	WI	DO	13.1	CLRE	MC		19	Criteria, metals, PAH, aromatics, halogenated HC, aldehydes, chlorobenzenes, chlorophenols
117	Alexandria Power Associates LP	NH	SS	218				29	Permits, criteria
118	Whitefield Power & Light	NH	SS	212				29	Permits, criteria
119	Treebrook 1	NH	SS	250			CC	29	Permits, criteria
120	Timco, Inc.	NH	SS	53				29	Permits, criteria
121	Pinetree Power - Tamworth	NH	SS	409				29	Permits, criteria
122	Pinetree Power - Bethlehem	NH	SS	289				29	Permits, criteria
123	Hemphill Power & Light	NH	SS	230				29	Permits, criteria
124	Ryegate Wood Energy Co.	VT	SS	300			SNCR CC	29 permit	Permits, criteria

(Continued)

Table 8-1. Plant information for emissions data sources (concluded).

Notes:

* Data from these references not used in statistical evaluations for reasons noted in text.

Permits: permit limits only

Boiler Types:

SS = Spreader Stocker
DO = Dutch Oven
FB = Fluidized Bed
CB = Cell Burner
AS = Air Suspension
NR = Not Reported

Fuel Types:

SILV = Silviculture
CLRE = Clean Recycled
BM = Biomass
CD = Constructio/Demolition Waste
RR = Railroad Ties
LAM = Laminated
OT = Other Treated

Particulate Controls:

MC = Mechanical Collector
ESP = Electrostatic Precipitator
WESP = Wet Electrostatic Precipitator
WS = Wet Scrubber
FF = Fabric Filter
GBF = Gravel Bed Filter

Emission Controls:

SNCR = Selective Non-Catalytic Reduction
CC = Commbustion Controls
SC = Staged Combustion
SI = Sorbant/limestone Injection

Power Inc. (POPI) facility in June of 1988. The test results were obtained from CARB in preliminary draft form in 1989 and in a final report in May 1990. The POPI facility operates two spreader stoker boilers in parallel, each controlled by three-field ESPs. Emissions were sampled in the common stack that exhausts both boilers. The test program was conducted to evaluate HAPs under two separate scenarios, one when the boilers were fired with "permitted" fuel and the second when the boilers were fired with "urban wood waste" in the ratio of 70% "permitted" fuel to 30% "urban waste wood". The HAPs evaluated included dioxins and furans, metals, halogenated and aromatic volatile organics, chlorobenzenes, chlorophenols, and PCBs. The facility was also tested for all criteria pollutants. This study also evaluated dioxin and furan concentrations in the ESP ash.

- CARB, 1990 - "Evaluation Test on a Wood Waste Fired Incinerator at Louisiana Pacific Hardboard Plant, Oroville Power California" (3)
- A similar test program to that conducted at POPI was conducted at the Louisiana Pacific Hardboard Plant in September of 1988. This facility consists of a Wellons four-celled wood-fired steam

generator firing nonindustrial wood chips and bark permitted by the Butte County Air Pollution Control District. Air pollution controls consist of a multicyclone and ESP. This facility was also tested for dioxins, furans, halogenated and aromatic volatile organics, PAHs, chlorobenzenes, chlorophenols and PCBs in addition to criteria pollutants. This study also evaluated dioxin and furan concentrations in the ESP ash.

- CARB, 1990 - "Evaluation Test on a Wood Fired Incinerator at Koppers Company, Oroville California" (8) - A similar test program to those conducted at POPI and Louisiana Pacific Hardboard was conducted at the Koppers Co. in September of 1988. This facility consists of a Wellons four-celled wood-fired steam generator firing nonindustrial wood chips and bark permitted by the Butte County Air Pollution Control District. A multicyclone is the only air pollution control device. This facility was also tested for dioxins, furans, halogenated and aromatic volatile organics, PAHs, chlorobenzenes, chlorophenols and PCBs in addition to criteria pollutants. This study also evaluated dioxin and furan concentrations in the multiclone ash.
- CARB, 1990 - "Evaluation Test on a Fluidized Bed Wood Waste Fueled Combustor Located in Central California" (4) - CARB conducted a similar program in China Station during May 1988 to the other three test programs conducted in Oroville. The tested facility consisted of a fluidized bed boiler operated for electricity generation and equipped with a multiclone and ESP for particulate control and a selective non-catalytic reduction (SNCR) system for NO_x control. The test program was more extensive than the other three CARB programs, collecting samples before and after the ESP. The ash analyses were also more extensive. Dioxins, furans, PAHs, chlorobenzenes, chlorophenols and PCBs were evaluated in the composite of the bottom, multiclone and ESP ash. Metals were also analyzed in the fuel and in the composite ash.
- National Council of the Paper Industry for Air and Stream Improvement (NCASI), 1992 (10) - This report is NCASI's summary of its effort to develop emission factors for formaldehyde from wood-residue fired boilers representative of current design and operating practices. NCASI tested formaldehyde emissions at seven different sites, five of which were spreader stoker boilers with ESPs or wet scrubbers. One site was a suspension-fired fuel cell fired with a wood dust known to contain formaldehyde-based resin. Data from a seventh site did not pass the program's quality assurance criteria. Although the actual locations of the test sites were not disclosed in the report, the effort was conducted out of NCASI's West Coast Regional Center.

Because there was no recognized standard or reference method for formaldehyde sampling and analysis at the time of the test program, NCASI collected three concurrent samples for three different analytical procedures for each test run to compare the results. The three test methods evaluated were (1) the chromotropic acid procedure, (2) the acetylacetone procedure, and (3) the pararosaniline procedure, each using colorimetric analysis. In addition, the CARB's method 430, using the 2,4 dinitrophenylhydrazine (DNPH) procedure with chromatographic analysis was conducted at two test sites for comparison with the

other NCASI sampling and analytical procedures³. A total of 37 data points were obtained from this program. The main conclusions of the study were:

- The emission potential for formaldehyde from wood-residue fired boilers was considerably (more than one to two orders of magnitude) less than from residential wood stoves. When operated at CO concentrations of 500 ppm or less, wood boilers would be expected to emit formaldehyde on the order of 0.001 lb/MMBTU heat input; and
- The information developed in the course of the test program indicated that collection of samples from a filtered gas stream in two midjet impinges placed in series in an ice bath, storage of the samples under refrigeration, and analysis with the chromatropic acid and/or acetylacetone procedures was appropriate. Use of the pararosaniline measurement procedure for this application satisfied quality assurance criteria for only a small percentage of the time. Comparison of the DNPH method with the colorimetric methods at two of the sites indicated comparable values when low concentrations were measured (< 1ppm).
- Wisconsin Department of Natural Resources, letter to CTD re: Request for Stack Test Data on Waste-wood Combustion (6). This letter is a source of formaldehyde and manganese emission data from six different wood-fired boilers in Wisconsin. Each of the sources is a relatively small boiler ranging in size from 6 to 34 MMBTU/hr. Average formaldehyde emissions ranged from 0.00008 to 0.0062 lb/MMBTU.
- Interpoll Laboratories, Inc. - "Results of the April 2 - 4, 1991 Wood Combustion Emission Study At the Birchwood Lumber and Veneer Plant In Birchwood, WI" (new boiler) and "Results of the April 3 - 5, 1991 Wood Combustion Emission Study At the Birchwood Lumber and Veneer Plant In Birchwood, WI" (19) and (24). These two reports are a summary of emission tests conducted at two of Birchwood Lumber and Veneer Plant's wood fired boilers, an old six MMBTU/hr spreader stoker boiler manufactured in 1918 and a recently installed 20 MMBTU/hr dutch oven type boiler. The tests were conducted in support of a wood combustion study of small industrial wood fired boilers in Wisconsin. The tests included determinations of particulate, trace metals, aldehydes, PAH, benzene, and criteria pollutants. During the course of the testing, boiler operating parameters in the new boiler were intentionally varied to simulate "poor combustion" conditions. The boiler was operated under normal conditions for the remainder of the test runs in order to compare emission factors representative of "good combustion" with "poor combustion". Benzene emissions from the "poor combustion" runs were increased by as much as eight times over the average of test runs representing "good combustion". Formaldehyde increased by as much as five times over the average of the "good combustion" runs. PAH emissions from the worst "poor combustion" run were approximately four times higher than the average of the "good combustion" runs.

³ (Editor's note: This method has since been certified by EPA as Method 0011)

- Interpoll, Inc. - Results of the August 12 and 13, 1986 Air Emission Compliance Tests For the Railroad Tie Test Burn On The No. 2 Boiler At The NSP Bay Front Plant In Ashland, WI" (13). This report summarizes compliance tests performed at Northern States Power Company Bay Front Plant in Ashland, WI during a railroad tie test burn. Three test runs each were run for 100% railroad ties and a 50:50 mixture of railroad ties and wood chips. The boiler, a 200 MMBTU/hr B & W spreader stoker boiler built in 1953, was tested for particulates, carbon monoxide, benzene, aldehydes, phenol and PAH. In general, the results show lower aldehyde, phenol and PAH emissions for the 50% railroad tie runs.
- NYSERDA - "Results of the Combustion and Emissions Research Project at the Vicon Incineration Facility in Pittsfield, Massachusetts" (17). Under contract to the Energy Authority, the Midwest Research Institute conducted a series of tests at the Vicon MSW incineration facility to investigate the relationships between combustion and operating conditions and organic emissions. The emissions tested for were polychlorinated dibenzo dioxins and furans (PCDDs/PCDFs), polychlorinated biphenyls (PCBs), chlorobenzenes, chlorophenols and PAH. Although the test program primarily involved combustion of MSW, a PVC-free fuel consisting mainly of wood and cardboard was combusted in four of the nineteen test runs. The waste was segregated from the normal MSW fuel and was not totally free of plastic (chlorinated) material, although the chlorine content was much less than that found in normal MSW. The data from the test program, including runs where MSW was combusted, indicates relatively low levels of PCDDs/PCDFs, about the same as the lowest levels measured at other incinerators. There was no evidence from the testing that the level of PVC in the waste affects the levels of PCDDs/PCDFs emissions. Concentrations of PCBs and PAHs were not significantly above the levels in field blanks. Concentrations of chlorobenzenes and chlorophenols were about 10 times higher than PCDDs/PCDFs, but were still quite low, on the order of 0.001 ppm.
- North Carolina Department of Natural Resources, "A POM Emissions Study For Industrial Wood-Fired Boilers" (20). This study was undertaken to establish polycyclic organic material, or PAH emissions from industrial wood fired boilers in North Carolina. The seven boilers tested in the study were chosen to be representative of the majority of the 400 or more industrial wood boilers in North Carolina when operating with good operating practices. Four horizontal return tube boilers, one water tube, one fluidized bed and one underfired unit were selected for testing. The boilers were relatively small units, rated capacities ranging from 5 to 70 MMBTU/hr. The results of this study indicated that properly fired wood boilers can achieve PAH emissions at least as low, and possibly lower than commercial boilers fired with bituminous coal.
- Energy, Mines and Resources Canada, "Combustion and Emission Research On Wood-Refuse Boilers, Vol. III, Part 2, Tabulated Results For Site 1" (22). This report summarizes PAH and criteria pollutant emissions from an approximate 400 MMBTU/hr Combustion Engineering boiler fired with wood refuse. The wood refuse sources include dry bark and chip-screening fines from the paper mill's wood room, pressed sludge from the mill's effluent treatment system and purchased mixed wastes (sawdust, shavings and bark) from local sawmills. Although measured CO and hydrocarbon

emissions from the test runs did not indicate good operating and combustion conditions, measured PAH emissions were very low, roughly equivalent to background concentrations in the blanks.

- State of Minnesota Pollution Control Agency, Office Memorandum of October 23, 1987 re: Test Report Review - Blandin Railroad Tie Test Burn (15). This memorandum summarizes the results of the railroad tie test burn conducted by Interpoll, Inc. at the Blandin Paper Co. in Grand Rapids. The boiler is a spreader-stoker design with a capacity of approximately 200 MMBTU/hr. The fuel fired during the test program consisted of a mixture of approximately 24% railroad ties, 65% untreated wood chips and 11% coal on a BTU basis. Compounds tested for included criteria pollutants, metals (Cd, Cr, As, Pb, Hg), PAHs, phenols, cresols, pentachlorophenol, hexachlorobenzene, benzene, aldehydes, HCl and HF.
- Electric Power Research Institute, "Alternative Fuel Firing in an Atmospheric Fluidized Bed Combustion Boiler" (23). This report details the results of test burns of alternative fuels, including wood and railroad ties, in a shallow bed atmospheric fluidized bed combustor (AFBC). The boiler tested in this study was a AFBC retrofit of the Boiler No. 2 at the Northern State Power French Island Plant in Minnesota. Test runs originally included in the database ranged from 100% clean wood to a 45:55 mixture of railroad ties and clean wood. Initial baselinetests with 100% clean wood showed insufficient mixing of the overfire air, which led to incomplete combustion. Extremely high levels of CO and organics (PAH, aldehydes, phenols) were measured under this condition. As a result, data from this report were not included in overall statistical evaluation of the database since the boiler was not operated under good combustion conditions.
- Energy, Mines and Resources Canada, "Emissions and Performance Characterization of Industrial/Commercial Biomass Combustion Systems - Draft Final Report" (21). This preliminary draft report summarizes the testing of two small biomass boilers, one KMW 3750 KW and one Ortech 300 KW combustion cell. The primary fuels used in the emissions tests were whole tree chips and residues from mixed wood species. The boilers were tested for emissions of criteria pollutants, PAH, aldehydes and aromatics, including benzene. Since the tests represented very small boilers and extremely high measured CO levels were indicative of poor combustion, the test data from this report were not included in the overall statistical evaluation of the database.
- Environment Canada, "Summary Report for a Test Burn of Chlorophenol Contaminated Wood Wastes at Northwood Pulp Mill, Prince George, B.C." (18). Environment Canada and British Columbia Ministry of Environment conducted a series of tests on an industrial wood waste (hog) fuel fired boiler at Northwood Pulp and Timber, Ltd. to determine the capability of this combustion system to destroy low levels of chlorophenols, dioxins and furans that sometimes contaminate hog fuel. The test burns involved hog fuel with and without adding chlorophenol solution. Chlorophenol solutions were added in concentrations ranging from 50 to 400 ug/g. The emissions testing indicated a minimum dioxin and furans destruction efficiency of 99.9993% and a minimum chlorophenol destruction efficiency of 99.9917%.

8.4 Data Collection Methodology

A thorough review of the test reports discussed in Section 8.3 was performed to compile data on wood fired boiler emissions factors. This section briefly summarizes the major assumptions and conventions that were used to present the data in a form that could be most conveniently evaluated.

In order to maximize the number of data points for subsequent analyses, data from each sampling run from a particular report, rather than the average of multiple runs were studied. Due to the variety of formats used to report units of measure in the different sources of data, the emission data required some preprocessing for standardization of units. With the exception of criteria pollutants, all emissions were converted to units of either micrograms or nanograms per dry standard cubic meter (ug/dscm or ng/dscm) corrected to 12 percent carbon dioxide (12% CO₂). Standard conditions were defined as 68°F (20°C) and 1 atm (760 mm Hg). The dry volumetric basis standardizes the data so that pollutant concentrations are independent of the varying moisture content of wood fuel and the 12% CO₂ correction serves as a normalization for varying excess air requirements of different boiler designs. Criteria pollutant emissions were converted to units of pounds per million BTU (lb/MMBTU), a common emission factor basis used by regulatory agencies.

In some cases, insufficient data on operating conditions at the time of the test program were available to convert reported data to the desired units. Reasonable assumptions were made in those cases in order to make the conversions. For example, some reports did not include gas volume rates and/or heat input rates in order to convert from mass rates to concentration units. In these cases, the EPA F factor (from 40 CFR 60.45), based on the approximate composition of wood fuel was used, which is in units of dscf/million Btu. In other cases, concentration units in some reports were given with no reference to dry conditions or percent CO₂. For purposes of data evaluation, these concentrations were assumed to be on a dry basis and corrected to 12% CO₂. A summary of conversions used to standardize the units of measure is included in Appendix H.

