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COST AND PERFORMANCE REPORT
APPLICATION OF THERMOCOUPLE CONVERSION TO DESTROY DEMOLITION DEBRIS FROM FORT ORD

by

Naval Facilities Engineering Service Center
ARI Technologies, Inc.

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14. ABSTRACT

A series of thermal treatment tests were conducted on military wood waste contaminated with lead-based paint for the U.S. Army Engineer Research & Development Center Construction Engineering Research Laboratory (ERDC/CERL), Champaign, Illinois, under a contract with the Naval Facilities Engineering Service Center (NFESC) in Port Hueneme, California. The tests were designed to collect data that would facilitate the design and capital/operational cost estimates for a transportable treatment system that could process such waste on site during demolition activities at current and former military installations.

The data produced from the tests facilitated the development of a design of a transportable processing system for the LBP-coated materials. The transportable processing system can process the waste for a cost of less than 1/3 the cost of land disposal of the waste designated as X008 waste (exempt household hazardous waste) and less than 1/5 the cost of land disposal if the waste originates from other than residential structures and is designated as RCRA hazardous waste.

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TABLE OF CONTENTS

1.0 Executive Summary **1**

2.0 Technology Description **3**

3.0 Scope of Work **5**

3.1 Regulatory Considerations 7

4.0 Project Operations **8**

4.1 Tube Furnace Test (small-scale) 8
4.2 Intermediate-Scale Test 9
4.3 Large-Scale Test 12
4.3.1 Fuel Consumption 15
5.0 Sampling and Analytical Program 16
5.1 Chemical Analysis 17
5.2 Electron Microprobe Analysis 20
5.3 Fluxed and Sintered Samples 23
5.4 Off-Gas Sampling and Analysis 23

6.0 Cost Assessment **26**

7.0 Performance Assessment **28**

7.1 Throughput Capacity 28
7.2 Volume and Mass Loss 28
7.3 Chemistry and Recyclability of the Ash 28
7.4 Regulatory Classification of Ash 30
7.5 Off-gas composition and System Processing Parameters 29
7.6 Wastewater Characteristics and Treatment/Discharge Requirements 29
7.7 Operational Economics for Deployment of the Technology for a Large Project 29
7.8 Distribution of Ash 29
7.9 Fuel Consumption/Energy Requirements 30

8.0 Conclusion **30**

9.0 Key Personnel **30**

FIGURES

Figure 1. Thermochemical Treatment System 4
Figure 2. Thermochemical Conversion Process Schematic 5
Figure 3. Tube Furnace Showing Sample Insertion Point and Probe with Nickel Boat 8
Figure 4. Intermediate-Scale Processing System 10
Figure 5. View inside hearth through sight port during processing 11
Figure 6. Ash on Hearth Following Processing 12
Figure 7. Ft. Ord Debris Unloaded from Shipping Container 13

Figure 8. Electron Photomicrograph of Rotary Hearth Ash from the Intermediate-Scale Test Showing Light and Dark Areas of Differing Composition....21
Figure 9. Particle of Bag House Ash Showing the Two Predominant Phases in this Material ..23
Figure 10A. Histogram of Particle Frequency Data from Large-Scale Test 25
Figure 10B. Histogram Showing Particle Mass Distribution from Large-Scale Test 26
Figure 11. Particle Size Distribution for Intermediate Scale Test 26

TABLES

Table 1. Summary of the Properties of Ash Collected from Intermediate-Scale Test 12
Table 2. Summary of Feed Rate Data 14
Table 3. Estimated Volumes of Ash Collected from Large-Scale System 15
Table 4. Ash, Lead, TCLP and Blowdown Water Analysis from Large-Scale Test 17
Table 5. Normalized Bulk Chemistry & Lead Analysis from the Large-Scale Test 17
Table 6. Total Lead and TCLP Results from the Intermediate-Scale Test Using EPA Tests 18
Table 7. Bulk Chemistry and Lead Analysis on Ash from the Intermediate-Scale Test 20
Table 8. Normalized WDS Analysis of Light and Dark Areas....21
Table 9. TCLP Results for Fluxed & Sintered Samples 23
Table 10. Lead Emission Results for the Large-Scale Test 24
Table 11. Summary of Operational Cost Estimate, 1.5 ton/hour System 27

1.0 EXECUTIVE SUMMARY

A series of thermal treatment tests were conducted on military wood waste contaminated with lead-based paint for the U.S. Army Engineer Research & Development Center Construction Engineering Research Laboratory (ERDC/CERL), Champaign, Illinois, under a contract with the Naval Facilities Engineering Service Center (NFESC) in Port Hueneme, California. The tests were designed to collect data that would facilitate the design and capital/operational cost estimates for a transportable treatment system that could process such waste on site during demolition activities at current and former military installations.

The tests included thermochemical processing of wood waste at three different scales with careful documentation of processing parameters and ash characteristics. Leach performance of ash produced from the test was evaluated including ash as-produced, fluxed and sintered ash and ash to which Portland cement and water had been added.

The tests showed a 97% volume reduction and a 90% reduction in the mass of the waste. Over 99.9% of the lead released to the off-gas system during processing was in particulate form >0.7 microns in effective diameter. Concentrations of lead in the residual ash ranged from about 7-12% from the processing of whole boards to about 25% from the processing of wood and paint shavings. The lead is believed to be primarily in the oxide form but a small portion is known to be in the chloride form. There was no evidence to suggest that any lead produced from these tests was in the form of lead metal.

The fine-grained airborne ash and the heavier coarser ash left on the hearth following processing exhibited chemical and physical differences as well as differences in leach performance. The hearth ash typically passed leach tests while the bag house ash did not. The addition of Portland cement tended to improve leach characteristics but relatively large quantities of cement are required to immobilize lead in bag house ash. Fluxing and sintering of ash impaired leach performance because of the lack of glass forming ions in the ash.

Data collected from off-gas monitoring and sampling suggest that emission control for processing the lead-based paint (LBP) waste will be relatively simple and consist of a dry filtration system. There will not be a need for a wet off-gas system thus eliminating issues surrounding management of wastewater.

The ash produced from these tests can be recycled to recover the lead and perhaps the zinc. The ability to recycle the ash from this process should result in regulation of this process as a recycling process rather than a hazardous waste combustor. This designation combined with the transportable nature of the system will greatly simplify permitting of this process.

The data produced from the tests facilitated the development of a design of a transportable processing system for the LBP-coated materials. The transportable processing system can process the waste for a cost of less than 1/3 the cost of land disposal of the waste designated as X008 waste (exempt household hazardous waste) and less than 1/5 the cost of land disposal if the waste originates from other than residential structures and is designated as RCRA hazardous waste.

2.0 INTRODUCTION

Decommissioning and demolition of military facilities that are no longer being utilized generates large quantities of waste. Many of the buildings at closed military sites that are being demolished were painted repeatedly over the years with lead-based paint (LBP). Some of the waste generated from demolition of these buildings has been shown to exhibit hazardous properties, in part because of the presence of LBP. In an effort to re-use materials produced from base closure activities, the Army is conducting a series of tests and investigations to evaluate various options for reuse, recycling, disposal and treatment of wastes generated from demolition activities.

This report presents the results of a series of tests that were performed on waste from demolition of 26 WWII-era wooden military buildings located at Ft. Ord, near Monterey, California, as part of a road improvement project executed by the Fort Ord Reuse Authority (FORA). Building materials from this demolition were made available to the U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC/CERL) for various research activities as part of a cooperative research project between the U.S. Army and FORA to evaluate alternatives to land disposal of waste generated from demolition and land reclamation activities.

Thermochemical conversion technology was selected for a treatability test on two types of waste generated from the demolition of buildings from Ft. Ord including wood siding coated with LBP and sawdust generated from planning LBP off of the siding.

Three scales of testing were performed including small-scale tests, intermediate-scale and large-scale processing. Even though it was known that the technology is capable of effectively treating the waste, there were several factors that needed to be evaluated in order to fully characterize the applicability of the technology and to help the U.S. Army determine if the technology is the right choice for full-scale application. These factors include:

- The throughput capacity attainable using a new system specifically designed for the subject waste,
- The actual volume and mass loss resulting from treatment,
- The chemistry of the treated waste and determination if the product can be recycled,
- Type and quantity of treated products generated from processing the waste,
- Regulatory classification of the treated product,
- Off-gas processing parameters necessary to operate within air discharge restrictions,
- Wastewater characteristics and treatment/discharge requirements,
- Projected operational economics for deployment of the technology for a large project.