In many cases, pollutants that are tested are not measured in the stack at quantities above minimum detection levels. The convention used to handle these data points was to indicate the detection limit with a negative sign. In subsequent statistical or graphical evaluation of the data, half of the absolute value was used.

Several computer software packages were used to facilitate collecting, standardizing and evaluation of the emissions data. The database manager DBASE IV Version 1.1 was used on an IBM-compatible personal computer to organize the collected data. A spreadsheet program, Lotus 1-2-3, Version 3.1 was used for further organization, graphing and presentation of the data. Statsoft's CSS: Statistica™ was used for statistical evaluation that was beyond the capabilities of Lotus 1-2-3.

8.5 Criteria Pollutant Permit Limits and Test Data

Although the focus of this part of the project was on hazardous air pollutants, much data were collected on criteria pollutant emissions from the various boiler types. Table 8-2 summarizes test data and permit limits for more than a hundred different facilities. The values reported for test data represent the averages of compliance test data. The data are also sorted by boiler type.

8.6 Summary and Evaluation of Non-criteria Emissions Data

Table 8-2. Criteria pollutant permit limits and test data.

Plant Name	Boiler: Type MMBtu/hr	(lb/MMBtu)									
		Particulate Matter: Permit Tested	Nitrogen Oxides: Permit Tested	Carbon Monoxide: Permit Tested	Sulfur Dioxide: Permit Tested	Hydrocarbons: (1) Permit Tested					
117 Alexandria Power Associates LP	SS	0.100	0.270	0.270	0.396	0.270	0.210	0.270	0.002		
113 Bio Energy Corporation	SS	0.100	0.119	0.790	0.165	0.790	0.210	0.270	0.002		
115 Birchwood Lumber & Veneer Plant (old)	SS										
107 Blandin Paper Co. #5 Boiler	SS										
033 Burney Forest Products	SS	0.020	0.120	0.400	0.426	0.400	0.046	0.100	0.039		
061 Catalyst Hudson Company	SS										
085 Craven County Wood Energy LP	SS	0.041	0.350	0.660	0.253	0.660	0.046	0.100	0.006		
083 Drexel Heritage Furnishings, Inc.	SS	0.671	0.235		0.273			0.077	0.006		
086 Ethan Allen Company	SS	0.534									
062 Georgia Pacific Corp. - CA	SS	0.056									
123 Hemphill Power & Light Co.	SS	0.100	0.270	0.270	1.490	0.270		0.270	0.033		
106 Long Beach	SS	0.050	0.290	0.120	0.220	0.120	0.008	0.030	0.011		
022 Louisiana Pacific	SS	0.150									
005 McNeil Generating Station	SS	0.007	0.157								
100 NC Study Site BP	SS										
098 NC Study Site EA (dry)	SS	0.206									
099 NC Study Site EA (wet)	SS	0.128									
103 NC Study Site EL	SS	0.317									
101 NC Study Site HH	SS	0.279									
097 NC Study Site K	SS	0.183									
102 NC Study Site SF	SS	0.152									
109 Northwood Pulp Mill - Baseline	SS	0.127									
110 Northwood Pulp Mill - Treated	SS	0.235	0.161		0.692				0.003		
063 Pacific Lumber Company	SS	0.215	0.139		0.896				0.008		
014A Pacific Oroville Power Inc.	SS	0.002			1.240				0.020		
014B Pacific Oroville Power Inc.	SS	0.036	0.140	2.300	1.567	2.300		0.150	0.026		
122 Pinetree Power - Bethlehem	SS	0.005	0.124		1.635				0.020		
121 Pinetree Power - Tamworth	SS	0.042	0.191	0.191	0.158	0.191					
105 P&G Port Ivory Complex	SS	0.025	0.265	0.500	0.230	0.500	0.0004	0.096	0.0004		
008 Redding Power Plants A & B	SS	0.100	0.300	0.220	0.155	0.220	0.008	0.060	0.004		
124 Ryegate Wood Energy Co.	SS	0.110	0.115	0.290	0.343	0.290	0.010	0.100	0.017		
007 Sierra Pacific Industries	SS	0.007	0.250	0.300		0.300	0.093	0.030	0.017		
	SS	0.048	0.280	0.380	0.700	0.380	0.010	0.120	0.028		

(Continued)

Table 8-2. Criteria pollutant permit limits and test data (continued)

Plant Name	Boiler: Type MMBtu/hr	(lb/MMBtu)				Carbon Monoxide: Permit Tested	Sulfur Dioxide: Permit Tested	Hydrocarbons: (1) Permit Tested
		Particulate Matter: Permit Tested	Nitrogen Oxides: Permit Tested	Carbon Monoxide: Permit Tested	Sulfur Dioxide: Permit Tested			
026 Stratton Power	SS 620	0.013	0.350	0.202	0.235		0.003	
087 Thomasville Furniture Industry	SS 18.3	0.785						
084 Thomasville Furn. Ind. Plant C	SS 15.9	0.410						
120 Timco, Inc.	SS 53	0.340	0.467	0.168	0.467			
119 Treebrook I	SS 250	0.100	0.230	0.375	0.230			
078 Unknown 1	SS 450				0.888			
079 Unknown 2	SS 1200				2.790			
080 Unknown 3	SS 840				0.837			
081 Unknown 3 uncontrolled	SS 840				0.451			
111 Unknown Site 6	SS 371				0.668			
112 Unknown Site 7	SS 353				0.000			
108 VICON Recovery Associates	SS 84			0.201	0.008			
064 Wheelabrator Shasia Energy Company	SS 339	0.030	0.150	0.144	0.265	0.377	0.004	
118 Whitefield Power & Light	SS 212	0.100	0.270	0.239	0.270	LD	0.083	
075 Zurn - U. of Idaho	SS 60			0.270	0.259		0.270	
089 Bay Front Generating Station Boiler #2	SS 202			0.368	0.343			
093 ORTECH	SS 0.8	0.061	0.186	0.186	0.122	0.029	0.066	
094 ORTECH	SS 0.7	0.177	0.101	0.101	4.161	0.053		
047 Chowchilla II	FB 191	0.037	0.250		4.248			
068A Confidential	FB 332	0.015		0.187	0.054	LD	LD	
068B Confidential - Uncontrolled	FB 324			0.193	0.050	LD	LD	
051 Delano	FB	0.014	0.080		0.140	0.033	0.080	
048 El Nido	FB 152	0.037	0.285		0.140	0.049	0.081	
050 Madera Capco	FB 400	0.025	0.150		0.150	0.073	0.060	
052 Mendota Biomass Power Ltd.	FB 418	0.020	0.088	0.059	0.021	0.003	0.003	
104 NC Study Site WW	FB 17.8	0.156			0.016	0.002	LD	
034 Ultrapower Chinese Station	FB 370	0.070			0.150	0.022	0.098	
056 Ultrapower Fresno	FB 402	0.016	0.080		0.090	0.028	0.030	
011 Yankee Energy Company	FB 175	0.030	0.240		0.470	0.046	0.090	
114 French Island Unit 2	FB 205	0.367	0.101	0.101	0.298			
116 Birchwood Lumber & Veneer Plant	DO 13.1	0.361	0.191	0.191	1.062	0.006	0.026	

(Continued)

Table 8-2. Criteria pollutant permit limits and test data (concluded).

(lb/MMBtu)

Plant Name	Boiler: Type MMBtu/hr	Particulate Matter:		Nitrogen Oxides:		Carbon Monoxide:		Sulfur Dioxide:		Hydrocarbons: (1)	
		Permit	Tested	Permit	Tested	Permit	Tested	Permit	Tested	Permit	Tested
028 Martell Power	NR	0.024		0.170		0.580				0.067	
036 Monterey Bay - ESP	NR	0.018	230	0.094		0.150		0.027		0.027	
037 Monterey Bay - FF	NR	0.029	216	0.063		0.038		0.027		0.027	
041 North Coast	NR	0.040	309	0.200		0.400					
024 Panorama Energy Corp.	NR			0.170							
042 Placer	NR		357	0.157							
023 Port St. Joe	NR	0.100		0.300							
053 Sanger	NR	0.022	175	0.073		0.091		0.052		0.042	
010 Sierra Forest Products	NR	0.070	140	0.140		0.640		0.110		0.120	
095 Site 1	NR		417		0.023		1.132				0.013
054 Superior Farms	NR	0.022	100	0.165		0.229		0.062		0.068	
055 TEDCO	NR	0.034	259	0.105		0.210		0.061		0.049	
006 Texas Electric Co-Op	NR	0.300	35	0.080		1.100		0.200		0.200	
030 Ultrapower I	NR		145								
029 Ultrapower II	NR		145								
020 Viking Energy	NR	0.100		0.250							
015 Washington Water & Power	NR	0.044	560	0.180							
021 West Vaco Corp.	NR	0.100		0.700							
027 Willamette Inds.	NR			0.700							
046 Wood Preservers, Inc.	NR	0.200	48	0.080		0.450				0.160	
090 Wood Tech, Inc.	NR	0.200	29	0.938		0.553		0.021		0.194	

(1) Total gaseous non-methane hydrocarbons
LD = less than detection limit

This section summarizes the non-criteria emissions data and evaluations results. As there are a significant number of entries representing different boiler types, operating conditions and emissions controls in the data summary, one of the objectives of this study was to evaluate the effects of these parameters on emissions. Therefore, statistical calculations were performed on different subsets of the data, organized by boiler type, emission controls and operating parameters representative of different combustion efficiencies, primarily to develop emission factors that are representative of efficient versus poorly operated and/or controlled boilers.

The descriptive statistical calculations that were performed on some subsets of the data included means, medians and standard deviations as well as the 25th and 75th percentiles from frequency distributions. For metals, emissions were also sorted by particulate control device before additional statistical calculations were performed. For organic emissions, the data were sorted by boiler type and by different ranges of CO, corresponding to different levels of combustion efficiency. Correlations between emissions and CO were also evaluated graphically and histograms were plotted for some pollutants.

It became apparent early in the process of evaluating the data that the emissions were not normally distributed, neither the data as a whole nor within the sorted subgroups. As with many cases involving environmental or pollution data sets, the data appeared to be skewed (asymmetrical) to the right and more appropriately modeled as a lognormal rather than a standard normal distribution. With right-skewed data distributions, the existence of a few data points at very high levels results in a positive bias to the mean or arithmetic average. Large differences between the calculated medians and means indicate skewed data distributions as do coefficients of skewness and kurtosis that differ from zero. As a better summary of the data, the median and geometric mean can be used instead of the arithmetic average.

Several cautions for use of the data summaries are appropriate. It is most important to understand that the data do not represent a set of controlled experiments performed on individual boilers to evaluate the effects of operating variables on emissions. Instead, data from a large number of test programs were compiled, representing many different boiler designs, sizes, fuel sources, and combustion controls. The conditions achieved during some of the test programs (in particular, compliance or performance tests) generally are not representative of the range of "normal" conditions but of "near-steady-state" conditions that are achieved by careful monitoring and control of the facility. In addition, a large number of different testing firms are represented, sometimes using different test methods and limits of detection to measure the same types of emissions.

The minimum detection levels (MDLs) used in emissions tests can also positively bias statistical summaries. For example, some compounds, like dioxins or PCBs are tested for because of their potentially significant health or environmental impacts, even though they may not be formed in quantifiable amounts from wood combustion. To deal with values below MDLs, one-half of the value was entered in the database for use in statistical calculations. However, if MDLs are relatively high for a given test program, data treated with this method could result in a significant bias to the summary.

Another source of bias is the variation in the number of tests performed at each plant. Since it was desired to evaluate the largest number of individual data points rather than the averages of a given test program, a relatively high number of data points verifying a given operating condition at one site may more than offset a small number of data points obtained from another test report.

Relatively few sources of emissions data were found on boilers combusting C/D, railroad ties, telephone poles or other treated wood. These data were summarized separately and compared with emissions from "clean" wood combustion sources in order to evaluate the effects of contaminants on emissions. This discussion is presented in Section 8.6.4.

Overall, the data summary should be very useful in characterizing emissions from wood-fired boilers. The overall caution, however, is that the statistical summaries should not be used exclusively without reviewing the raw data used to calculate them.

8.6.1 Statistical Analysis of Different Boiler Designs

This section contains summaries of descriptive statistical analyses performed on the emissions data from the different boiler designs burning clean or recycled wood fuel. This summary does not include emissions from those facilities burning "treated wood", such as railroad ties. A summary of those data is presented in Section 8.6.4. It is important to emphasize that the data summaries contained in this section are also not sorted by operating parameters that have an effect on emissions, such as particulate controls and combustion efficiency. These evaluations, which are presented in Sections 8.6.2 through 8.6.3, provide more useful information for predicting emissions that are functions of these variables.

Table 8-3 contains a summary of descriptive statistics for spreader stoker boilers, the boiler category for which the largest number of data points were obtained. The compounds listed in Table 8-3 are grouped by emissions of metals, organics and criteria pollutants. Based on the large differences seen between the arithmetic means and the medians, as well as the relatively high coefficients of skewness and kurtosis, it is evident that the data are not normally distributed. For these distributions, therefore, the median or geometric mean are better indicators of the "average" of the data.

There are fewer data points representative of emissions from other boiler types; an abbreviated statistical analysis of these data has been summarized in Tables 8-4 through 8-7 for dutch ovens, fluid beds, cell burner and air suspension boilers, respectively. The minimum, maximum, average and standard deviation of emissions data are presented in these tables.

8.6.2 Particulate and Metals Emissions

Total particulate and metals emissions data are discussed together in this section because of the relationship between particulate and metals control efficiency. Evaluation of the data clearly demonstrates the effectiveness of high efficiency particulate controls on trace metals emissions.

Figure 8-1 is a histogram showing the distribution of total particulate emissions according to type of control device. This figure shows that most of the wood boilers equipped with ESPs achieved controlled particulate emissions of less than 0.01 grains/dscf corrected to 12% CO₂ (all ESPs achieved less than 0.05 gr/dscf). Boilers equipped with wet scrubbers achieved particulate emissions in the range of 0.01 and 0.1 gr/dscf and most boilers equipped only with mechanical cyclones had controlled particulate emissions of greater than 0.05 gr/dscf.

This information on total particulate emissions of the major particulate control devices was used to structure the evaluations performed on the metals emissions data. Metals emissions data were sorted into four ranges of total particulate emissions that correspond to the different control devices. Two sort ranges were created for ESPs; one representative of the best ESPs (<0.005

Table 8-3. Summary statistics for spreader stokers (all values corrected to 12% CO₂).

pollutant	units	# of points	minimum	25th percentile	geometric mean	median	mean	75th percentile	maximum	standard deviation
Particulate Matter	gr/dscf	109	0.0004	0.0030	0.0169	0.0181	0.0690	0.1196	0.6700	0.1054
Nitrogen Oxides	ppm	55	28	71	84	85	90	106	208	34
Carbon Monoxide	ppm	152	3	193	359	333	615	865	5000	671
Sulfur Dioxide	ppm	26	ND	0.50	0.31	0.60	21.40	1.00	190.69	52.18
Hydrocarbons (1)	ppm	95	0.42	7.00	18.07	23.00	39.01	44.00	525.20	71.18
Arsenic	ug/dscm	18	0.100	0.163	0.750	0.204	5.428	6.630	36.200	10.576
Berillium	ug/dscm	15	0.1500	0.1630	0.1817	0.1730	0.1840	0.2080	0.2485	0.0308
Cadmium	ug/dscm	17	0.1500	0.2000	0.3953	0.2500	0.6283	0.7880	2.4200	0.6933
Chromium	ug/dscm	30	0.247	0.683	2.297	1.890	5.534	6.500	21.000	6.983
Hexavalent Chromium	ug/dscm	11	2.25	2.47	3.13	2.61	3.27	4.43	4.90	1.01
Copper	ug/dscm	14	1.00	2.56	5.88	3.83	10.78	16.90	31.30	10.70
Iron	ug/dscm	3	79	79	97	103	98	113	113	18
Lead	ug/dscm	18	1.00	1.66	5.20	4.13	11.43	11.40	51.00	14.88
Manganese	ug/dscm	16	8.0	35.8	60.1	52.7	254.2	70.6	3136.0	769.9
Mercury	ug/dscm	15	0.18	0.25	0.40	0.33	0.48	0.95	1.01	0.32
Nickel	ug/dscm	18	1.50	1.66	2.55	2.36	2.82	4.16	4.86	1.28
Selenium	ug/dscm	15	1.500	1.630	1.999	1.905	2.076	2.485	3.490	0.633
Zinc	ug/dscm	15	2.0	20.3	68.9	106.8	161.1	277.0	471.8	158.2
Formaldehyde	ug/dscm	54	36	325	701	624	1660	1730	14615	2896
Acetaldehyde	ug/dscm	14	66	74	139	115	173	224	414	125
Benzaldehyde	ug/dscm	0								
Acrolein	ug/dscm	0								
Benzene	ug/dscm	15	222	347	896	1120	1668	2403	6016	1788
Phenol	ng/dscm	6	16	32	867	7387	12120	21700	38200	14940
Chlorinated Phenols	ng/dscm	10	0.1	0.1	30.9	148.0	438.1	350.8	1807.8	649.2
Non-chlorinated Phenols	ng/dscm	6	16	33	887	7638	12429	22113	37138	15313
Total Phenols	ng/dscm	10	16	74	828	909	7896	15337	37272	12922
Naphthalene	ng/dscm	33	6	19482	26447	108582	166198	303000	666000	188246
Carcinogenic PAH (2)	ng/dscm	36	5	21	269	484	2094	2020	17355	3650
Total PAH	ug/dscm	36	0.04	12.17	29.37	71.23	170.43	267.55	667.10	192.15
Dioxins	ng/dscm	4	0.87	0.90	1.49	1.56	1.70	1.56	2.82	0.97
Furans	ng/dscm	4	2.668	3.352	5.540	4.613	7.189	4.613	16.860	6.530
PCBs	ng/dscm	0								
Chlorobenzenes	ng/dscm	0								

(1) includes benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenzo[a,h]anthracene, indeno[1,2,3]pyrene, and benzo[ghi]perylene.
 (2) Total gaseous non-methane hydrocarbons as methane.

Table 8-4. Summary statistics for dutch ovens (all values corrected to 12% CO₂).

Pollutant	Units	Count	Average	Maximum	Minimum	Std.Dev.
Arsenic	ug/dscm	14	6.646	36.10	ND	9.456
Beryllium	ug/dscm	6	0.3257	0.4920	0.2520	0.084618096
Cadmium	ug/dscm	6	3.665	6.890	1.140	2.139
Chromium	ug/dscm	11	16.05	51.20	0.5550	18.67
Hexavalent Chromium	ug/dscm	6	5.383	12.60	1.690	3.571
Copper	ug/dscm	14	102.5967	164.3	30.60	42.26
Iron	ug/dscm	0				
Lead	ug/dscm	13	51.91	91.50	4.511	28.50
Manganese	ug/dscm	14	2572	9140	55.53	2712
Mercury	ug/dscm	7	54.41	372.2	0.4030	129.7
Nickel	ug/dscm	13	16.18	82.50	2.170	21.28
Selenium	ug/dscm	14	2.882	6.940	0.5760	1.586
Silica	ug/dscm	1	1.322	1.322	1.322	0
Zinc	ug/dscm	14	1670	2988	509.0	787.1
Formaldehyde(HCHO)	ug/dscm	16	394.8	1412	71.00	392.4
Acetaldehyde	ug/dscm	15	67.13	401.0	0.0600	109.8
Benzaldehyde	ug/dscm	9	0.8138	3.002	0.0980	0.8450
Crotonaldehyde	ug/dscm	0				
Hexanaldehyde	ug/dscm	0				
Acrolein	ug/dscm	9	0.2439	0.9002	0.0306	0.2532
Benzene	ug/dscm	14	537.1	1818	16.00	584.4
Phenol	ng/dscm	12	2615	11605	10.90	3045
Chlorinated Phenols	ng/dscm	12	7482	19929	0.4400	6106
Non-chlorinated Phenols	ng/dscm	12	5206	17854	13.41	4589
Total Phenols	ng/dscm	12	12689	34005	13.85	10157
Naphthalene	ng/dscm	15	86693	153000	17895	46606
Carcinogenic PAHs (1)	ng/dscm	15	2098	5005	30.00	1757
Total PAHs	ng/dscm	15	120.8	306.6	35.47	69.96
Dioxins	ng/dscm	0				
Furans	ng/dscm	0				
PCBs	ng/dscm	0				
Chlorobenzenes	ng/dscm	0				
Particulate Matter	gr/dscf	20	0.1780	0.4300	0.0260	0.1276
Nitrogen Oxides	ppm	6	100.9	130.6	70.30	17.57
Carbon Monoxide	ppm	40	418.6	1100	98.00	217.4
Sulfur Dioxide	ppm	0				
Hydrocarbons (2)	ppm	23	19.01	161.4	0.9600	33.37

(1) Includes benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenzo[a,h]anthracene, indeno[1,2,3]pyrene, and benzo[ghi]perylene.

(2) Total gaseous non-methane hydrocarbons as methane.

Table 8-5. Summary statistics for fluidized beds (all values corrected to 12% CO₂).

Pollutant	Units	Count	Average	Maximum	Minimum	Std.Dev.
Arsenic	ug/dscm	15	11.35	32.60	0.1830	13.91
Beryllium	ug/dscm	3	0.1945	0.2120	0.1830	0.0126
Cadmium	ug/dscm	15	1.591	5.000	0.1885	1.808
Chromium	ug/dscm	17	19.31	70.40	0.2980	25.48
Hexavalent Chromium	ug/dscm	3	2.320	2.835	1.490	0.5928
Copper	ug/dscm	3	4.280	6.500	1.030	2.349
Iron	ug/dscm	12	5496	18793	47.10	7003
Lead	ug/dscm	15	98.46	315.7	1.090	120.5
Manganese	ug/dscm	14	567.9	1799	8.100	688.8
Mercury	ug/dscm	3	0.2588	0.2730	0.2380	0.0150
Nickel	ug/dscm	15	28.53	101.0	1.700	35.40
Selenium	ug/dscm	3	3.210	5.680	1.830	1.751
Silica	ug/dscm	0				
Zinc	ug/dscm	3	28.87	42.80	17.40	10.52
Formaldehyde(HCHO)	ug/dscm	4	399.0	1517	12.00	645.7
Acetaldehyde	ug/dscm	3	24.50	51.00	5.500	19.32
Benzaldehyde	ug/dscm	0				
Crotonaldehyde	ug/dscm	0				
Hexanaldehyde	ug/dscm	0				
Acrolein	ug/dscm	0				
Benzene	ug/dscm	12	13.60	64.00	3.000	15.34
Phenol	ng/dscm	0				
Chlorinated Phenols	ng/dscm	8	1717	1989	1419	215.0
Non-chlorinated Phenols	ng/dscm	0				
Total Phenols	ng/dscm	8	1717	1989	1419	215.0
Naphthalene	ng/dscm	14	79537	485000	3758	156868
Carcinogenic PAHs (1)	ng/dscm	14	1659	4619	26.50	1175
Total PAHs	ng/dscm	14	92.28	485.7	9.475	153.1
Dioxins	ng/dscm	8	27.87	202.5	0.4510	66.05
Furans	ng/dscm	8	12.59	34.29	2.809	11.40
PCBs	ng/dscm	8	57.43	133.0	0.1190	48.97
Chlorobenzenes	ng/dscm	8	1518	3760	2.551	1367
Particulate Matter	gr/dscf	31	0.0762	0.8893	0.0011	0.1817
Nitrogen Oxides	ppm	44	92.59	134.0	29.37	29.65
Carbon Monoxide	ppm	58	116.1	380.0	1.270	109.0
Sulfur Dioxide	ppm	41	0.6364	4.840	ND	0.8076
Hydrocarbons (2)	ppm	36	0.9564	5.000	ND	1.249

- (1) Includes benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenzo[a,h]anthracene, indeno[1,2,3]pyrene, and benzo[ghi]perylene.
- (2) Total gaseous non-methane hydrocarbons as methane.

Table 8-6. Summary statistics for cell burners (all values corrected to 12% CO₂).

Pollutant	Units	Count	Average	Maximum	Minimum	Std.Dev.
Arsenic	ug/dscm	12	3.859	18.10	ND	5.816
Beryllium	ug/dscm	6	1.779	4.150	0.1350	1.680
Cadmium	ug/dscm	12	2.070	9.200	0.4750	2.306
Chromium	ug/dscm	18	25.19	59.60	2.900	20.42
Hexavalent Chromium	ug/dscm	6	98.05	227.0	2.235	96.76
Copper	ug/dscm	6	83.57	185.0	35.10	54.17
Iron	ug/dscm	6	405.0	730.0	180.0	205.7
Lead	ug/dscm	12	108.2	444.0	1.780	139.3
Manganese	ug/dscm	12	1029	2060	1.450	869.7
Mercury	ug/dscm	6	0.8683	1.800	0.2050	0.6837
Nickel	ug/dscm	12	9.026	23.10	1.415	6.692
Selenium	ug/dscm	6	11.54	24.45	1.710	9.850
Silica	ug/dscm	0				
Zinc	ug/dscm	6	305.3	410.6	162.0	92.67
Formaldehyde(HCHO)	ug/dscm	11	1020	1749	540.0	409.4
Acetaldehyde	ug/dscm	6	478.2	954.0	160.0	275.6
Benzaldehyde	ug/dscm	0				
Crotonaldehyde	ug/dscm	0				
Hexanaldehyde	ug/dscm	0				
Acrolein	ug/dscm	0				
Benzene	ug/dscm	13	27.57	44.00	12.50	8.505
Phenol	ng/dscm	3	323.3	670.0	10.00	270.5
Chlorinated Phenols	ng/dscm	7	122.5	240.3	3.480	75.68
Non-chlorinated Phenols	ng/dscm	3	656.7	1045	330.0	295.1
Total Phenols	ng/dscm	7	403.9	1135	3.480	358.7
Naphthalene	ng/dscm	9	208791	853000	750.0	307720
Carcinogenic PAHs (1)	ng/dscm	9	86.22	269.0	19.05	73.80
Total PAHs	ng/dscm	9	211.7	860.9	1.311	310.1
Dioxins	ng/dscm	8	2.902	8.486	0.1520	3.301
Furans	ng/dscm	8	5.017	14.15	0.4840	4.662
PCBs	ng/dscm	3	22781	64920	297.3	29819
Chlorobenzenes	ng/dscm	3	509.1	793.7	337.3	202.7
Particulate Matter	gr/dscf	18	0.4498	2.050	0.0040	0.6389
Nitrogen Oxides	ppm	17	94.88	126.0	73.00	16.24
Carbon Monoxide	ppm	56	931.5	3550	13.00	1201
Sulfur Dioxide	ppm	22	5.295	25.00	0.5000	8.963
Hydrocarbons (2)	ppm	39	9.577	43.00	0.5000	10.901

(1) Includes benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenzo[a,h]anthracene, indeno[1,2,3]pyrene, and benzo[ghi]perylene.

(2) Total gaseous non-methane hydrocarbons as methane.

Table 8-7. Summary statistics for air suspension (all values corrected to 12% CO₂).

Pollutant	Units	Count	Average	Maximum	Minimum	Std.Dev.
Arsenic	ug/dscm	3	0.8620	0.9980	0.7550	0.1013
Beryllium	ug/dscm	3	0.4310	0.4990	0.3775	0.0507
Cadmium	ug/dscm	3	1.993	2.520	1.460	0.4328
Chromium	ug/dscm	5	10.17	15.80	5.090	3.886
Hexavalent Chromium	ug/dscm	2	6.825	7.400	6.250	0.5750
Copper	ug/dscm	3	31.33	32.40	29.60	1.236
Iron	ug/dscm	0				
Lead	ug/dscm	3	15.10	18.60	11.50	2.899
Manganese	ug/dscm	3	1547	1674	1403	111.2
Mercury	ug/dscm	3	0.3545	0.3775	0.3120	0.0301
Nickel	ug/dscm	3	8.983	9.480	8.310	0.4937
Selenium	ug/dscm	3	4.215	4.740	3.750	0.4064
Silica	ug/dscm	0				
Zinc	ug/dscm	3	281.0	286.8	269.3	8.250
Formaldehyde(HCHO)	ug/dscm	3	175.3	260.0	71.00	78.40
Acetaldehyde	ug/dscm	3	8.333	10.00	5.000	2.357
Benzaldehyde	ug/dscm	0				
Crotonaldehyde	ug/dscm	0				
Hexanaldehyde	ug/dscm	0				
Acrolein	ug/dscm	0				
Benzene	ug/dscm	3	3073	7000	474.0	2825
Phenol	ng/dscm	0				
Chlorinated Phenols	ng/dscm	0				
Non-chlorinated Phenols	ng/dscm	0				
Total Phenols	ng/dscm	0				
Naphthalene	ng/dscm	3	293333	365000	205000	66374
Carcinogenic PAHs (1)	ng/dscm	3	125.8	232.5	52.50	77.17
Total PAHs	ng/dscm	3	317.9	394.1	228.9	68.03
Dioxins	ng/dscm	0				
Furans	ng/dscm	0				
PCBs	ng/dscm	0				
Chlorobenzenes	ng/dscm	0				
Particulate Matter	gr/dscf	5	0.1030	0.1100	0.0910	0.0068
Nitrogen Oxides	ppm	0				
Carbon Monoxide	ppm	15	1837	4790	477.0	1073
Sulfur Dioxide	ppm	0				
Hydrocarbons (2)	ppm	15	34.87	97.00	16.00	20.38

(1) Includes benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenzo[a,h]anthracene, indeno[1,2,3]pyrene, and benzo[ghi]perylene.

(2) Total gaseous non-methane hydrocarbons as methane.

Table 8-8. Trace metals emission rates versus total particulate control level* ($\mu\text{g}/\text{dscm}$, corrected to 12% CO_2).

Pollutant	Particulate Matter 0-0.005 gr/dscf (0-11,440 $\mu\text{g}/\text{dscm}$)					Particulate Matter 0.005-0.01 gr/dscf (11,400-22,880 $\mu\text{g}/\text{dscm}$)				
	Count	Average	Maximum	Minimum	Std. Dev.	Count	Average	Maximum	Minimum	Std. Dev.
Arsenic	13	0.19	0.64	LD	0.14	13	0.75	2.80	LD	0.74
Beryllium	11	0.18	0.22	0.15	0.02	1	0.21	0.21	0.21	--
Cadmium	12	0.46	1.80	0.15	0.47	13	0.37	0.61	0.20	0.13
Chromium	21	1.40	5.50	0.25	1.34	13	9.92	49.00	0.84	15.43
Hexavalent Chromium	9	2.73	4.03	1.49	0.67	0				
Copper	10	3.19	6.50	1.00	1.66	1	1.03	1.03	1.03	--
Iron	2	161.50	220.00	103.00	58.50	12	213.30	730.00	47.10	229.65
Lead	13	3.38	18.00	1.00	4.39	13	23.24	110.00	1.26	31.03
Manganese	10	43.79	187.80	1.80	51.60	13	104.98	400.00	1.45	140.56
Mercury	11	0.29	0.50	0.18	0.08	1	0.27	0.27	0.27	--
Nickel	13	3.13	5.50	1.50	1.46	13	4.02	9.10	1.65	2.59
Selenium	11	2.10	5.68	1.50	1.15	1	2.12	2.12	2.12	--
Silica	0					0				
Zinc	11	63.57	369.00	2.00	100.83	1	26.40	26.40	26.40	--

Pollutant	Particulate Matter 0.01-0.05 gr/dscf (22,880-114,400 $\mu\text{g}/\text{dscm}$)					Particulate Matter 0.05+ gr/dscf (114,400+ $\mu\text{g}/\text{dscm}$)				
	Count	Average	Maximum	Minimum	Std. Dev.	Count	Average	Maximum	Minimum	Std. Dev.
Arsenic	10	11.33	36.20	LD	11.26	23	8.75	36.10	LD	11.39
Beryllium	9	0.22	0.27	0.17	0.04	12	1.10	4.15	0.14	1.37
Cadmium	10	1.32	2.42	0.23	0.71	15	3.55	9.20	1.34	2.24
Chromium	18	8.42	21.00	0.56	7.50	26	27.27	70.40	3.14	20.70
Hexavalent Chromium	8	4.25	6.10	2.25	1.26	11	56.24	227.00	1.69	84.93
Copper	9	25.01	32.70	15.60	6.62	20	96.87	185.00	29.60	47.00
Iron	1	240.00	240.00	240.00	--	3	10819.90	18792.50	3181.90	6377.39
Lead	10	39.85	88.80	11.40	22.33	22	102.00	444.00	1.78	123.92
Manganese	8	141.01	489.00	3.15	145.43	23	2133.17	9140.00	55.53	1961.75
Mercury	9	0.74	1.01	0.21	0.29	13	29.62	372.20	0.21	98.90
Nickel	10	11.76	62.50	1.99	23.68	22	18.91	101.00	1.42	22.85
Selenium	9	2.64	3.49	1.72	0.53	20	5.70	24.45	0.58	6.76
Silica	0					1	1.32	1.32	1.32	--
Zinc	9	399.50	665.00	188.50	171.63	20	1211.75	2988.12	162.00	950.76

Notes:
a Outliers removed from database for statistical analyses for reasons noted in text.