Thermochemical conversion technology was considered a potential candidate for treatment of the subject wastes for several reasons including:

- The large percentage of wood in the debris was expected to result in high volume reduction thus minimizing the quantity of treated product and concentrating the lead into a small volume. The goal was to maximize the potential for recycling the product,

- The BTU value provided by the wood in the waste was expected to supplement energy requirements and reduce processing costs,
- The absence of asbestos and PCBs in the waste facilitated processing at relatively low temperatures thus reducing costs and minimizing volatilization of lead,
- The static nature of the process (no waste agitation) was expected to result in low levels of particulate generation in the off-gas thus simplifying off-gas treatment.

The tests were designed to address each of the factors listed above and to facilitate an evaluation regarding the technical and economic appropriateness of the technology for use on the subject waste. The treatability tests performed were successful and provided the data required to adequately qualify the technology for use on waste generated from demolition of buildings at Ft. Ord and other similar types of waste. The data from the tests also produced a preliminary design for a new efficient and transportable LBP processing system and an estimate of its operating costs.

2.0 TECHNOLOGY DESCRIPTION

Thermochemical conversion is a versatile thermal treatment technology capable of effectively treating a wide variety of hazardous and radioactive materials. The process utilizes a rotary hearth equipped with the capability to operate at a wide range of treatment temperatures and waste residence times and an off-gas treatment system to process the gases produced from heating the waste. The process destroys organic contamination through a combination of pyrolysis and oxidation and can simultaneously immobilize and/or remove metals and radionuclides, and destroy asbestos converting the waste into a rock-like product.

The process can be used on waste and debris with a wide variety of contaminant types and concentrations. It has particular technical and economic advantages on waste containing multiple contaminant types that would complicate the regulatory classification of the waste and/or require more than one treatment process such as waste containing metals and organic compounds.

The process consists of four basic systems that include a waste preparation system, the thermal treatment unit, the off-gas treatment system, and the product removal system. The systems are modular and can be adapted/adjusted for the specific process requirements.

The existing system currently located in Tacoma, Washington was used for the large-scale testing activities. This system as it is currently configured is described below:

- The waste preparation system consists of conveyors, a shredder, mixer and compactor that condition the waste for treatment. Fluxing agents or other chemicals can be added during the mixing process depending upon the processing protocol. The compaction unit is used to increase the density of feed. This, in turn increases the throughput capacity and heat transfer characteristics of the feed.
- The thermal treatment module is a rotary hearth that consists of an enclosed rotating refractory bed upon which the waste is exposed to high temperatures. Heating for this test was accomplished by combustion of propane. The waste is introduced onto the hearth where it is heated during its single revolution and then is removed. The

temperature of the hearth can be varied up to approximately 2,400ºF (1,300ºC). The rotational speed of the hearth can also be adjusted from 15 minutes to over an hour.

- The off-gas treatment system consists of a secondary combustion chamber, followed by a quench cooler, caustic scrubber, demister, pre-heater and HEPA filtration. These components are also modular and may or may not be utilized depending upon the process requirements.
- The waste discharge system consists of an alloy blade that scrapes the treated product off of the hearth into a screw conveyor for removal to holding bins. Figure 1 shows a photograph of the treatment system including the hearth and off-gas treatment system.

Figure 1. Thermochemical Treatment System

3.0 SCOPE OF WORK

The types of waste that were the subject of testing from the Ft. Ord demolition activities included:

- Wood siding coated with lead-based paint,
- Wood shavings and LBP generated from attempts to remove the LBP and recycled lumber.

Figure 2 shows a schematic of the Thermochemical Conversion Process.

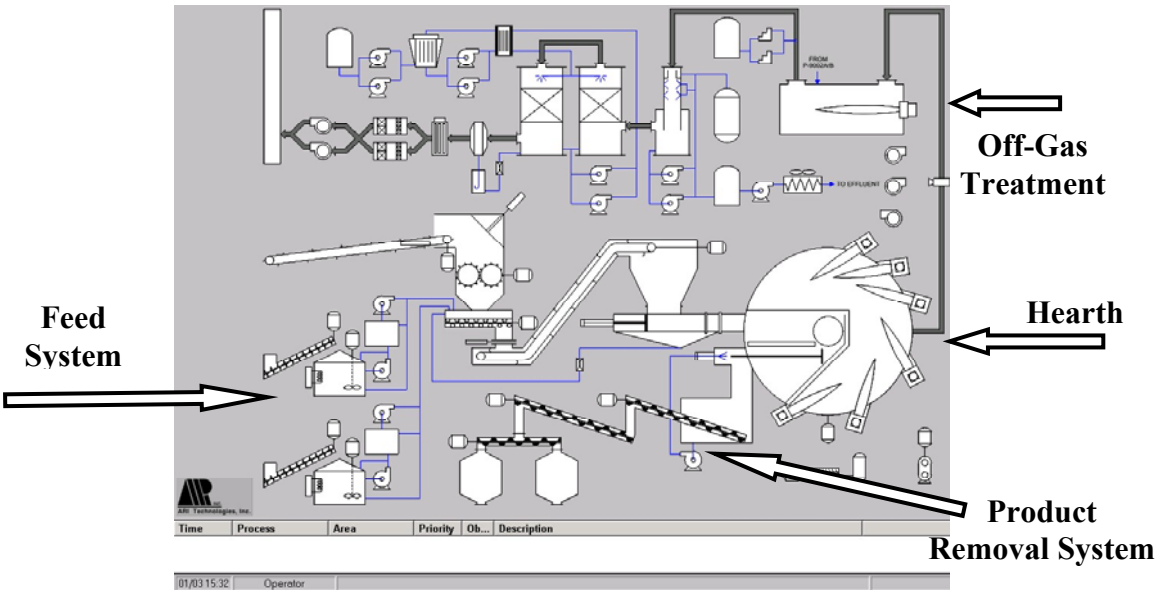

Figure 2. Thermochemical Conversion Process Schematic

Three scales of testing were selected to fully evaluate treatment of these wastes using thermochemical technology. These three scales included:

1. Laboratory-scale using a tube furnace,
2. Intermediate-scale using a rotary hearth 6-ft (183-cm) in diameter,
3. Large-scale using the system in Tacoma (described above).

The tube furnace testing was conducted to gather data that would help determine the operating parameters (e.g., processing temperature and residence time) that would be used for the larger scale tests.

The intermediate-scale testing was used on the sawdust generated from the paint removal tests being conducted by another laboratory. It was known that the quantity of sawdust generated from these activities was not adequate to support testing with the large-scale system. It was anticipated that there would be enough to conduct tests using the intermediate-scale system. This is why it was chosen for this waste stream.

The large-scale system was used to process whole wood siding. The main purpose of using the large-scale system was to gain experience with handling and preparing the waste for processing, evaluate wet scrubber performance, and to evaluate fuel consumption and energy contribution provided by the wood.

The large large-scale system was designed to process asbestos and PCBs. The system is not designed to process wood. It was determined that the large-scale system would not be particularly efficient at processing this waste but by changing some of the operational parameters, the Ft. Ord waste could be processed to the extent that useful data could be collected. This data could then be used for the design of a new, more efficient system. Changes that were made included:

- Changes in the manner in which the waste was handled prior to processing,
- Operating temperature lower than design parameters,
- Increased air flow in the hearth,
- Acid scrubbing was not performed.

The three scales of tests were conducted with the goal of producing three different products, each of which were likely to result in different disposal options for the treated product. These three products included:

- Unmodified ash,
- Sintered/melted ash,
- Ash stabilized with varying quantities of Portland cement.

Because of the high volume reduction associated with the process, it was expected that the lead concentrations in the unmodified ash would be relatively high and that the chemistry of the ash might be suitable for recycling in a lead smelter. If it were found that this option was not available, the next-best option is to reduce the leach characteristics of the ash so that it would pass the TCLP test for lead and be suitable for land disposal. Reduction of leach rates for lead can be attained by vitrification and by stabilization using Portland cement. Thus, these three products were produced during the test activities and leach characteristics for each evaluated.

Detailed evaluations of processing conditions along with ash properties, composition and distribution were conducted for the intermediate and large-scale tests. These tests included evaluations of:

1. Density of each type of ash,
2. Volume generated of each type of ash,
3. Distribution of ash throughout the system,
4. Chemical composition of ash,
5. Lead concentration in ash,
6. Leach properties of ash in three different forms including as-produced, sintered/melted, and stabilized using Portland cement,
7. Off-gas composition,

8. Waste feed rate,
9. Fuel consumption/energy requirements,
10. Volume reduction of waste.

The data collected from the testing activities was compiled and used to evaluate three options for final disposition of the ash from the process. These three options include:

1. Recycling of the lead in the ash by use of a lead smelter
2. Stabilization of the ash with Portland cement followed by land disposal
3. Stabilization of the ash by sintering followed by land disposal

The data produced from the testing activities was used to create a preliminary design and cost estimate for a mobile processing system that could be used to process similar waste for the Army on-site during demolition activities.

3.1 Regulatory Considerations

Construction debris containing (LBP) has historically been regulated under RCRA provided it was Toxicity Characteristic (TC) waste and was not exempt as household waste.

The U.S. EPA changed its regulations concerning the treatment and handling of lead-contaminated waste on May 26, 1998. The previous TCLP threshold non-wastewater limit for determining if a waste was a TC waste was 5.0 ppm. This limit used to be the same for treated and untreated wastes alike. This limit remains the same for untreated waste but the new standard for treated waste is now 0.75 ppm.

On July 31, 2000, the EPA Office of Pollution Prevention and Toxics provided clarification to the regulatory status of waste generated by contractors and residents from lead-based activities conducted in households. The clarification allows wastes from residential dwellings "like single family homes, apartment buildings, row houses, military barracks or college dormitories" such as "doors, window frames, painted woodwork, and paint chips" to be disposed of as household waste for the time being.

The EPA has proposed new rules for LBP debris disposal that would regulate the waste under TSCA rather than RCRA and allow disposal of the waste in construction and demolition (C&D) landfills. States will have two years after the final rule is issued to adopt the new TSCA disposal and management standards after which the Federal standards would become effective in States without authorized programs.

In the State of Washington, the solid waste from Ft. Ord is considered a Dangerous Waste if it exhibits Toxicity Characteristics. In Washington, this is 5 ppm of lead in a TCLP extract. It was not known if the Ft. Ord debris qualified as a Dangerous Waste in Washington because no analytical work was provided on this debris. Based upon communications from the Army, it was assumed that the waste was a Washington Dangerous Waste and handled appropriately. Approvals from the Washington State Department of Ecology (Ecology), City of Tacoma Water and Sewer District TWSD and the Puget Sound Air Quality Agency (PSCAA) were required in

order to conduct the test in Washington. Requests for permission to conduct the test in Washington were submitted to Ecology and PSCAA on July 16, 2002 and to TWSD on August 2, 2002. Approvals from these agencies were received prior to conducting the test.

4.0 PROJECT OPERATIONS

Testing operations consisted of three tests at three different and progressively increasing scales. The small-scale tube furnace test was conducted first followed by the large-scale test and finally the intermediate-scale test. The original goal was to conduct the tests beginning with the small-scale test and end with the large-scale test. However, the whole siding was available before the sawdust from planning operations so the large-scale test was conducted before the intermediate-scale test.

4.1 Tube Furnace Test (small-scale)

A tube furnace is a horizontal electrically heated chamber that houses a refractory tube. The diameter of the tube is about 2 inches. Samples are prepared by packing them into an elongated nickel container called a "boat". The loaded boat is then pushed into the refractory tube and allowed to reside in the furnace for a specific period of time. There were two series of tests involving the tube furnace. The first series of tests were performed on wood shavings. The second series of tests were performed on ash produced from the intermediate-scale processing of wood shavings. Figure 3 is a photograph of the tube furnace used for these tests.

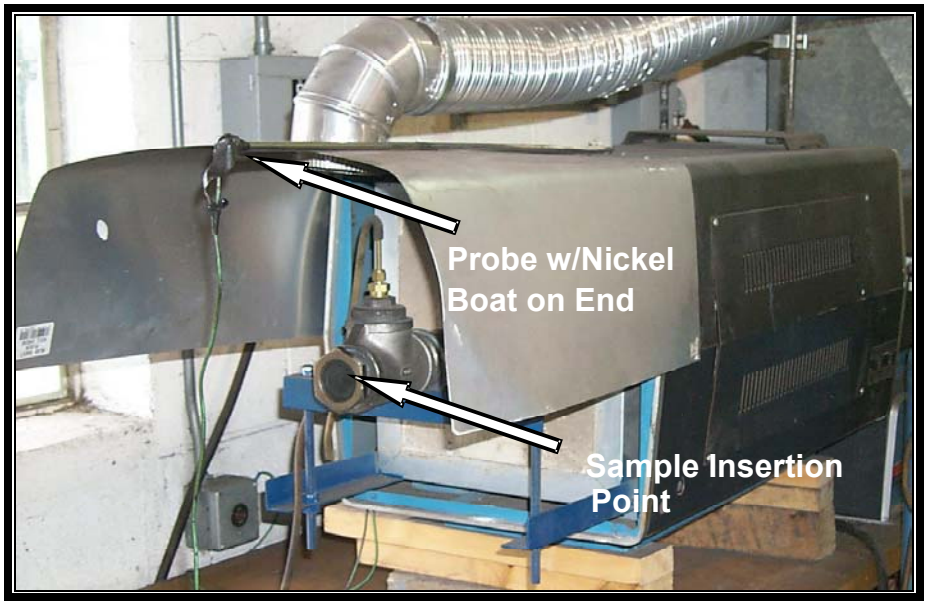

Figure 3. Tube Furnace Showing Sample Insertion Point and Probe with Nickel Boat

The first series of tests were designed to gather data that would help establish operating parameters for the larger scale tests. Wood shavings were packed into the nickel boat and processed at a variety of residence times ranging from 5 to 30 minutes at process temperatures including 1,400 and 1,500º F. In each test, the wood shavings were converted completely to ash within a very short period of time. Ash produced from these tests was removed from the nickel boats and weighed to determine the mass loss and to estimate the volume reduction resulting

from processing. Each of the tests resulted in 96% to 98% mass loss and there was very little ash to work with or to evaluate further. Volume reduction could not be measured but appeared to be in the same range. Based upon this series of tests, the initial processing parameters for the large-scale tests were established.

The second series of tube furnace tests were not initially planned or part of the original scope of work. Observations made during processing of the wood chips in the large-scale test and in the intermediate-scale tests suggested that fluxing and processing the wood chips at high temperature might not be the best alternative for several reasons including:

1. Large quantities of fluxing solution would be required to wet all of the wood shavings to assure that fluxing agents were homogeneously distributed throughout the shavings,
2. The presence of large quantities of aqueous solution in the wood shavings would significantly increase the energy requirements for production processing because of the necessity to evaporate or boil off the water before conversion to ash could take place,
3. There was uncertainty regarding how much of the processed ash would remain on the hearth and whether fractionation of the fluxing agents would take place during processing,
4. The high temperatures (e.g., 2,200º F) required for sintering the waste at production scale would require higher energy requirements and necessitate more complex and more expensive equipment than that required for simply converting the waste into ash,
5. If while processing at high temperatures, ash were to sinter and become airborne, there is a chance that this airborne material would stick to the refractory liners in the hearth and off-gas system and eventually complicate processing,
6. The very high volume reduction that takes place during processing makes it economically and technically more attractive to sinter the ash separately especially at larger scales.

For these reasons, the original plan of fluxing the wood chips and processing them at high temperature was abandoned. Instead, the decision was made to test the sintering properties of the fluxed ash in the tube furnace.