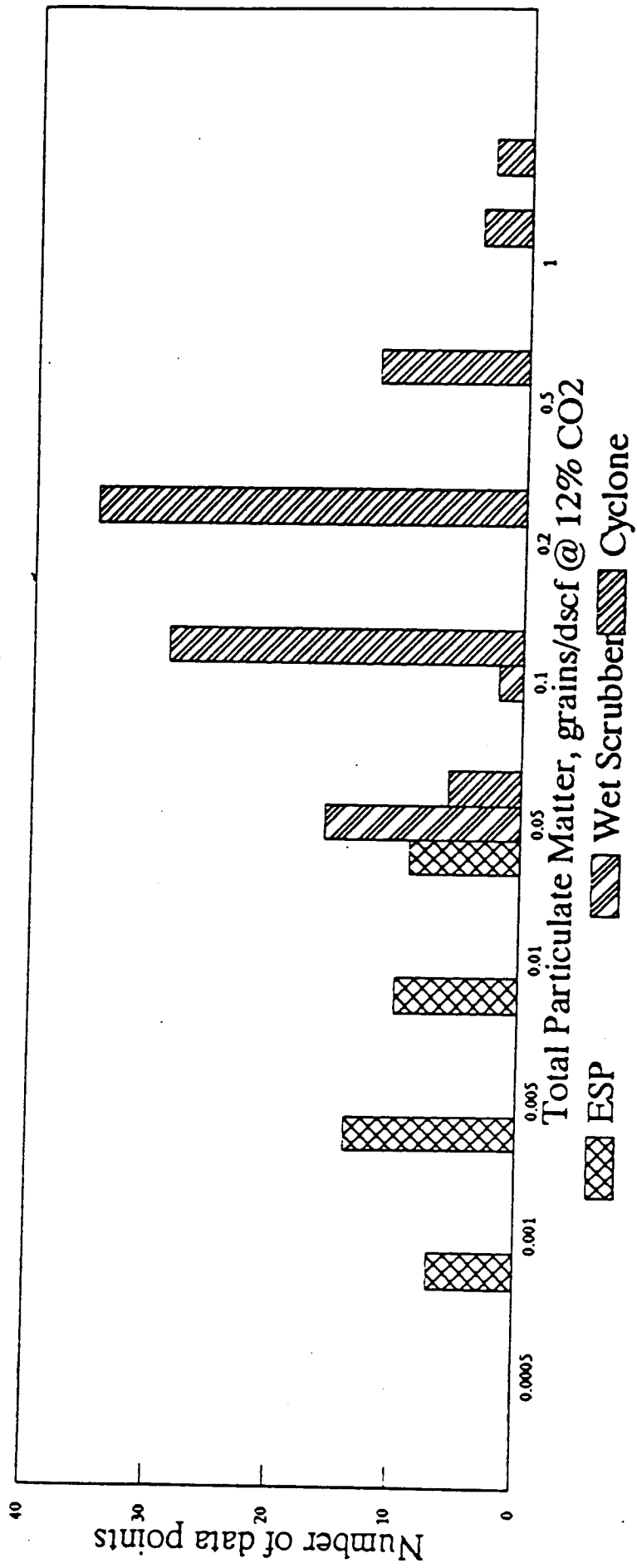


Figure 8-1. Distribution of particulate emissions by control device.

gr/dscf) and the other for those achieving between 0.005 and 0.01 gr/dscf. The third sort range was structured to represent wet scrubbers (0.01 to 0.05 gr/dscf) and the fourth range represents mechanical cyclones (> 0.05 gr/dscf). Table 8-8 presents the average, maximum, minimum and standard deviation for each of the sort ranges. As expected from the plots of metals versus particulate emissions, the average metal concentrations increase significantly as the particulate emission range is increased.

Only one source of metals emissions was found in this study to contain actual test data measured both at the inlet and the outlet of the particulate control device (in this case, an ESP). These data, obtained from one of CARB's test reports (4), was used to directly calculate metals control efficiency across the ESP. The efficiencies for seven metals (As, Cr, Cd, Fe, Pb, Mn and Ni) are summarized in Table 8-9. In general, all metals were controlled by more than 97 percent, with the exception of Ni and Cd. However, it is likely that actual control efficiencies for Ni, Cd, Cr and Pb were higher, since most of the outlet concentrations for these metals were determined to be below minimum detection levels. Control efficiencies in these cases were calculated by using half of the detection level for the outlet concentration. Unfortunately, the CARB test report for these data did not contain uncontrolled total particulate emissions. Therefore, total particulate control efficiency could not directly be compared to the metals control efficiency.

However, controlled particulate emissions were less than 0.01 gr/dscf for each of three tests, indicating very high overall particulate control. The data summarized in Table 8-8 can also be used to provide another estimate of metals control efficiency. These data infer that for most metals the control efficiency is at least as good as total particulate control efficiency. This judgment is made by comparing the averages of each metal concentration in the fourth sort range (> 0.05 gr/dscf particulate) to those in the first sort range (<0.005 gr/dscf). The reduction in total particulate emissions between these two ranges is at least 90 percent. As shown in Table 8-10, the percent reduction in the average metals emissions is also generally more than 95 percent (Be, Cd, Ni and Se have less than 90 percent reduction). Although mercury shows an unexpected 99 percent reduction, the fact that there are significantly more mercury data points in the fourth range than in the first range (15 vs. 4) probably skews the results.

As another method of studying the relationship between total particulate and metals emissions control, individual metal emissions data (As, Cr, Cu, Pb, Zn and Hg) were plotted against the corresponding total particulate matter emissions data. In general, the plots of metals versus total particulate matter emissions show a strong positive relationship; i.e. an increasing trend of metals emissions with increasing particulate emissions was observed. Examples of these plots are presented in Figures 8-2 through 8-9 for As, Cr, Cu, Pb, Zn, and Hg. In the plots for lead (Figures 8-5 and 8-6) and zinc (Figures 8-7 and 8-8), two plots are presented due to the wide range of data and the concentration of data points near the origin (0,0 coordinates). In these cases, an even stronger correlation between increasing particulate emissions and increasing metals emissions is seen by magnifying that portion of the graph.

Since mercury has a relatively high vapor pressure, its stack emissions are controlled less efficiently than other metals by dry particulate control devices. Therefore, the relationship between stack temperature and mercury emission was also evaluated. The wide scatter of the data shown in Figure 8-10 indicates that a temperature relationship could not be established from this data, probably due to a wide variation of mercury content in the fuel streams.

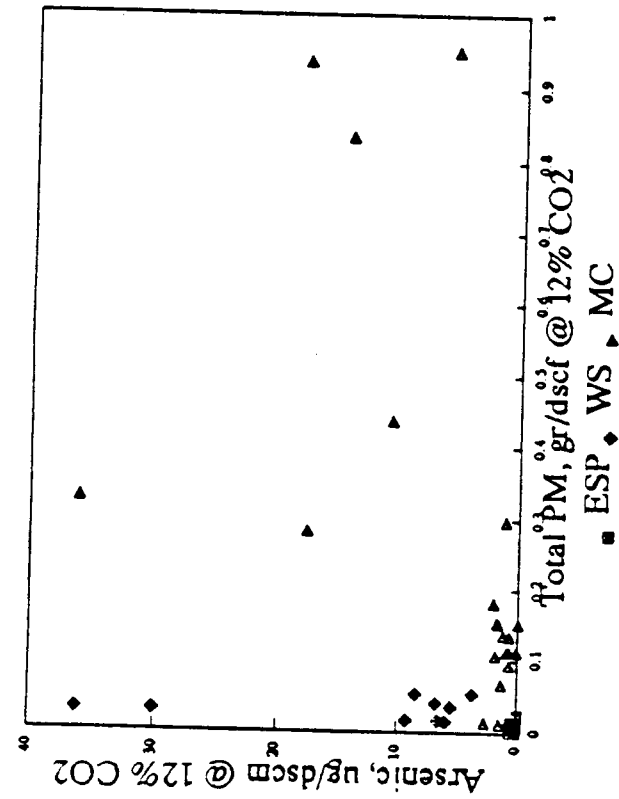


Figure 8-2. Arsenic versus total PM.

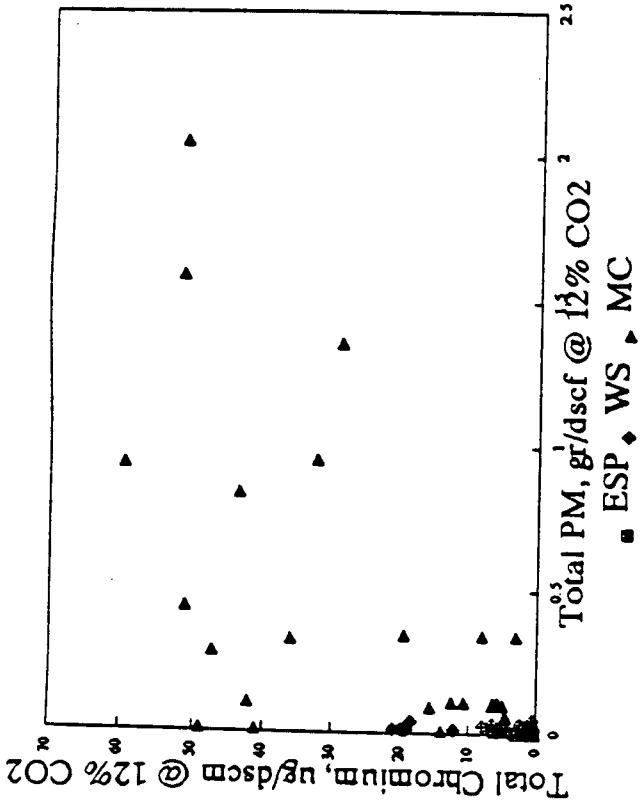


Figure 8-3. Total chromium versus total PM.

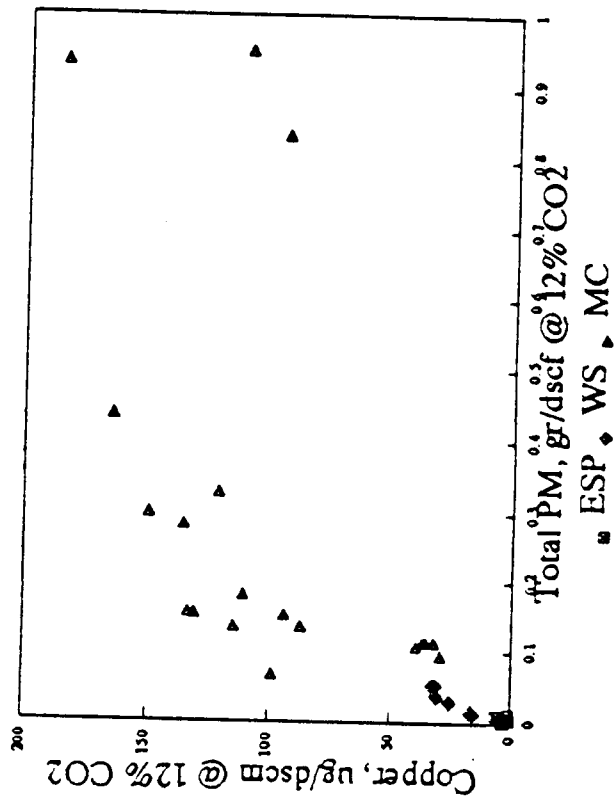


Figure 8-4. Copper versus total PM.

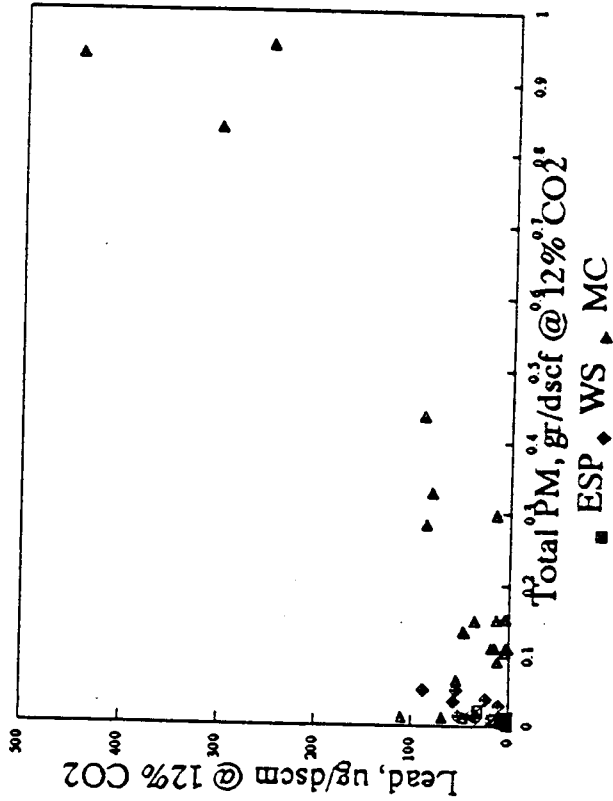


Figure 8-5. Lead versus total PM (High Range).

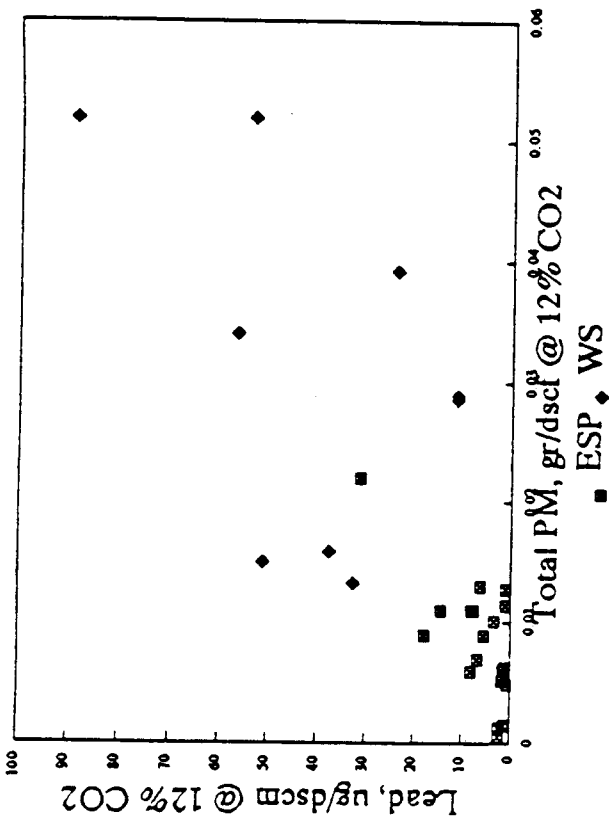


Figure 8-6. Lead versus total PM (Low Range).