The ash from the bag house and hearth produced from the intermediate-scale test were fluxed and sintered separately. The samples were first prepared by mixing 10% fluxing solution with the ash to saturate the samples. The samples were dried at 220° F (100º C) for approximately one hour. The dried samples were then packed into a nickel boat and pushed into the tube furnace where they remained for 10 minutes. After initial sintering tests, it was decided to run the ash collected from hearth at 2,200° F (1,204º C). The bag house ash exhibited a propensity to sinter at cooler temperatures. Consequently, it was processed at 1,800° F (982º C). Several boatloads of both types of ash were sintered in order to accumulate quantities of sintered material sufficient for analytical testing.

4.2 Intermediate-Scale Test

The intermediate-scale rotary hearth furnace is owned and operated by Maumee Research and Engineering, Inc. (MR&E) and is part of this company's development center and laboratory located in Perrysburg, Ohio. The wood shavings were delivered to the facility on October 16, 2002 at approximately 1430 hours. Although the total weight of the delivery was 950 lb. (431

kg), this weight included three pallets with Gaylord boxes (heavy, 1 yd^3 or 0.76 m^3 cardboard boxes) approximately ¾ full of wood shavings. One of the boxes contained wet shavings and the other two were dry. The weight of the dry shavings was approximately 130 lb. for each box containing dry shavings. The weight of the wet shavings was not determined.

The intermediate-scale rotary hearth is 6 ft. in overall diameter with an effective hearth area of 4.7 ft^2. This furnace was chosen for the intermediate-scale test program because it is the right size for the quantity of ash available from the wood reclamation tests that produced the planer shavings. In addition, the system is designed to be closely monitored and provide reproducible data. Figure 4 is a photograph of the intermediate-scale system.

The furnace has five burners located around the circumference of the hearth to provide even heating at the desired processing temperature. The furnace gases exit through an afterburner section where air can be added to aid the combustion of unburned gases if present. Following the afterburner is a two stage quench section designed to lower the temperature of the furnace gases to the 300° to 350° F range before they are filtered through a bag house to remove particulate matter.

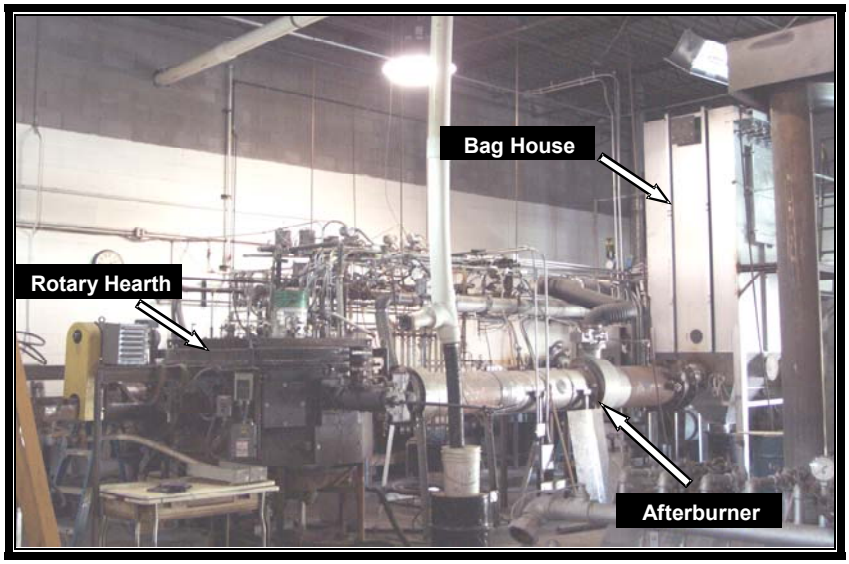

Figure 4. Intermediate-Scale Processing System

The hearth was fed manually through two slide gates (similar to an air lock) into a profiled metal "spoon" which held a furnace charge. A charge was introduced once each minute. The loaded "spoon" was pushed into the furnace and turned over so that material would drop onto the hearth. The "spoon" was then withdrawn and loaded with another charge of wood chips and the process repeated. The mass of each charge was 108 g. This feeding system distributed the wood chips over an eleven-inch radius of the hearth with a peak thickness of two inches. The rate of rotation for the hearth was set to 2.25 revolutions per hour. This gave the charged material a residence time of 20 minutes from charge to discharge position.

During these tests, four of the five furnace burners were in operation. A fifth burner located in the roof of the system near the charge section of the furnace was not operated to prevent blowing

the newly charged material out of the furnace before combustion could take place. All of the burners in operation were fired with excess air. The hearth is maintained at a negative pressure via an induced draft fan located at the outlet of the bag house. The pressure differential in the hearth was maintained at approximately –0.5 inches w.c., relative to ambient, and the bag house maintained a pressure drop of about 1 - 4 inches w.c. across the bags. As expected, the pressure drop across the bag house gradually increased throughout the duration of the test consistent with particulate loading.

Observations of the material on the hearth showed that the volatile components in the wood and LBP were oxidized within a few minutes leaving primarily carbon. The reaction of carbon to CO_2 tends to be relatively slow and is directly dependant upon the availability of oxygen. To accelerate the reaction and to help minimize the time required to completely oxidize the carbon, additional air was allowed to enter the hearth through ports located around the circumference of the hearth. This additional air aided in the conversion of carbon from the wood chips into CO_2 within one hearth rotation. Approximately 109.8 lb. (49.8 kg) of wood chips were charged into the furnace over a 7.5 hr. period. Figure 5 shows waste undergoing the reaction on the hearth.

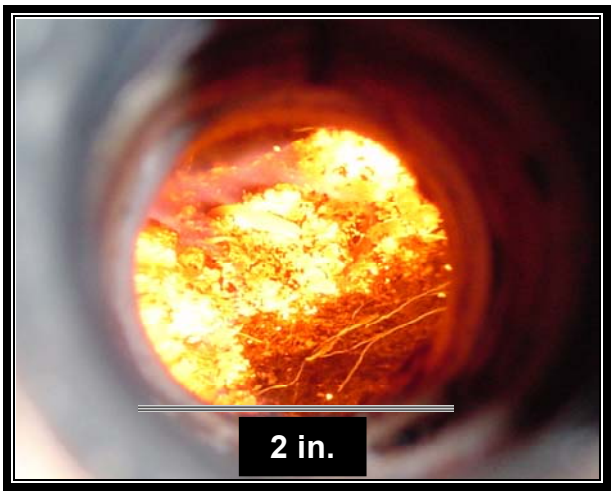

Figure 5. View inside hearth through sight port during processing

Process operations ceased at approximately 6:00 P.M. on October 17 and the system was left to cool overnight. On October 18, ash was removed from the bag house and the ash on the hearth was swept into a stainless steel container. Both types of ash were kept separate and weighed. A total of 10.30 lb. (4796 g) of ash was collected from the hearth surface and 0.86 lb. (389 g) was collected from the bag house. The density of both ash samples was measured by weighing a known volume of the un-compacted ash. These measurements showed that the bag house ash has a dry, un-compacted bulk density of 0.247 g/cm^3 and the hearth ash has a dry un-compacted bulk density of 0.726 g/cm^3. By knowing the density of each type of ash and the total mass produced from the test, the total volume of ash was 8,366.2 cm3. The volume of wood chips processed was 276,600 cm3. Thus, the overall volume reduction of the waste was 96.97%. Sampling of both ash types took place on October 18 in preparation of analytical work. Figure 6 shows the ash on the hearth after being allowed to cool. Table 1 summarizes the mass and volume data collected.

Figure 6. Ash on Hearth Following Processing

4.3 Large-Scale Test

The large-scale test took place in Tacoma, Washington at the contractors test facility. The construction debris arrived in a 40-ft shipping container on September 25, 2002. The debris was unloaded from the container onto plastic sheets covering the ground and was placed into a large shredder to reduce the particle size of the debris. Size reduction was necessary in order to introduce the material into the existing shredder because this shredder was not designed to accept long boards. As the material was shredded, it was delivered back into the shipping container by conveyor and remained there until it was processed. Water spray and plastic sheets were used to control dust during the shredding operations. Figure 7 shows the waste as it was removed from the shipping container.

The facility's systems were energized and heating of the rotary hearth commenced at 1900 hours on October 1, 2002. The hearth was brought up to the designated operating temperature of 1500º F (816º C) at 0430 on October 2 and the rotational speed of the hearth was adjusted to attain a residence time of 20 minutes. The hearth was allowed to "soak" at the operating temperature while final preparations were completed.

Table 1. Summary of the Properties of Ash Collected from Intermediate-Scale Test

	Bag House Ash		**Hearth Ash**		**Total Ash**	
Mass Collected	389 g	0.858 lb.	4930 g	10.87 lb.	7885 g	11.73 lb.
Density Measured	0.247 g/cm^3	15.42 lb/ft^3	0.726 g/cm^3	45.32 lb/ft^3	--	--
Volume Calculated	1574.9 cm^3	--	6797.3 cm^3	--	8366.2 cm^3	--
Volume Reduction	--	--	--	--	96.97%	--

Figure 7. Ft. Ord Debris Unloaded from Shipping Container

Chipped waste was loaded into wheelbarrows using snow shovels and was then dropped onto a mobile conveyor. The mobile conveyor transferred the chips to a modified bag-feed conveyor that dropped the chips into the rip-shear shredder. The shredder reduced the size of the feed material to <2-in. Since no chemicals were added to the feed, the mixer was not needed. However, since it is an integral part of the existing system the material was required to pass through it. Therefore, the mixer was simply left running with the feed gate open so feed simply passed through the mixer and dropped onto the flexwall conveyor and into the feed hopper. The material was picked up from the base of the feed hopper by the ram feeder and pushed onto the hearth.

The wheelbarrow loads were weighed and the time was noted each time a load was introduced into the system. The average net weight of a wheelbarrow load was 30-lb. Some material was heavy and wet from the chipping operations but this material was not considered representative of the load of material so the weight of this heavier material was not included in the feed rate figures. The density of the wood chips was measured by filling 5 gal. buckets with representative wood chips and weighing. Using this method, the average un-compacted density of the wood chips was 10.38 lb/ft^3. (0.17 g/cm^3). The very low density of the material coupled with the volumetric capacity of once cycle of the ram feeder (0.56 ft^3/cycle or 15, 930 cm^3/cycle) resulted in a low feed rate with respect to mass. During the 6 hours of operation, 1,080 lb. (490 kg) of wood chips were processed. A one-hour "snapshot" of the loading operations during which no interruptions were encountered showed a volumetric feed rate of 24 ft^3/hr (0.68 m^3/hr). This is consistent with the volumetric design capacity of the system. Table 2 summarizes the feed rate information.

Table 2. Summary of Feed Rate Data

	Number of Loads	Density		Average Mass/Load		Test Duration		Feed Rate
Wood Chips	36	10.38 lb/ft3	0.17 g/cm3	30 lb	13.6 kg	6 hr.	180 lb./hr	81.7 kg/hr

Processing took place uninterrupted from 0930 until 1330 at which time the active induced draft fan malfunctioned and the backup induced draft (ID) fan was automatically energized. The system experienced positive pressure for approximately 30 sec. when the switch to the alternate fan took place. Processing of waste continued thereafter until 1527. Shortly after the test was initiated, the HEPA filters became clogged with water due to excessive water carryover from the scrubber. The decision was made to continue the test with the HEPA filters in place but allow off-gas to bypass them rather than terminate the test. The expectation was that the quench and scrubber would provide removal efficiency sufficient for the limited operational duration. Several process parameters were monitored during processing including:

1. Stack gas emissions,
2. Hearth atmosphere emissions,
3. Scrubber water pH,
4. Hearth temperature at three locations,
5. Feed rate (volume and mass),
6. Fuel consumption,
7. Pressure change across the 1-micron blowdown water bag filter,
8. Negative pressure in the hearth and off-gas system.

In addition to the numerical data collected, the condition of the waste on the hearth was frequently observed to determine the progression of waste processing. The most notable observation was that the volume reduction caused by oxidation of the wood left virtually nothing on the hearth for the removal blade to scrape off. During the entire operation, no ash was removed from the hearth into the screw conveyor. All process residuals either stayed on the hearth or were transferred to the off-gas system.

By 1527, the goal of acquiring the data outlined in the scope of work (i.e., feed rate, hearth atmosphere off-gas, stack gas, operating temperatures & residence times data) had been acquired. It was determined that continuing to run the system without a backup ID fan and with HEPA filter bypass represented an unnecessary risk of a release for no apparent benefit. Therefore, the shutdown procedures for the system were initiated.

The system was allowed to cool until October 8 at which time ash samples from various parts of the hearth and off-gas system were collected and ash quantities from various components were estimated.

Ash was collected from the hearth, hearth walls, secondary combustion chamber and the quench tank. At the time the samples were collected, the quantity of ash was measured and estimates of the total quantity of ash were made. The ash on the hearth was concentrated primarily near the center of the hearth with smaller quantities distributed on the outer half. This material was coarse-grained. A much finer grained ash was coating the walls of the hearth and the refractory

lining of the ductwork. The secondary combustion chamber contained a light coating of ash on the lower half of the chamber. To estimate the quantity of ash in this chamber, a known surface area was swept with a whiskbroom and the ash from this area collected and its volume measured. The total volume of ash from the secondary combustion chamber was then estimated by extrapolating a similar coating for the entire floor of the chamber. The quantity contained in the quench tank was estimated by measuring the depth of accumulated ash in the bottom of the tank, calculating the volume from the known diameter of the tank and assuming a 40% volume loss upon drying. A summary of the quantities of ash estimated and the calculated volume reduction from the large-scale test is shown in Table 3.

Table 3. Estimated Volumes of Ash Collected from Large-Scale System

Material Measured	Estimated Volume	
Rotary Hearth	2.66 ft^3	(75,040 cm^3)
Hearth Walls	0.25 ft^3	(7,014 cm^3)
Duct Work	0.19 ft^3	(5,249 cm^3)
Secondary Combustion Chamber	0.11 ft^3	(3,030 cm^3)
Quench Tank	0.68 ft^3	(19,306 cm^3)
Totals	3.79 ft^3	(109,639 cm^3)

The total quantity of wood chips processed was 490 kg (1,080 lb.) that had a density of 10.38 lb/ft^3. Therefore using the estimates provided in Table 3, the total volume reduction that took place during the large-scale test is 96.35%. This estimate is within 1% of and consistent with the volume reduction measured in the intermediate-scale test.

4.3.1 Fuel Consumption

The system in Tacoma is not equipped with an in-line fuel-flow measurement system. Four 1000 gal. propane tanks supply the system each of which are equipped with a meter showing the quantity of propane in the tank. In order to determine the fuel usage for this test, the tank meters were monitored at strategic times during the test to evaluate fuel usage. The tank supplier has indicated that the meters are accurate within 5%.

The tank levels were recorded at three times during the test. These times included:

1. Before the system was energized at 1900 on Oct. 1,
2. When the feeding of wood chips was initiated at 0930 on Oct. 2,
3. When the system was shut down at 1745 on Oct. 2.

During the 14.5 hours during which the system was warming up, hourly fuel usage was 42.0 gal./hr. During the 8.25-hour period during which wood was being fed into the system, hourly usage was 40.7 gal/hr. This indicates that fuel consumption was reduced by only 3% due to BTU's added by wood. This small contribution by the wood is smaller than expected since this type of wood contains between 6,000 and 7,000 BTU's/lb. There are four reasons for the smaller than expected change in fuel consumption including:

1. After the feeding of wood was initiated it was noticed that carbon products on the hearth were converting to CO_2 and ash at a sluggish rate. To accelerate the reaction, more air

was allowed to enter the hearth. This system is not equipped to channel air directly onto the hearth so sight ports were used to introduce air. Sight ports are basically pipes equipped with air inlet valves and sight glasses so that observations can be made during processing. By removing the sight glasses, the pipe allows air to enter the hearth. This method of air introduction allowed much more air to be introduced than was necessary to accomplish accelerated reaction rates than if the air were channeled directly onto the waste by a system specifically designed to do this. While this resulted in satisfactory reaction rates, it also required more fuel to heat the large volume of relatively cold air that was entering the system.