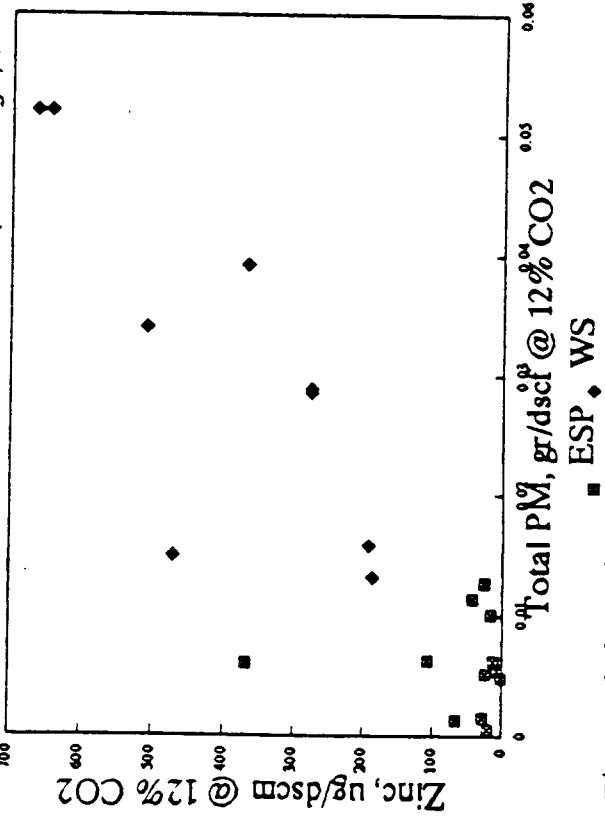


Figure 8-8. Zinc versus total PM (Low Range).

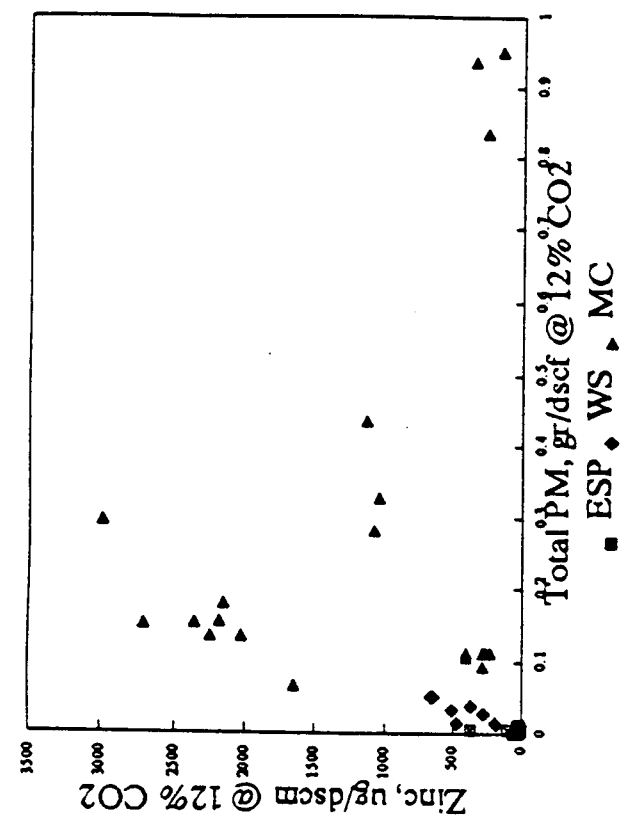


Figure 8-7. Zinc versus total PM (High Range).

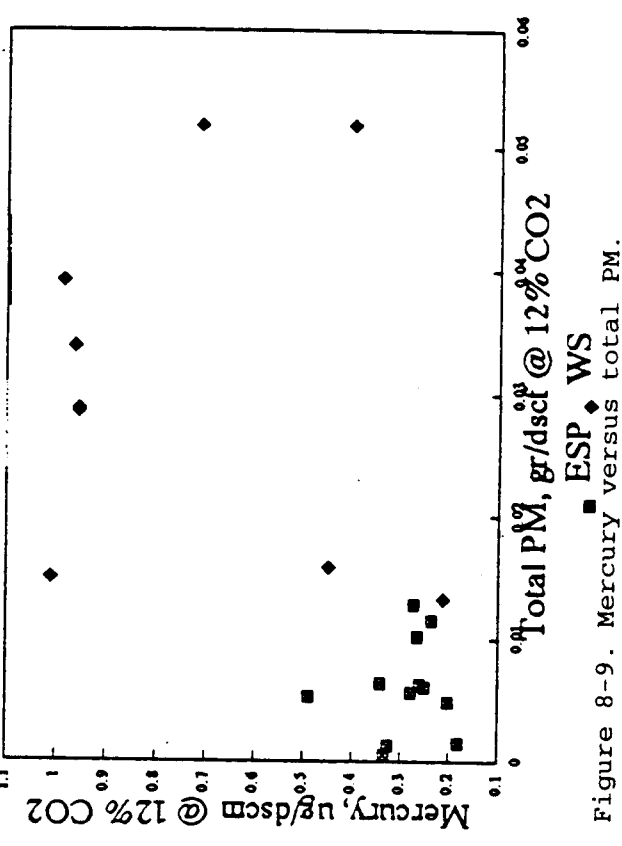


Figure 8-9. Mercury versus total PM.

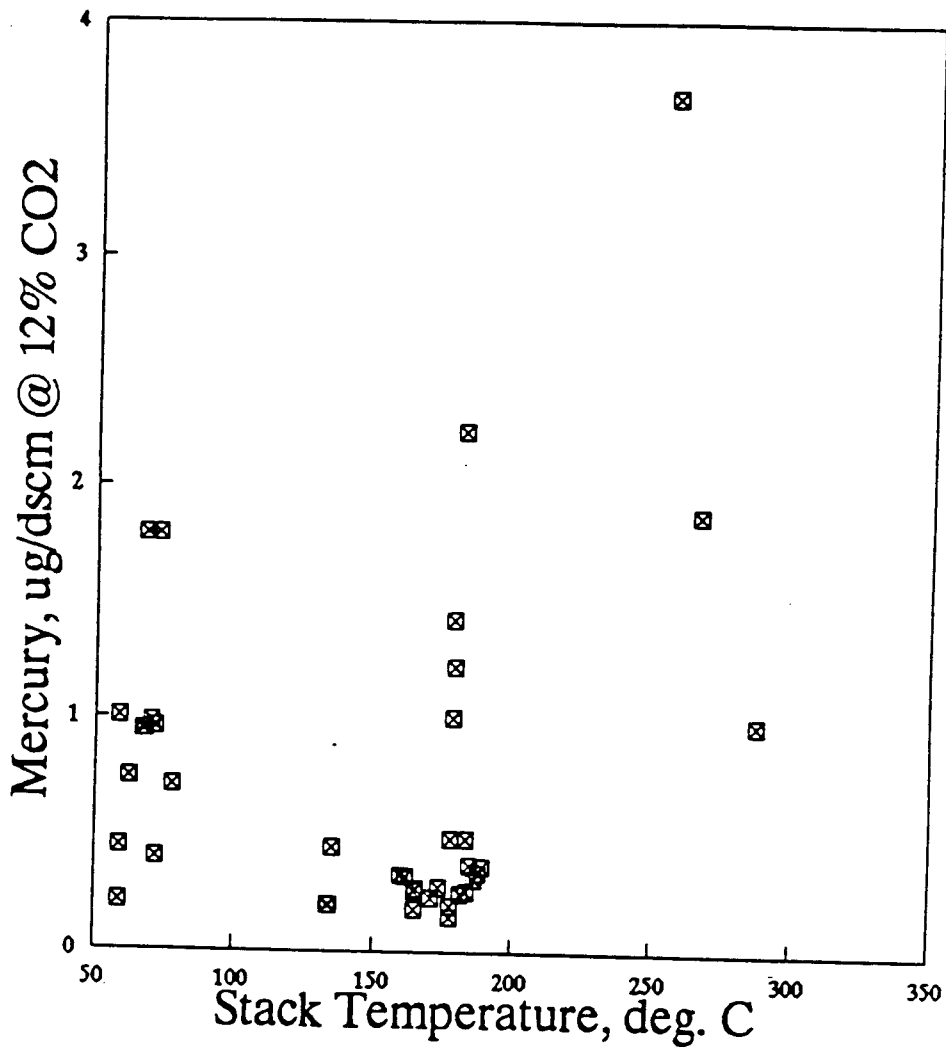


Figure 8-10. Mercury concentration in stack gases versus temperature.

Table 8-9. Metals control efficiency with ESP.

Metal	% Control Efficiency	(Based on average of 3 inlet + outlet numbers)
As	97	
Cr	>97	(All 3 w/ ESP less than MDL) (1)
Cd	>91	(All 3 w/ ESP less than MDL)
Fe	99	
Pb	>97	(All 3 w/ ESP less than MDL)
Mn	99	
Ni	92	(2 of 3 w/ ESP less than MDL)

(1) MDL = Minimum Detection Limit, taken as 0.5 of average MDL for w/ ESP

Table 8-10. Metals control efficiency estimated from database.

Metal	% Control
Arsenic	97
Beryllium	84
Cadmium	87
Chromium	94
Hexavalent Chromium	95
Copper	97
Lead	96
Manganese	98
Mercury	99
Nickel	73
Selenium	63
Zinc	95

8.6.2.1 Metals Emissions Estimated From Wood and Ash Composition

Although the metals emissions data collected for this study demonstrate the relationship between particulate and metals control, the actual emission rates as summarized in Table 8-8 may only be representative of "clean" wood. The majority of facilities represented by the emissions data reportedly combust "clean" or recycled wood. (However, based on site visits and wood analyses data from this and prior projects, some of these facilities may also be combusting some treated or C/D-derived wood). As discussed in Chapter 7, although trace amounts of metals are present in "clean" wood, higher concentrations are found in "treated" wood. Since "treated" or coated wood can make up a portion of wood separated from construction/demolition debris, metal concentrations in wood from such sources are also higher than from "clean" wood sources.

In an attempt to estimate metals emissions that may be more representative of C/D wood combustion, the wood composition data presented in Chapter 7 were used with conservative assumptions about metals partitioning. First, the metals were conservatively assumed to partition 100 percent to the fly ash (i.e. no partitioning of metals to bottom ash) when the wood is combusted. For example, the metals concentrations in the individual wood samples were divided by the respective total ash content of the sample to calculate the concentration of the metal in the ash. The distribution of metals in the ash calculated by this method was then multiplied by the total PM emission rate representative of BACT (0.01 grains/dscf) in order to estimate metals emission rates. The only exception to this method was Hg, for which emissions were estimated by assuming that two-thirds of the Hg in the ash would be volatilized and uncontrolled by the ESP or baghouse. Table 8-11 summarizes the metals emissions developed with this methodology.

Comparison of metals emissions estimated from the C/D wood composition with actual metals test data generally shows higher emissions estimated from the

C/D wood analyses. For this comparison, metals emissions estimated from the 95th percentile of the wood composition data were compared with the maximum of the stack test data for "good" ESPs (i.e. total particulate emissions less than 0.01 gr/dscf). Arsenic, chromium, copper, lead, mercury and zinc emissions from the wood analyses were approximately 3 to 22 times higher than actual stack emissions. This comparison indicates that the C/D wood samples obtained for this study probably contained higher concentrations of metals than wood fuel typically combusted at existing facilities. Combustion of wood fuel obtained from these sources, therefore, would be expected to result in higher emissions of some metals. It should be noted, however, that some of the assumptions that were used in estimating emissions from the wood analyses may be overly conservative. Nevertheless, these conservative assumptions would probably not account for the order of magnitude discrepancy seen for copper and arsenic. Elevated levels of these metals in particular are probably indicative of the presence of CCA-treated wood.

8.6.3 Organic Products of Incomplete Combustion

In theory, emissions of organic compounds from combustion of any fuel are produced only as a result of incomplete combustion. If all of the carbon and hydrogen in a fuel are completely oxidized to carbon dioxide (CO₂) and water vapor there would be no carbon monoxide (CO) or unburned hydrocarbons (HC) formed. Therefore, both unburned HC and CO are indicators of incomplete

Table 8-11. Estimated metals emission based on wood analysis data from six processors.

	Wood		Ash		Emissions	
	Median ppm ^a	95%tile ^b ppm	Median ppm ^c	95%tile ppm	Median µg/dscm ^d	95%tile µg/dscm
Arsenic	7.3	142.4	158.4	2933.0	3.31	61.36
Barium	87.0	550.0	1067.5	10658.9	22.33	222.99
Cadmium	0.7	1.6	9.7	43.9	0.20	0.92
Chromium	17.6	106.0	340.0	5760.9	7.11	120.52
Copper	22.0	84.67	329.8	2536.6	6.90	53.07
Lead	127.0	575.5	2281.6	21413.3	47.73	447.97
Mercury	0.13	0.13	1.2	6.1	0.08	0.38
Nickel	5.0	22.0	96.9	390.2	2.03	8.16
Silver	0.1	2.5	1.9	69.8	0.04	1.46
Titanium	391.5	1066.0	6413.6	11148.8	134.17	233.24
Zinc	134.0	340.0	1864.8	8843.5	39.01	185.01

Notes: (a) Parts per million dry wood

(b) 95 percentile

(c) Parts per million in ash

(d) Micrograms per dry standard cubic meter, corrected to 12% CO₂

Example calculation: arsenic (median) in ash > emissions

$$158.4 * 10^{-6} \text{ ppm} * (0.02 \text{ lb ash/MMBtu}) * (35.31 \text{ ft}^3/\text{m}^3) * (453.6 * 10^6 \text{ µg/lb}) * (1/9280 * 1.65) (\text{MMBtu/dscm @ 12 \% CO}_2) = 3.31 \text{ µg/dscm}$$

Calculation based on assumed controlled PM rate of 0.01 gr/dscf (0.02 lb/MMBtu) except for mercury. Two-thirds of mercury in wood is assumed to volatilize and be emitted from stack. Conversions from concentrations in wood to concentrations in ash based on ash contents of individual samples.

combustion. The lower the emission rates of CO and HC measured in actual flue gas from a particular boiler, the closer the combustion process approaches perfect, complete combustion.

The organic emissions data collected for this project were evaluated using these basic principles of combustion. Figure 8-11 is a graph of total HC emissions versus CO for all boiler types. Figure 8-12 is the same graph, but only including data for spreader stoker boilers. Both figures illustrate the trend of increasing total HC emissions with increasing CO. Table 8-12 is a summary of specific organic compounds for all boiler types sorted according to different ranges of CO emissions that represent different levels of combustion efficiency. The first two ranges, 0 to 200 ppmv and 200 to 500 ppmv CO are representative of "good combustion" conditions.

Most recently installed wood fired boilers with good combustion designs and/or control systems achieve CO levels within these ranges. Well designed and operated spreader stoker and fluid bed boilers usually operate within these ranges. Older, less efficient or poorly designed wood boilers achieve CO emissions in the third range, 500 to 1500 ppmv. Boilers operating under very poor combustion conditions fall into the fourth range, greater than 1500 ppmv CO. The data summarized in Table 8-12 demonstrate the trend of increasing organic compounds with increasing CO emissions. For nearly all the compounds listed, the averages of the compounds increase as the CO range is increased. The same trends are also demonstrated in Tables 8-13 and 8-14 for spreader stoker and fluid bed boilers, respectively.

The specific compounds that are summarized in Tables 8-12 through 8-14 were selected either because they have been identified as components of wood smoke or because of their relative potential for adverse health impacts. Aldehydes, such as formaldehyde, acetaldehyde and acrolein have been identified by health professionals as pollutants of concern for persons suffering from asthma, chronic bronchitis, and emphysema. Formaldehyde and acetaldehyde have also been classified by EPA as probable human carcinogens. Benzene, polynuclear aromatic hydrocarbons (PAH) and phenol have also been identified as present in wood smoke as well as most other combustion sources. Benzene and several of the fifty or more compounds that make up the category of PAH are also classified as potential carcinogens.

The other pollutants of interest that are listed in Tables 8-12 through 8-14 are chlorinated hydrocarbons, such as dioxins, furans, polychlorinated biphenyls (PCB), chlorinated phenols and benzenes. All these compounds are scrutinized by environmental regulatory agencies because of their suspected carcinogenic potential. These compounds would theoretically only be formed if chlorine was present in the fuel or combustion air. Although chlorine is negligible in clean wood fuel, it has been measured in appreciable concentrations in C/D wood fuel. Because the data summarized in these tables represent the combustion of "clean" wood fuel, chlorinated organic compounds were, in general, measured at extremely low concentrations. Furthermore, by examination of the raw data, most of these compounds were reported at less than minimum detection limits.