2. During warm-up, heat losses are lower because of a lower temperature difference between the hearth and the outside atmosphere. Thus, fuel consumption is lower during warm-up than that at higher temperatures and may not accurately reflect the fuel required to maintain operating temperatures,
3. While the volumetric feed rate was consistent with the design capacity, the low feed-rate with respect to mass of wood resulted in lower than expected addition of BTUs to the system.
4. The design of the system in Tacoma is simply not an efficient design for the type of waste that was being processed.

By utilizing a system design that allows for higher throughput rates, more controlled introduction of air and by using a heat exchanger, the efficiency for a properly-designed production system is expected to be significantly better than that demonstrated during the test.

5.0 Sampling and Analytical Program

The sampling and analytical program for this project was designed to fully characterize the secondary products and off-gas produced by the process. These data were collected to determine how a production system would be designed and operated and to evaluate various options available for either recycling and/or disposal of process residuals.

The sampling and analytical work focused on the intermediate-scale test and the large-scale test. Following both of these tests, samples of ash from various parts of both systems were collected. The ash was evaluated for several parameters including physical and chemical characteristics. Off-gas samples were also collected to determine the off-gas system design criteria for a field production unit and to comply with local regulations.

A sampling nomenclature was developed to make identification of individual samples and what the samples represent easy to recognize. Samples collected from the Tacoma system are designated as “Ord” and samples collected from the Ohio system are designated as “Ord2”. Additional designations include: rotary hearth “RH”, afterburner “AB”, quench tank “QT”, blowdown water “BW” and bag house “BH”. Samples to which Portland cement was added had “PC” added to the sample number along with a number indicating the percent by weight of cement added. For instance, a sample of bag house ash from the intermediate-scale test to which 50% Portland cement was added is: Ord2-BH-PC-50. Sampling nomenclature for samples that were fluxed and sintered included nomenclature for the temperature and length of time sample was heated. For example, a rotary hearth ash from the intermediate-scale test that was fluxed and then sintered at 2,200º F for 10 min. would have a sample name of: Ord2-RH-2200-10.

5.1 Chemical Analysis

Selected ash samples from both tests were analyzed for total lead, whole rock analysis (bulk chemistry), sulfur, zinc, grain size distribution, Toxic Characteristic Leach Procedure (TCLP) and electron microprobe analysis. In addition, a sample of the blowdown water from the large-scale test was collected and analyzed for total lead, dissolved lead and total suspended solids. These analyses were performed to identify the regulatory classification and to fully characterize the byproducts from this process so that the potential for recycling the material can be evaluated. Table 4 summarizes total lead and TCLP analysis on ash and analysis of blowdown water from the large-scale test.

Table 4. Ash, Lead, TCLP and Blowdown Water Analysis from Large-Scale Test

Sample No.	Sample Type	Analytical Method	Analyte	Concentration	Units
Ord-RH-1	Ash	TOT-6010B*	Lead	35,600	ppm-dry
Ord-RH-2	Ash	TOT-6010B	Lead	42,600	ppm-dry
Ord-RH-3	Ash	TOT-6010B	Lead	37,800	ppm-dry
Ord-RH-4	Ash	TOT-6010B	Lead	35,900	ppm-dry
Ord-AB-1	Ash	TOT-6010B	Lead	41,600	ppm-dry
Ord-QT-1	Ash	TOT-6010B	Lead	58,000	ppm-dry
Ord-RH-3	Ash	TCLP-6010	Lead	<0.1	ppm
Ord-RH-4	Ash	TCLP-6010	Lead	0.2	ppm
Ord-AB-1	Ash	TCLP-6010	Lead	<0.1	ppm
Ord-QT-1	Ash	TCLP-6010	Lead	345	ppm
Ord-BW	Water	SW6010B	Lead	54.9	ppm
Ord-BW	Water	SW6010B	Dissolved Lead	0.85	ppm
Ord-BW	Water	EPA 160.2	Total Suspended Solids	250	ppm

* EPA test methods typically do not result in efficient extraction from silicates.

The data shown in Table 4 was generated by using analytical methods required by the EPA for characterization of hazardous materials/wastes. It is known that EPA method 6010 employs a digestion method that is not efficient at extracting metals from silicates (such as glass and rock). Thus, EPA test-methods to identify total metals concentration in silicates typically results in reported concentrations that are lower than actual concentrations. The processing conditions that prevail on the rotary hearth result in a high likelihood that some silicates were formed.

Therefore, additional analyses were performed to confirm the concentrations of lead in the ash. The type of analyses performed for bulk chemistry employ a more aggressive digestion technique and will result in accurate metal concentrations in silicates or other difficult to extract media. Table 5 shows the results of the bulk chemistry and lead analysis on ash samples from the large-scale test using the more aggressive digestion technique. These results show that the actual lead concentrations are about double that reported by EPA test methods.

Table 5. Normalized Bulk Chemistry & Lead Analysis from the Large-Scale Test

Oxide/Analyte	Ord-RH-3	Ord-RH-4	Ord-AB-1	Ord-QT-1
Al_2O_3	6.88	10.66	11.84	24.31

BaO	0.12	0.14	0.11	0.04
CaO	12.84	13.17	12.76	5.00
Cr_2O_3	0.08	0.06	0.39	0.03
Fe_2O_3	8.11	7.61	9.07	3.87
K2O	0.59	0.62	0.66	0.53
MgO	4.88	7.82	8.31	3.13
MnO	0.15	0.21	0.26	0.05
Na_2O	6.23	5.74	4.17	10.07
P_2O_5	0.33	0.48	0.77	0.39
SiO_2	28.59	32.12	32.40	38.23
SrO	0.00	0.00	0.01	0.01
TiO_2	12.51	6.84	3.47	1.71
LOI	1.05	1.23	2.84	3.83
Pb	12.79	8.75	9.74	7.66
Zn	4.84	4.55	3.18	1.14
SO_3	--	--	--	--
Total	100.00	100.00	100.00	100.00

Samples of ash from the hearth and bag house produced during the intermediate-scale test were collected and analyzed. Analyses included total lead, bulk chemistry and TCLP analyses. Samples of hearth and bag house ash were also mixed with Portland cement and water at a variety of concentrations to examine the influence that Portland cement would have on the leach rates for lead. Table 6 shows the total lead and TCLP results for the intermediate-scale test using EPA test methods.

Table 6. Total Lead and TCLP Results from the Intermediate-Scale Test Using EPA Tests

Sample No.	Analysis	Lead Concentration*	Units
Ord2-BH	TOT-6010B	24,700	ppm-dry
Ord2-BH	TOT-6010B	23,400	ppm-dry
Ord2-BH	TOT-6010B	25,400	ppm-dry
Ord2-BH-PC-5	TOT-6010B	61,100	ppm-dry
Ord2-BH-PC-10	TOT-6010B	54,700	ppm-dry
Ord2-BH-PC-20	TOT-6010B	60,400	ppm-dry
Ord2-BH-PC-50	TOT-6010B	61,000	ppm-dry
Ord2-BH-PC-100	TOT-6010B	53,100	ppm-dry
Ord2-RH	TOT-6010B	30,300	ppm-dry
Ord2-RH-PC-5	TOT-6010B	39,300	ppm-dry
Ord2-RH-PC-10	TOT-6010B	39,800	ppm-dry
Ord2-RH-PC-20	TOT-6010B	46,400	ppm-dry
Ord2-RH-PC-50	TOT-6010B	36,900	ppm-dry
Ord2-RH-PC-100	TOT-6010B	33,900	ppm-dry
Ord2-BH	TCLP-6010	320	ppm
Ord2-BH	TCLP-6010	473	ppm

Ord2-BH	TCLP-6010	310	ppm
Ord2-BH-PC-5	TCLP-6010	764	ppm
Ord2-BH-PC-10	TCLP-6010	723	ppm
Ord2-BH-PC-20	TCLP-6010	248	ppm
Ord2-BH-PC-50	TCLP-6010	80.0	ppm
Ord2-BH-PC-100	TCLP-6010	28.5	ppm
Ord2-RH	TCLP-6010	49.2	ppm
Ord2-RH-PC-5	TCLP-6010	1.9	ppm
Ord2-RH-PC-10	TCLP-6010	1.2	ppm
Ord2-RH-PC-20	TCLP-6010	0.2	ppm
Ord2-RH-PC-50	TCLP-6010	2.2	ppm
Ord2-RH-PC-100	TCLP-6010	0.3	ppm

*Total Lead concentrations shown here are low by as much as a factor of 10 due to inefficiency of EPA extraction methods on this media.

The data in Table 6 shows first that total lead concentrations are not accurate. The most obvious indication of this is that total lead concentrations are basically unchanged compared to the samples to which Portland cement was added. Even though there is a known level of dilution from the addition of cement, this dilution is not reflected in the lead concentration. Consistent with the data in Table 4, the total lead concentrations obtained by using EPA test methods on the ash generated from this test should be ignored.

The TCLP results are interesting. All of the rotary hearth ash samples surpassed TCLP requirements of 5.0 ppm by up to a factor of 10. There is a general trend of improvement from the addition of cement to the hearth ash. The bag house ash failed the TCLP test by a significant margin. The data suggests that the addition of small quantities of Portland cement actually increases the rate of lead leaching by about a factor of 2. The addition of higher concentrations of Portland cement reduces leach rates by a considerable margin. The improvement in leach performance is more than that expected from dilution so the cement does accomplish some immobilization of the lead. The addition of 100% Portland cement by weight was not sufficient to make this material pass the test. The trend in improvement in leach performance resulting from the addition of cement suggests that perhaps 200% cement by weight would result in successful leach performance.

The bulk chemistry and total lead results produced by ALS Chemex on the ash from the intermediate-scale test are presented in Table 7. The results in Table 7 show that most of the Al, Ca, Mg, Si & Ti tended to stay on the hearth while most of the Fe and Na tended to be released into the bag house. Lead concentrations are about the same for the hearth and bag house. The large loss on ignition (LOI) for the bag house dust can be attributed in part to the presence of chloride compounds. Chlorides were identified by elemental dispersive spectroscopy (EDS) using the electron microprobe and were later added to the analytical protocol for ALS to quantify. Natural wood is not known for having more than negligible concentrations of chlorine and it is unlikely that the paint used had chlorine in it either. The source of the chlorine can only be speculated but it is likely that its source is from the ocean. Ft. Ord is located near the ocean

and it is likely that over the years salt spray carried on the wind permeated the structures and caused a gradual increase in the concentration of salt in the wood siding and paint.

Table 7. Bulk Chemistry and Lead Analysis on Ash from the Intermediate-Scale Test

Oxide/Analyte	Ord2-RH (wt%)	Ord2-BH (wt%)
Al_2O_3	3.84	0.40
BaO	0.06	0.00
CaO	12.57	0.64
Cr_2O_3	0.03	0.00
Fe_2O_3	7.05	29.12
K2O	0.18	0.55
MgO	2.13	0.07
MnO	0.22	0.00
Na_2O	3.96	6.93
P_2O_5	0.21	0.04
SiO_2	10.57	0.73
SrO	0.00	0.00
TiO_2	21.13	0.20
LOI	0.41	24.37
Pb	26.63	21.21
ZnO	10.36	14.94
$S0_3$	0.65	0.78
Total	100.00	100.00

5.2 Electron Microprobe Analysis

Ash samples from the rotary hearth and bag house were sintered and analyzed with an electron microprobe. Samples of these materials were immersed in epoxy and allowed to cure. Once cured, the epoxy plugs containing particles of ash were polished with diamond paste and mounted on slides. The slides were then examined with a JOEL 733 Superprobe electron microprobe located at the University of Washington Department of Geological Sciences. The purpose of performing microprobe analysis was to identify elements in the ash for which analysis was not performed in the whole rock analysis and to determine if any elements were present for which analysis was not performed in the laboratory analyses.

Differences in shades of gray in the electron photomicrographs correspond to differences in density of the features observed. Lighter shades are denser than darker shades. Differences in density can be attributed to differences in chemistry and/or crystallization differences. These differences were examined in part by acquiring EDS spectra of back-scattered electrons. These spectra reveal the elements that are present in the target area of the sample and semi-quantitatively identify the relative concentration of the elements from the height of the spectral peak.

In addition to EDS, wavelength dispersive spectroscopy (WDS) analysis was performed on selected targets in the sample. WDS provides better detection limits than EDS and better

resolution of the emission peaks. EDS resolution is about 180 eV (corresponding to about 0.2 wt% of the element) and WDS resolution is about 6 eV.

Figure 8 is an electron photomicrograph of a hearth ash particle from the intermediate-scale test. During the course of microprobe examination, many particles were examined and scanned. EDS spectra were acquired to compare the general compositions of the different ash particles and to assess inter-particle and intra-particle compositional differences.

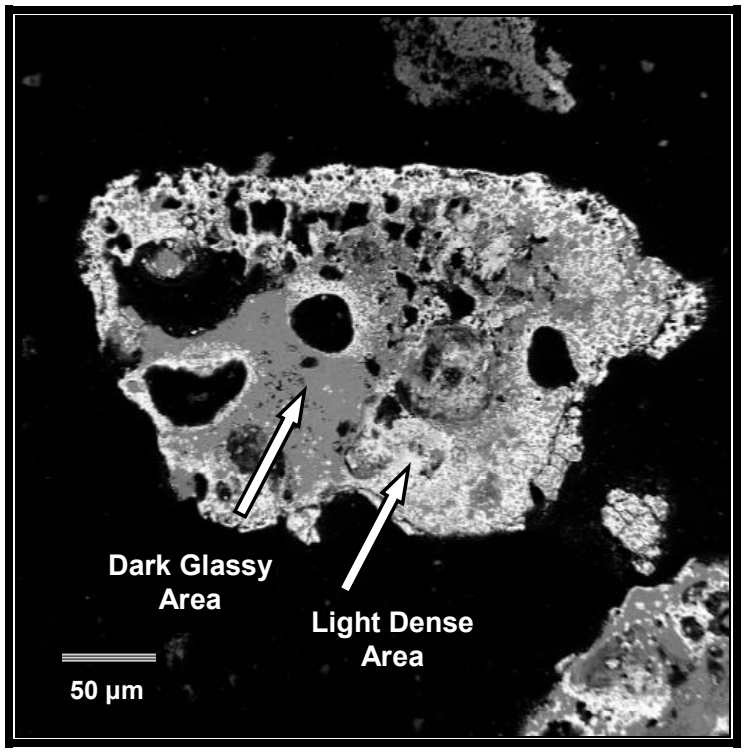

Figure 8. Electron Photomicrograph of Rotary Hearth Ash from the Intermediate-Scale Test Showing Light and Dark Areas of Differing Composition

The hearth ash is porous and exhibits features consistent with the release of volatiles during processing. The ash consists primarily of two phases. These can be seen in Figure 8 as light-colored areas and dark-colored areas. WDS was performed on representative portions of the light and dark areas to determine compositional differences. Table 8 shows the compositions acquired from these areas.

Table 8. Normalized WDS Analysis of Light and Dark Areas

Oxide*	Dark Area (wt%)	Light Area (wt%)
Al_2O_3	2.08	0.37
CaO	2.11	6.29
Fe_2O_3	3.14	0.57
MgO	3.26	0.15
Na_2O	0.82	0.29
SiO_2	6.07	0.66

TiO_2	50.28	33.92
PbO	8.34	54.97
ZnO	23.91	2.79
$S0_3$	0.00	0.00
Totals	100.00	100.00

* Oxides known to comprise a minor portion of the sample (e.g., BaO) were not analyzed because of the time required for instrument calibration for multiple elements. Results are normalized to 100%.

The data in Table 8 shows that the dark glassy phase in the hearth ash consists primarily of titanium dioxide and zinc oxide while the light-colored area contains most of the lead. While it is likely that the dark area is actually a glass, there does not appear to be enough glass-forming ions present in the light-colored area to form a glass. Thus, the light-colored areas most likely consist of a non-glassy but amorphous accumulation of the oxides.