Limited data are available for comparison of emissions from C/D and other "treated" wood fuel to "clean" wood combustion. The results from several test programs (discussed in more detail in Section 8.6.4) generally demonstrate that organic emissions are not increased due to burning of C/D and treated wood. Metals emissions are also comparable to clean wood or marginally higher.

In an attempt to further evaluate the relationship between combustion efficiency and organic products of incomplete combustion, graphs of

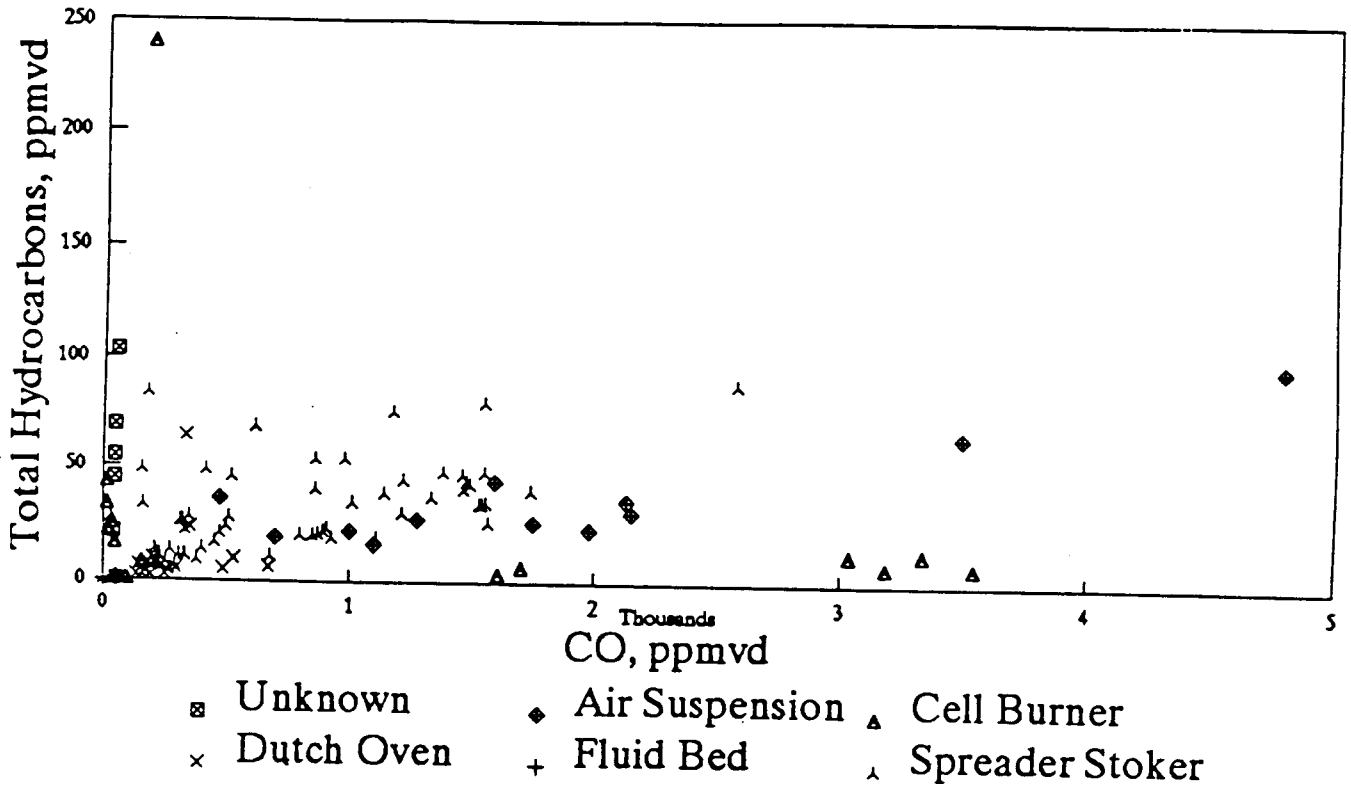


Figure 8-11. Total hydrocarbons versus CO.

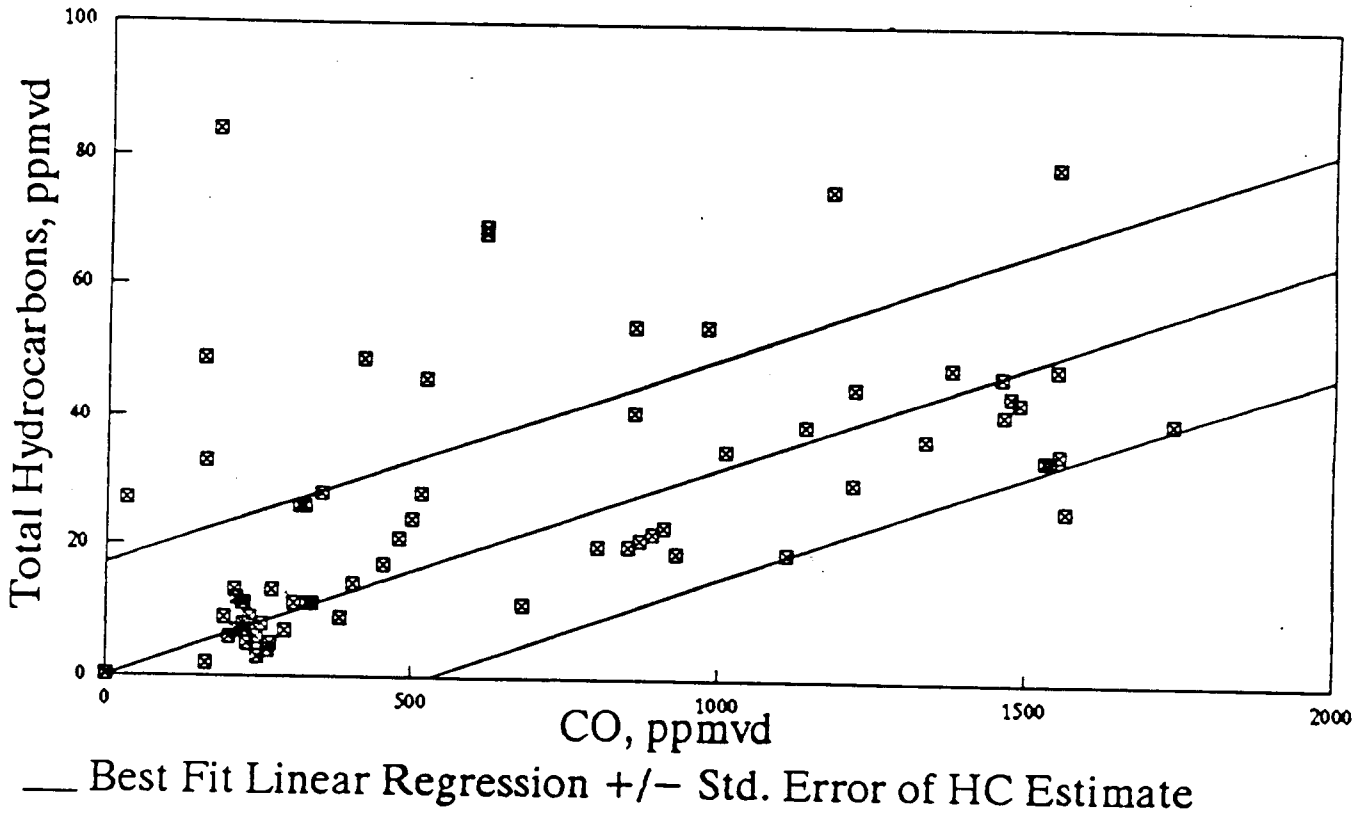


Figure 8-12. Total hydrocarbons versus CO for spreader stokers.

Table 8-12. Organic emission rates versus CO stack concentration, all boilers.

(all values corrected to 12% CO2)

Pollutant	Units	Carbon Monoxide 0-200 ppm				Carbon Monoxide 200-500 ppm					
		Count	Average	Maximum	Minimum	Count	Average	Maximum	Minimum	Std.Dev.	Std.Dev.
Formaldehyde	ug/dscm	46	660.8	5496.0	12.0	14	1081.4	2623.0	71.0	974.7	974.7
Acetaldehyde	ug/dscm	20	212.80	954.00	3.97	7	89.64	340.00	10.00	104.59	104.59
Benzaldehyde	ug/dscm	3	1.191	3.002	0.280	0					
Crotonaldehyde	ug/dscm	0				0					
Hexanaldehyde	ug/dscm	0				0					
Acrolein	ug/dscm	3	0.3579	0.9002	0.0851	0					
Benzene	ug/dscm	30	72.6	347.0	3.0	4	724.7	1343.0	133.0	448.1	448.1
Phenol	ng/dscm	4	43	74	16	5	14528	36200	11	13727	13727
Chlorinated Phenols	ng/dscm	17	770.9	1989.0	0.1	5	86.2	160.5	0.4	70.6	70.6
Non-chlorinated Phenols	ng/dscm	4	44	74	16	5	14900	37138	13	14066	14066
Total Phenols	ng/dscm	17	781	1989	3	5	14966	37272	14	14125	14125
Naphthalene	ng/dscm	25	172860	853000	6	9	216389	666000	6500	213403	213403
Carcinogenic PAHs (1)	ng/dscm	28	361.8	1989.0	5.2	9	1648.8	11900.0	21.0	3666.6	3666.6
Total PAHs	ug/dscm	28	157.59	860.87	0.04	9	247.44	667.10	25.81	213.16	213.16
Dioxins	ng/dscm	13	18.405	202.480	0.152	0					
Furans	ng/dscm	13	9.316	34.292	0.484	0					
PCBs	ng/dscm	8	8600	64920	60	0					
Chlorobenzenes	ng/dscm	8	1707.4	3760.0	337.3	0					

Pollutant	Units	Carbon Monoxide 500-1500 ppm				Carbon Monoxide 1500+ ppm					
		Count	Average	Maximum	Minimum	Count	Average	Maximum	Minimum	Std.Dev.	Std.Dev.
Formaldehyde	ug/dscm	20	2125.1	12616.0	85.8	1	14615.0	14615.0	14615.0	0.0	0.0
Acetaldehyde	ug/dscm	8	187.38	414.00	5.00	0					
Benzaldehyde	ug/dscm	0				0					
Crotonaldehyde	ug/dscm	0				0					
Hexanaldehyde	ug/dscm	0				0					
Acrolein	ug/dscm	0				0					
Benzene	ug/dscm	14	2110.0	7000.0	12.5	0					
Phenol	ng/dscm	3	323.33	670.00	10.00	0					
Chlorinated Phenols	ng/dscm	3	86.7	90.0	80.0	0					
Non-chlorinated Phenols	ng/dscm	3	657	1045	330	0					
Total Phenols	ng/dscm	3	743	1135	420	0					
Naphthalene	ng/dscm	9	213367	530000	250	0					
Carcinogenic PAHs (1)	ng/dscm	9	91.5	269.0	0.7	0					
Total PAHs	ug/dscm	9	226.05	547.98	0.33	0					
Dioxins	ng/dscm	4	1.705	2.819	0.871	0					
Furans	ng/dscm	4	7.189	16.860	2.668	0					
PCBs	ng/dscm	0				0					
Chlorobenzenes	ng/dscm	0				0					

(1) Includes benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenzo[a,h]anthracene, indeno[1,2,3]pyrene, and benzo[ghi]perylene.

Table 8-13. Organic emission rates versus CO stack concentrations, spreader stokers.

Pollutant	Units	Carbon Monoxide 0-200 ppm					Carbon Monoxide 200-500 ppm				
		Count	Average	Maximum	Minimum	Std. Dev.	Count	Average	Maximum	Minimum	Std. Dev.
		ug/dscm	ug/dscm	ug/dscm	ug/dscm	ug/dscm	ug/dscm	ug/dscm	ug/dscm	ug/dscm	ug/dscm
Formaldehyde	ug/dscm	31	720.9	5496.0	36.2	1049.9	10	1426.1	2623.0	380.0	944.6
Acetaldehyde	ug/dscm	7	165.48	390.00	74.16	102.19	4	136.50	340.00	66.00	117.50
Benzaldehyde	ug/dscm	0					0				
Crotonaldehyde	ug/dscm	0					0				
Hexanaldehyde	ug/dscm	0					0				
Acrolein	ug/dscm	0					0				
Benzene	ug/dscm	4	275.4	347.0	222.0	45.6	1	524.0	524.0	524.0	0.0
Phenol	ng/dscm	3	40	74	16	24	3	24200	36200	14700	8954
Chlorinated Phenols	ng/dscm	7	564.4	1807.8	0.1	699.0	3	143.3	160.5	134.0	12.2
Non-chlorinated Phenols	ng/dscm	3	41	74	16	24	3	24817	37138	15202	9157
Total Phenols	ng/dscm	7	582	1808	16	685	3	24961	37272	15337	9154
Naphthalene	ng/dscm	7	133790	321000	6	154554	7	245571	666000	6500	233697
Carcinogenic PAHs (1)	ng/dscm	10	32.7	132.0	5.2	36.7	7	2102.7	11900.0	21.0	4044.4
Total PAHs	ug/dscm	10	94.04	322.05	0.04	143.44	7	283.00	667.10	25.81	229.36
Dioxins	ng/dscm	0					0				
Furans	ng/dscm	0					0				
PCBs	ng/dscm	0					0				
Chlorobenzenes	ng/dscm	0					0				

Pollutant	Units	Carbon Monoxide 500-1500 ppm					Carbon Monoxide 1500+ ppm				
		Count	Average	Maximum	Minimum	Std. Dev.	Count	Average	Maximum	Minimum	Std. Dev.
		ug/dscm	ug/dscm	ug/dscm	ug/dscm	ug/dscm	ug/dscm	ug/dscm	ug/dscm	ug/dscm	ug/dscm
Formaldehyde	ug/dscm	11	3157.0	12616.0	209.0	4010.7	1	14615.0	14615.0	14615.0	0.0
Acetaldehyde	ug/dscm	3	241.33	414.00	86.00	134.47	0				
Benzaldehyde	ug/dscm	0					0				
Crotonaldehyde	ug/dscm	0					0				
Hexanaldehyde	ug/dscm	0					0				
Acrolein	ug/dscm	0					0				
Benzene	ug/dscm	7	2664.4	6016.0	411.0	2022.2	0				
Phenol	ng/dscm	0					0				
Chlorinated Phenols	ng/dscm	0					0				
Non-chlorinated Phenols	ng/dscm	0					0				
Total Phenols	ng/dscm	0					0				
Naphthalene	ng/dscm	2	501750	530000	473500	28250	0				
Carcinogenic PAHs (1)	ng/dscm	2	19.5	21.0	18.0	1.5	0				
Total PAHs	ug/dscm	2	519.58	547.98	491.18	28.40	0				
Dioxins	ng/dscm	4	1.705	2.819	0.871	0.838	0				
Furans	ng/dscm	4	7.189	16.860	2.668	5.655	0				
PCBs	ng/dscm	0					0				
Chlorobenzenes	ng/dscm	0					0				

(1) Includes benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenzo[a,h]anthracene, indeno[1,2,3]pyrene, and benzo[ghi]perylene.

Table 8-14. Organic emission rates versus CO stack concentration, fluidized beds.
(all values corrected to 12% CO₂)

Pollutant	Units	Carbon Monoxide 0-200 ppm					Carbon Monoxide 200-500 ppm				
		Count	Average	Maximum	Minimum	Std.Dev.	Count	Average	Maximum	Minimum	Std.Dev.
Formaldehyde	ug/dscm	3	26.3	54.0	12.0	19.6	0				
Acetaldehyde	ug/dscm	3	24.50	51.00	5.50	19.32	0				
Benzaldehyde	ug/dscm	0					0				
Crotonaldehyde	ug/dscm	0					0				
Hexanaldehyde	ug/dscm	0					0				
Acrolein	ug/dscm	0					0				
Benzene	ug/dscm	12	13.6	64.0	3.0	15.3	0				
Phenol	ng/dscm	0					0				
Chlorinated Phenols	ng/dscm	5	1711.2	1989.0	1419.0	227.0	0				
Non-chlorinated Phenols	ng/dscm	0					0				
Total Phenols	ng/dscm	5	1711	1989	1419	227	0				
Naphthalene	ng/dscm	8	129311	485000	5320	192631	0				
Carcinogenic PAHs (1)	ng/dscm	8	1080.9	1989.0	26.5	831.8	0				
Total PAHs	ug/dscm	8	132.32	485.72	9.48	191.52	0				
Dioxins	ng/dscm	5	43.210	202.480	0.451	79.677	0				
Furans	ng/dscm	5	16.195	34.292	2.909	12.591	0				
PCBs	ng/dscm	5	92	133	60	26	0				
Chlorobenzenes	ng/dscm	5	2426.3	3760.0	1275.5	886.6	0				

Pollutant	Units	Carbon Monoxide 500-1500 ppm					Carbon Monoxide 1500+ ppm				
		Count	Average	Maximum	Minimum	Std.Dev.	Count	Average	Maximum	Minimum	Std.Dev.
Formaldehyde	ug/dscm	0					0				
Acetaldehyde	ug/dscm	0					0				
Benzaldehyde	ug/dscm	0					0				
Crotonaldehyde	ug/dscm	0					0				
Hexanaldehyde	ug/dscm	0					0				
Acrolein	ug/dscm	0					0				
Benzene	ug/dscm	0					0				
Phenol	ng/dscm	0					0				
Chlorinated Phenols	ng/dscm	0					0				
Non-chlorinated Phenols	ng/dscm	0					0				
Total Phenols	ng/dscm	0					0				
Naphthalene	ng/dscm	0					0				
Carcinogenic PAHs (1)	ng/dscm	0					0				
Total PAHs	ug/dscm	0					0				
Dioxins	ng/dscm	0					0				
Furans	ng/dscm	0					0				
PCBs	ng/dscm	0					0				
Chlorobenzenes	ng/dscm	0					0				

(1) includes benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenzo[a,h]anthracene, indeno[1,2,3]pyrene, and benzo[ghi]perylene.

formaldehyde, benzene, phenol and PAH versus CO were constructed. A clear relationship was not observed from all these plots due to considerable scatter of the data, in particular, for formaldehyde and phenol. Examples of these plots are presented in Figures 8-13 and 8-14 for formaldehyde and benzene. Since the majority of PAH compounds are either particulates or adsorbed onto particulates, the relationship between particulate and PAH concentrations was also evaluated. A clear relationship was also not observed from these plots. The scatter of the data or its inability to clearly fit expected relationships is likely due to the nature of the database, i.e. the fact that there are so many different sources of data rather than a few controlled experiments.

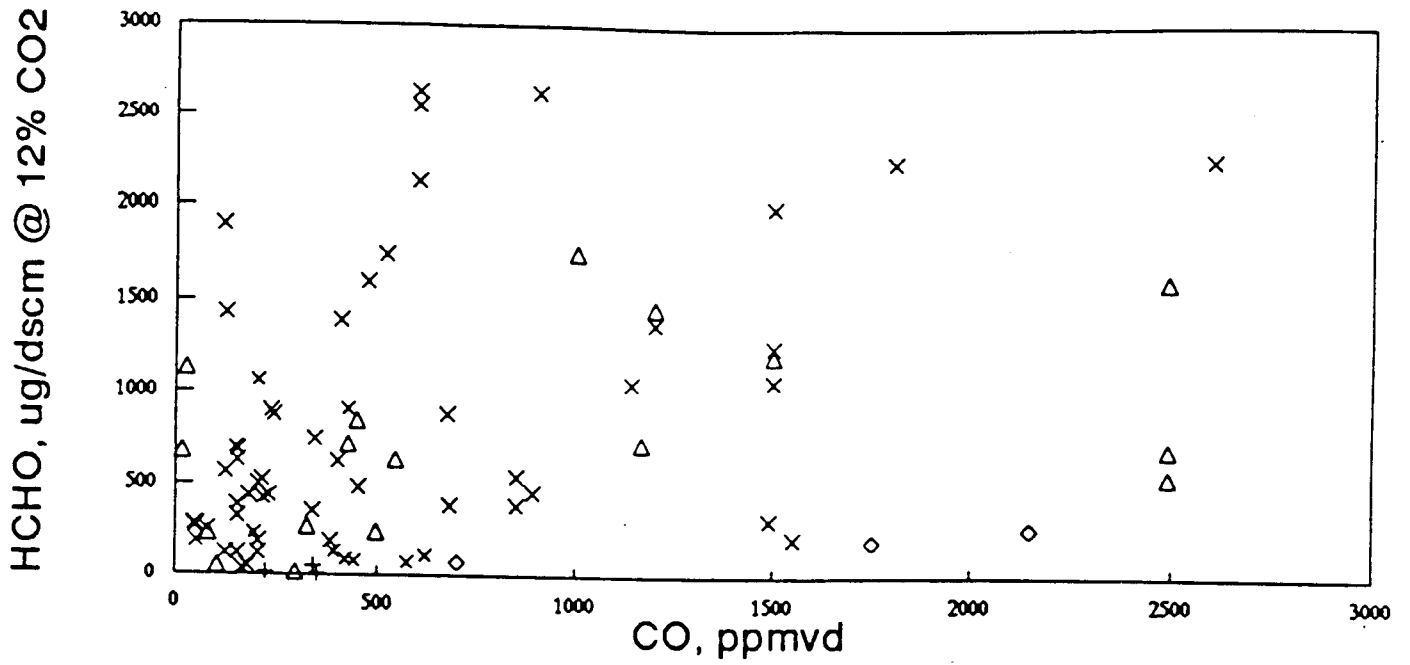
8.6.4 Emissions From C/D, Railroad Ties and Other Treated Wood Fuel

There were relatively few plants that were found from the data search to be combusting C/D, railroad ties or other treated wood as part of the fuel supply. Emissions data were found from a total of three facilities that burn or have burned C/D wood waste, four facilities that burn or have performed test burns with railroad ties and one plant that ran a test program with chlorophenol-contaminated wood. These facilities are identified in Table 8-15. Table 8-16 summarizes the average of the emissions data from each of these facilities. Where available, averages of test data from combustion of each facility's normal or clean fuel are also presented for comparison.

The most meaningful use of these data is for comparison of the clean to the C/D or treated wood test runs within the same boiler rather than comparison with different boilers burning clean wood fuel. The most extensive data for this comparison are available from the CARB test program at the Pacific Oroville Power plant which burns a mixture of 30% urban waste wood (C/D), from the Site #5 facility, which conducted test burns of creosote-treated railroad tie mixtures (50% of fuel makeup with chipped railroad ties by heat input), and from the Northwood Pulp Mill in Canada which ran the test program with chlorophenol-contaminated wood. Less extensive emissions data are available from the Northern States Power facility (Bay Front Generating Station) for comparison of two different mixtures of railroad ties (100% and 50% with clean wood). Data only from the burning of railroad ties are available from the Blandin Paper Co. facility; therefore, no internal comparison was possible.

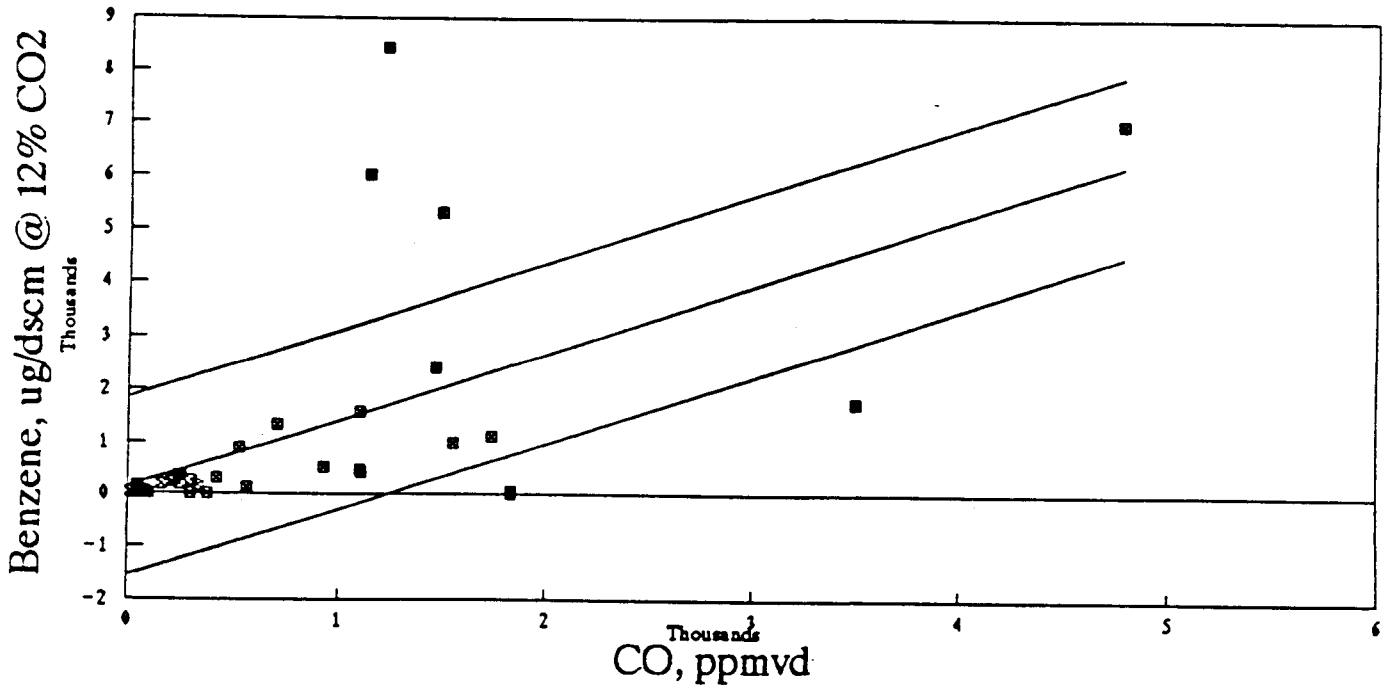
The data are summarized in Table 8-16. In general, comparison of data from the different wood fuels within the same boiler demonstrate that emissions are not significantly affected by burning C/D or treated wood. In fact, in both data sets that allow a direct comparison of different wood fuels, emissions are about the same for the C/D wood (Pacific Oroville) and railroad ties (Site #5) test burns in comparison with the clean wood runs. In the CARB Pacific Oroville test, arsenic was the only metal that was measured at a higher stack concentration in the C/D test burn. The other metals tested: chromium, lead, iron and manganese were lower in the C/D test burn. All organics in the C/D test burn, with the exception of benzene, were measured at lower concentrations than in the permitted fuel test burn. It should be noted that the Pacific Oroville facility tested by CARB represented very poor combustion conditions during the test program. CO emissions averaged close to 1500 ppm during the tests. Organic emissions during both series of test runs were extremely high relative to other facilities operating under better combustion conditions.

The data from Site #5 railroad tie test burn also generally indicated lower or comparable emissions to the clean wood fuel tests. As expected, SO₂ emissions were higher than the normal wood fuel blend due to the higher sulfur content of railroad ties. However, SO₂ emissions were still in compliance with the AQMD permit limit when burning railroad ties. While some of the metals (As, Cd, Cu and Hg) were marginally higher in the railroad tie tests, aldehydes and



- Not Reported
- ◇ Air Suspension
- Δ Cell Burner
- x Dutch Oven
- + Fluid Bed
- x Spreaders Stoker

Figure 8-13. -Formaldehyde versus CO, all data.



— Best Fit Linear Regression Line +/- Std. Error (R squared = 0.32)

Figure 8-14. Benzene versus CO, all data.

Table 8-15. Plants burning C/D, railroad ties, and other treated wood.

ID	Plant Name	Town	State	Boiler Type	Type of Wood	Particulate Controls	CO & NOx Controls
Plants Burning Construction/Demolition Wood							
106	Long Beach	Long Beach	CA	SS	CD LAM	MC WS	SNCR CC
014B	Pacific Oroville Power Inc.		CA	SS	SILV CLRE CD	MC ESP	
105	P&G Port Ivory Complex	Staten Island	NY	SS	SILV CD LAM	MC WS	
Plants Burning Railroad Ties							
089	Bay Front Generating Station Boiler #2	Ashland	WI	SS	RR	MC	SNCR CC SNCR CC
107	Blandin Paper Co. #5 Boiler	Grand Rapids	MN	SS	RR		
056	Ultrapower Fresno	Malaga, Fresno	CA	FB	CLRE BM RR		
066	Site 5 (RR)			SS	SILV RR		
Plants Burning Chlorophenol Contaminated Wood							
110	Northwood Pulpmill	Prince George	CN	SS	CLRE OT	MC	

Boiler Types: SS = Spreader Stoker, FB = Fluidized Bed

Fuel Types: SILV = Silvicultural, CLRE = Clean Recycled, BM = Biomass, CD = Construction/Demolition Waste, RR = Railroad Ties, LAM = Laminated, OT = Other Treated

Particulate Controls: MC = Mechanical Collector, ESP = Electrostatic Precipitator, WS = Wet Scrubber

Emission Controls: SNCR = Selective Non-Catalytic Reduction, CC = Combustion Controls, SI = Sorbant/limestone Injection

Table 8-16. Average of test data for C/D, RR tie, and other treated wood combustors.

(all values corrected to 12% CO2)

Pollutant	Units	Construction/Demolition Wood				Railroad Ties				PCP Treated		
		Pacific Oroville		Long Beach	Port Ivory	Bay Front	Blandin	Ultrapower Fresno	Site 5		Northwood Pulp Mill	
		(clean)	(C/D)						(clean)	(RR)	(clean)	(PCP)
Particulate Matter	gr/decf	0.00500	0.00250	0.02840	0.04877	0.19075	0.00887	0.00465	0.00077	0.00080	0.10724	0.09681
Nitrogen Oxides	ppm	68.57	69.25	149.16	119.62	206.09			79.00	67.00	87.76	75.12
Carbon Monoxide	ppm	1427.1	1467.0	73.7	139.3	112.4	45.8		238.0	468.0	621.9	784.6
Sulfur Dioxide	ppm	ND	ND	0.773	2.123				ND	16.000		
Hydrocarbons (1)	ppm	42.143	31.250	17.303					8.000	9.000	4.247	11.815
Arsenic	ug/decf	0.1667	0.5500						0.8215	ND	0.8333	
Beryllium	ug/decf								ND	ND		
Cadmium	ug/decf	ND	ND						2.311	ND	0.800	
Chromium	ug/decf	5.800	4.100						93.102	ND	ND	
Hexavalent Chromium	ug/decf									ND	ND	
Copper	ug/decf									1.667	3.667	
Iron	ug/decf	98.20	56.65									
Lead	ug/decf	7.267	6.450									
Manganese	ug/decf	49.167	19.500									
Mercury	ug/decf											
Nickel	ug/decf	ND	ND									
Selenium	ug/decf											
Zinc	ug/decf											
Formaldehyde	ug/decf					2644.8	ND			11.667	4.500	
Acetaldehyde	ug/decf					1258.2	ND			292.4	138.0	
Benzaldehyde	ug/decf					39.155	ND			79.2	26.6	
Acrolein	ug/decf					201418	ND					
Benzene	ug/decf	2403	8443			8894	126			257	162	
Phenol	ng/decf					523	ND					
Chlorinated Phenol	ng/decf		662.2				ND					
Naphthalene	ng/decf		171500				ND					
Total Dioxins	ng/decf	1.705	0.565				ND					
Total Furans	ng/decf	7.189	1.314									0.193
PCBs	ng/decf		51.68									0.452
Chlorobenzenes	ng/decf		406.7									
Benz[a]anthracene	ng/decf		142.67				26.30		ND	ND		
Benz[a]pyrene	ng/decf		ND			ND	20.077		ND	ND		
Chrysene	ng/decf		232.5				255.3		ND	ND		
Chloroform	ng/decf	ND	ND						ND	ND		
2,3,7,8-TCDD	ng/decf	ND	ND						ND	ND		
Total TCDD	ng/decf	ND	0.00217									
Toluene	ug/decf	202.80	195.50						ND	23.49		
Hydrogen Chloride	ppm						ND				10.390	7.331

ND: Not Detected (i.e., below detection limit)

PCP: Pentachlorophenol

Blanks indicate no data

(1) Total gaseous non-methane hydrocarbons as methane

benzene were lower than in the clean wood tests. PAH, PCBs and chloroform emissions were below detection limits for both series of tests. Toluene emissions were measured in the railroad tie tests, but were below detection in the clean runs. The Northwood Pulpmill and the Blandin Paper Co. facilities contained the only data found in this study on hydrogen chloride (HCl) emissions, with the exception of one test program conducted at the Vicon Pittsfield incinerator (17). Although the Vicon test summarized in

this study reportedly was conducted with "PVC-free" wood chips (from pallets) and cardboard, the HCl emissions were almost ten times higher than the highest of all the other HCl emissions data. The fact that PVC-spiked MSW was fired in other tests during the same program makes the results of the "PVC-free" test run suspect. HCl emissions from the Blandin Paper Co. boiler firing railroad ties were below the level of detection (<0.1 ppm). At the Northwood Pulpmill chlorophenol-contaminated test program, HCl emissions ranged from 3 to 18 ppm.

8.7 Environmental Impacts

Environmental impacts due to waste wood combustion emissions were evaluated for this study using the following method:

1. Emissions from a hypothetical spreader stoker boiler burning C/D waste wood and controlled with a high efficiency ESP were developed from the emissions, wood and ash data compiled for this project.
2. Ambient impacts were estimated with dispersion modeling for two hypothetical cases: (1) an approximate 15 MW facility with non-GEP stack height located in relatively flat, rural terrain and (2) a 15 MW facility with GEP stack located in a valley with some terrain higher than stack height.
3. Ambient impacts of hazardous air pollutants were compared with short term (acute) and long term (chronic) exposure levels as established by state regulations in the project study area.

The spreader stoker with ESP was chosen over other boiler types for this analysis because of the prevalent use of this combination for moderate to large size wood power plants. In addition, based on the data, even the best operated spreader stokers would likely have slightly lower combustion efficiencies than fluid bed boilers for biomass and wood applications. Therefore, organic emissions from spreader stokers are conservatively high for this analysis.

To develop worst-case organic emissions, the emissions database was partitioned so that data from only the spreader stokers operating under "good" combustion conditions (i.e., less than 500 ppm carbon monoxide) were used. The maximum values were used as the maximum short-term emissions, and the average values as the average annual emissions. For dioxin emissions, all available data regardless of boiler type and the associated CO concentration were used to obtain maximum and average values because none of the dioxin data were obtained from boilers operating under "good" combustion conditions.

Metals emissions were developed by the method discussed in Section 8.6.2 (see Table 8-11) using conservative assumptions about ash partitioning. The wood composition data were used for this analysis so that the metals emissions would be representative of C/D wood combustion. Specifically, the metals when combusted in wood were conservatively assumed to remain in the fly ash (no metals partitioning to bottom ash) and the metals control efficiency of the ESP was assumed to be equivalent to the total particulate control efficiency except for mercury, for which a 30% removal efficiency was assumed. The 95th percentile wood metals concentrations was used as the basis for the maximum stack emission rates, and the median values as the basis for average annual emission rates.

As discussed in Section 8.6.4, the highest HCl data found from this study are not representative (relatively high HCl levels were measured in a reportedly "pvc-free" test run at an MSW incinerator). The only other HCl data sources

were a railroad tie test burn and a chlorophenol-contaminated wood test burn. HCl emissions from the railroad tie test burn were not detected (<0.1 ppm) and wood waste spiked with chlorophenol solution is not deemed to be representative of the burning of C/D wood. Therefore, HCl emissions were not evaluated in the ambient impact analysis.

Maximum ambient impacts caused by emissions from the hypothetical facilities were conservatively estimated using dispersion modeling procedures usually required by EPA and the states in the study area when permitting new sources. The two cases were chosen to represent a range of terrain versus stack height conditions that will have a significant effect on ambient impacts. The various steps of the modeling procedures are designed to over predict maximum impacts, accounting for uncertainties in emission rates, stack parameters, and meteorological conditions through use of conservative modeling assumptions. Using these modeling procedures, maximum normalized one-hour average and annual average impacts were determined at any location surrounding the hypothetical plants. These normalized values represent the maximum predicted impact corresponding to an emission rate of one gram per second of any pollutant. Maximum impacts for each individual pollutant are then calculated by multiplying the pollutant's emission rate by the normalized impact of interest.

The one-hour and annual average impacts were compared to regulatory guidelines obtained from the air quality regulations from several states in the study area. The state regulations selected for this analysis represent the range of guideline concentrations in the study area. In general, New York and Vermont typically have the most stringent guideline concentrations, and the annual guidelines are more difficult to meet than the short-term guidelines.

The assumptions and calculations used to perform the air impact analysis are summarized in Table 8-17. The results of the analysis are presented in Tables 8-18 and 8-19 for the short-term and annual average impacts, respectively.

As expected, the dispersion modeling case that results in the higher ambient impact is the one involving the facility situated in a valley (Case II). Short-term (one-hour) impacts are seventeen times higher for Case II than for Case I, the flat terrain situation. Annual average impacts for Case II are almost three times higher than Case I.

As a result, an exceedance of one state's (New York's) short-term guideline is predicted for arsenic for the Case II analysis, while no exceedances are predicted for Case I. Similarly, annual-average impacts from the Case II scenario are slightly above the guideline concentrations for As and Cr, while no exceedances of annual average guideline concentrations are predicted for Case I. It should be noted that the total Cr guideline in VT is more than a thousand times more stringent than other states and of the same order of magnitude as the hexavalent chromium guideline for other states. Vermont is most likely applying a health-derived standard for hexavalent chromium to total chromium emissions.

No exceedances of short-term or annual guideline concentrations are predicted for any of the organic compounds, even with the conservativeness of the methods used to develop some of the emission rates and impacts. For example, it should be noted that the TCDD and HxCDD emissions used for this analysis are based on a few data points that are one to two orders of magnitude higher than the bulk of the data. Furthermore, these data are not representative of boilers operating under good combustion conditions (See Section 8.6.4). It is, therefore, expected that dioxins emissions would be even further below guideline concentrations.

Table 8-17. Assumptions for ambient impact analyses.

Stack Emissions:

Metals: Calculated from construction/demolition wood metals analyses. (See Table 8-11 for calculations.)
Chromium VI calculated as 5% of Chromium III value.
Manganese & Selenium (not tested for in c/d wood) from database for pm < 0.01 gr/dscf.
Short-term (table 8-18) values are based on the 95th percentiles.
Annual (table 8-19) values based on the medians.

Organics: Taken from database, spreader stokers with good combustion (CO < 500 ppm), with exception of dioxins. All dioxins data from all boiler types used for analyses.
Short-term values from maximums.
Annual values from averages.

Ambient Impacts:

Case I: Dispersion modeling analyses on 15 MW, non-GEP stack in flat terrain

Stack height: 180 feet
Gas vol. rate: 2068.83 dscf/min
Temp: 310 deg. F
Normalized impacts: 1-hour: 11.31 (ug/m3)/(g/s)
Annual: 1.131 (ug/m3)/(g/s)

Case II: Dispersion modeling analyses on 15 MW, GEP stack in valley with some terrain higher than stack

Stack height: 180 feet
Gas vol. rate: 53440 dscf/min
Temp: 300 deg. F
Normalized impacts: 1-hour: 189.8 (ug/m3)/(g/s)
Annual: 3.25 (ug/m3)/(g/s)

Example conversions: (for Arsenic, Case I, 1-hour)
(ug/dscm) in stack --> (g/s) emission rate
 $61.36 \text{ ug/dscm} * (1 \text{ cu.m}/35.31 \text{ cu.ft}) * (1 \text{ g}/10^{-6} \text{ ug}) * (2068.83 \text{ dscf}/\text{min}) * (1 \text{ min}/60 \text{ sec}) = 0.0000599 \text{ g}/\text{sec}$
(g/s) emission rate --> (ug/m3) normalized impact
 $0.0000599 \text{ g}/\text{s} * 11.31 \text{ (ug/m3)/(g/s)} = 0.00068 \text{ ug}/\text{m}^3$

Table 8-18. Air quality analyses of short-term (1 hour) ambient impacts.

Pollutants	Maximum Stack Emissions ug/dscm(1)	Short-Term Ambient Impacts		State 1-Hour Guidelines		
		Case I ug/m3	Case II ug/m3	North Carolina	New York	Wisconsin
				ug/m3	ug/m3	ug/m3
<i>Metals:</i>						
Aluminum						1000
Arsenic	61.36	0.00068	0.29		0.2	20
Barium	222.99	0.0025	1.1		120	50
Cadmium	0.92	0.000010	0.0044		0.2	5
Chromium III	120.52	0.0013	0.58		120	50
Chromium VI					0.1	5
Copper	53.07	0.00059	0.25		240	100
Iron						100
Lead	447.97	0.0049	2.1			15
Manganese					240	
Mercury	0.38	4.23E-06	0.0018		12	5
Nickel	8.16	0.000090	0.039		1.5	100
Selenium					48	20
Silver	1.46	0.000016	0.0070			10
Titanium	233.24	0.0026	1.1			
Zinc	185.01	0.0020	0.89		150	
<i>Organics:</i>						
Acetaldehyde	390	0.0043	1.9		43000	18000
Benzene	347	0.0038	1.7		30	3200
Formaldehyde	5496	0.061	26		30	120
Phenol	0.0735	8.12E-07	0.00035	950	4500	1900
Toluene	15.51	0.00017	0.074		89000	37700
Naphthalene	321	0.0035	1.5		12000	5000
TCDD	0.002	2.2E-08	9.58E-06			
HxCDD	0.0036	4.0E-08	1.72E-05			
Benzo[a]pyrene	0.00435	4.8E-08	2.08E-05			

Case I: 15 MW, non-GEP stack height, flat terrain

Case II: 15 MW, GEP stack height, valley with some terrain higher than stack

Guidelines: Wisconsin All Wood Ambient Impact Limit 1 hr basis

North Carolina 1-Hour Acute Systemic Toxicants

New York Short-term Guideline Concentrations (1-hour)

(1): Corrected to 12% CO₂.

Table 8-19. Air quality analyses of annual ambient impacts.

Pollutants	Average Stack Emissions ug/dscm(1)	Annual Ambient Impacts		State Annual Guidelines		
		Case I ug/m3	Case II ug/m3	North Carolina	New York	Vermont
				ug/m3	ug/m3	ug/m3
<i>Metals:</i>						
Aluminum						
Arsenic	3.31	3.66E-06	0.00027	0.00023	0.00023	0.00023
Barium	22.33	0.000025	0.0018		0.5	11.9
Cadmium	0.20	2.24E-07	0.000017	0.0055	0.0005	0.00057
Chromium III (2)	7.11	7.86E-06	0.00058		0.1	0.000085
Chromium VI				0.000083	0.00002	
Copper	6.90	7.62E-06	0.00057		2.4	100
Iron						
Lead	47.73	0.000053	0.0039		1.5	1.5
Manganese				31	0.3	
Mercury	0.08	8.32E-08	6.17E-06	0.06	0.3	0.144
Nickel	2.03	2.24E-06	0.00017	6	0.02	0.0033
Selenium					4.8	4.8
Silver	0.04	4.39E-08	3.26E-06			0.24
Titanium	134.17	0.00015	0.011			
Zinc	39.01	0.000043	0.0032		50	12
<i>Organics:</i>						
Acetaldehyde	165.48	0.00018	0.014		430	1800
Benzene	275.38	0.00030	0.023	0.12	0.12	0.12
Formaldehyde	720.87	0.00080	0.059		0.06	0.08
Phenol	0.0404	4.46E-08	3.31E-06		9.6	1900
Toluene	15.51	0.000017	0.0013		2000	8930
Naphthalene	133.79	0.00015	0.011		120	120
TCDD	0.0003	3.31E-10	2.46E-08	3.0E-06	3.0E-08	
HxCDD	0.00078	8.61E-10	6.39E-08	7.6E-05		
Benzo[a]pyrene	0.00246	2.72E-09	2.02E-07	3.30E-02	2.00E-03	3.00E-04

Case I: 15 MW, non-GEP stack height, flat terrain

Case II: 15 MW, GEP stack height, valley with some terrain higher than stack

Guidelines: North Carolina Annual Carcinogens
New York Annual Guideline Concentrations
Vermont HLV Annual Average

(1): Corrected to 12% CO2.

(2): Vermont standard is for total chromium.

The following conclusions can be drawn from this ambient impact analysis:

1. By using conservative assumptions to estimate metal emissions, the combustion of C/D waste wood may result in exceedances of state guideline concentrations for As and Cr. Reduction in the amount of CCA-treated wood may be necessary for facilities to meet State guidelines.
2. The combustion of "clean" wood is not likely to result in guideline exceedances. As and Cr emissions from "clean" wood combustion are estimated to be at least one order of magnitude lower than emissions estimated from C/D wood metals analysis.
3. Emissions of organic compounds, which do not appear to be affected by fuel composition (see Section 8.6.4), are expected to result in ambient impacts that meet state guidelines.
4. The topography (e.g., high terrain) of the area surrounding a facility can significantly affect ambient impacts and the ability of plant emissions impacts to meet stringent guidelines.

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TECHNICAL REPORT DATA
(Please read instructions on the reverse before completing)

1. REPORT NO. EPA-600/R-96-119a		2.	3. RECIPIENT'S ACCESSION NO.	
4. TITLE AND SUBTITLE Wood Products in the Waste Stream-- Characterization and Combustion Emissions, Volume 1. Technical Report			5. REPORT DATE October 1996	
7. AUTHOR(S) Richard S. Atkins (ERL) and Christine T. Donovan (CTD Assoc.)			6. PERFORMING ORGANIZATION CODE	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Environmental Risk Limited, 120 Mountain Ave., Bloomfield, Connecticut 06002 C. T. Donovan Associates, Inc., P. O. Box 5665, Burlington, Vermont 05402			8. PERFORMING ORGANIZATION REPORT NO.	
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Air and Energy Engineering Research Laboratory Research Triangle Park, NC 27711			10. PROGRAM ELEMENT NO.	
			11. CONTRACT/GRANT NO. CR815271 (NYSERDA)	
			13. TYPE OF REPORT AND PERIOD COVERED Final; 3/91-7/92	
			14. SPONSORING AGENCY CODE EPA/600/13	
15. SUPPLEMENTARY NOTES AEERL project officer is Robert C. McCrillis, Mail Drop 61, 919/541-2733. Volume 2 consists of appendices A-H.				
16. ABSTRACT The report gives results of a study of technical, public policy, and regulatory issues that affect the processing and combustion of waste wood for fuel. (NOTE: Waste wood is wood that is separated from a solid-waste stream, processed into a uniform-sized product, and reused for other purposes, such as fuel.) The report provides data to enable environmental regulators, project developers, and others to make informed decisions on the use of waste-wood materials as a combustion resource. It identifies potential environmental problems and solutions, including combustion system operating parameters and air pollution control technologies that can minimize emissions of identified air and solid-waste contaminants from the combustion of waste wood. The report: (1) identifies the quantity and quality of waste wood; (2) characterizes waste-wood processing and combustion facilities; (3) characterizes representative waste-wood samples; and (4) gives results of analyses of collected emissions data from operating combustion facilities. Described waste wood includes: pallets; construction and demolition waste; wood treated with paints, stains, preservatives, pesticides, or fungicides; and wood containing glues, binders, resins, plastics, or vinyl.				
17. KEY WORDS AND DOCUMENT ANALYSIS				
a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS		c. COSATI Field/Group
Pollution Wood Wastes Processing Combustion Emission		Pollution Control Stationary Sources		13B 11L 13H 21B 14G
18. DISTRIBUTION STATEMENT Release to Public		19. SECURITY CLASS (This Report) Unclassified		21. NO. OF PAGES 308
		20. SECURITY CLASS (This page) Unclassified		22. PRICE