Figure 9 is an electron photomicrograph of a bag-house ash particle. As with the rotary hearth ash, many particles were examined and the particle in Figure 9 is comprised of the two predominant phases found during the examination of the bag-house dust. The dark (left) side of the particle actually consists of two sub-phases. Of these two sub-phases, the darkest material is predominantly iron oxide and the intimately associated slightly lighter phase contains small quantities of other oxides including zinc, calcium, potassium, chlorine and perhaps sulfur (sulfur and lead peaks overlap and can be difficult to distinguish). The light-colored phase (right side) consists primarily of lead, zinc and chlorine. At least a portion of the lead and zinc are probably in the form of chlorides. As mentioned above, the presence of chlorine in the sample was unexpected. The source is suspected to be long-term exposure to atmospheric salt due to proximity to the ocean.

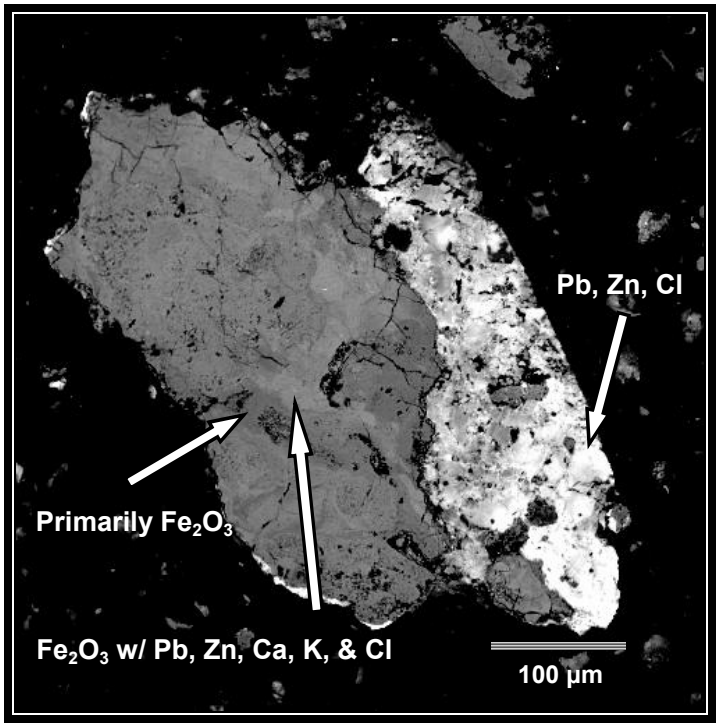

Figure 9. Particle of Bag House Ash Showing the Two Predominant Phases in this Material

5.3 Fluxed and Sintered Samples

One of the goals of the test program was to determine if there was a benefit to fluxing the byproducts of the test program and sintering them (the anticipated benefit being an improvement in lead leach performance). To evaluate the potential benefit, samples of the hearth ash and bag house ash from the intermediate-scale test were selected for evaluation. These samples were selected because it was anticipated that they would have the highest lead concentrations and thus the highest probability of failing the TCLP test. The samples were saturated with a 10% solution of sodium borate and then heated in the tube furnace at a variety of temperatures for 10 minutes. The hearth ash was heated at temperatures of 2050, 2100, 2150, and 2200ºF and the bag house dust was heated at 2000. Two of the fluxed, heated samples were then subjected to TCLP analysis to see how leach performance was affected. Table 9 shows the results of this analysis.

Table 9. TCLP Results for Fluxed & Sintered Samples

Sample Number	EPA Method (Preparation/Analysis)	TCLP Result (ppm)
Ord2-RH-2200-10	1311/6010B	167
Ord2-BH-1800-10	1311/6010B	331

The data in Table 9 clearly shows that fluxing and sintering the ash in its current state results in an increase in the lead leach rates for the hearth ash and has little or no effect on the bag house leach rates (compare with TCLP results in Table 6 for Samples Ord2-RH and Ord2-BH). The reason for the unexpected results is that there are not enough glass-forming oxides in the ash to accommodate the lead. So instead of the lead bonding in a silicate matrix (which would result in reduced leach rates) it is present in the oxide, chloride or carbonate form and thus susceptible to release. If fluxing and sintering were a preferred method for stabilizing the lead in this ash, additional glass-forming agents (preferably SiO2) would need to be added to result in successful stabilization. Based upon previous experience, the composition of the ash would need to be modified to contain approximately 40% SiO_2 prior to sintering to assure successful immobilization of the lead. While this is certainly an option for the bag house ash, it does not appear to be necessary for the hearth ash. Appendix A presents data and quality assurance documentation as presented from the laboratories.

5.4 Off-Gas Sampling and Analysis

Off-gas from the intermediate and large-scale tests was sampled and analyzed. Both tests involved different sampling strategies but were focused primarily on particle size analysis and lead concentration in the particulate.

For the Large-scale test, particulate stack-gas testing was performed in accordance with requirements by the Puget Sound Air Quality Agency. The data collected from the stack (down stream of the off-gas treatment system) does not provide useful data for evaluating the proper type of off-gas system for this waste. Therefore, a test port was prepared downstream of the rotary hearth to collect particulate emissions that exit the hearth. One sample period of stack gas

emission and two sample periods of hearth outlet gas emission were conducted during the test. A summary of the data from this evaluation is summarized in Table 10.

Table 10. Lead Emission Results for the Large-Scale Test

Data Type	Hearth Exit	Process Stack
Start Time	1319/1449	0952
Stop Time	1339/1528	1622
Sample Length (min)	60	390
Volume Sampled (dscm)	1.628	7548
Gas Airflow (dscf/min)	2472.9	1985.6
Lead Emission Results		
Method Detection Limit (ppb)	0.01	0.01
Sample Volume (ml)	730	1120
Sample Detection Limit (µg)	7.3	11.2
Total Lead (µg)	91000	140000
Total Lead Emission Concentration (mg/dscm)	55.9	18.5
Total Lead Emission Rate (bl/hr)	0.518	0.138
Lead Removal Efficiency		73.4

The results shown in Table 10 indicate that 4.27 lb. (1.94 kg) of lead left the hearth and entered the off-gas treatment system. Of this quantity, 1.14 lb. (0.517) of lead would have escaped the stack indicating that the lead removal efficiency for the quench and scrubber was 73.4%. This level of lead release is not acceptable for production processing. The clogging and subsequent bypassing of the HEPA filters is responsible for the higher-than-expected release rates. Allowable release rates vary depending upon geographic regions and different associated regulations but typically are restricted to 0.1 lb/hr although there are some allowances as high as 0.5 lb/hr for major industrial facilities (Ref. A). The federal standard for secondary lead smelters is 2.0 mg/dscm (dry standard cubic meter) (Ref. B). In California, allowable release rates tend to be lower than federal standards but vary based upon location and proximity to areas of high population. For instance, the Bay Area Air Quality Management District has imposed a lead release limit of 0.10 mg/dscm for a medical waste incinerator located in Oakland (Ref. C). They have also set a maximum release rate for any facility of 3.2 lb/day of lead with an average annual maximum release of 0.6 tons/year. Facilities that can demonstrate 0.1 µg/dscm are considered exempt (Ref. D).

The particle size analysis for the large-scale test was conducted using an Elzone computerized particle size analyzer. This type of analysis produces population or frequency data and mass data for the particulate matter collected with an effective working range of 0.5 to 400 microns. The population data compares the number of particles to the size of the particles (or the number of particles in each size range). The mass data shows the mass of particles represented by particle size ranges. The histogram for the frequency data shows that there are likely a large number of particles smaller than 0.5 microns. However, the histogram of the mass data shows that the

particles smaller than 0.705 microns represent 0.1% of the total mass of particles in the population. The histograms for frequency and mass data are shown in Figures 10 A and B respectively.

By using only a HEPA filter capable of filtering particles 0.705 microns with the emissions from the hearth outlet, a removal efficiency of 99.9% would be attained. This would result in lead release rates of 0.0005 lb/hr (0.012 lb/day), or about 0.196 mg/dscm, which is not exempt but is in an acceptable range. Supplemental emission controls such as agglomeration prior to filtration would result in additional improvements in emission rates if such improvements were necessary. Thus, operation of the large-scale system while controlling lead emissions within reasonably expected regulatory limits does not appear to represent a significant technical challenge.

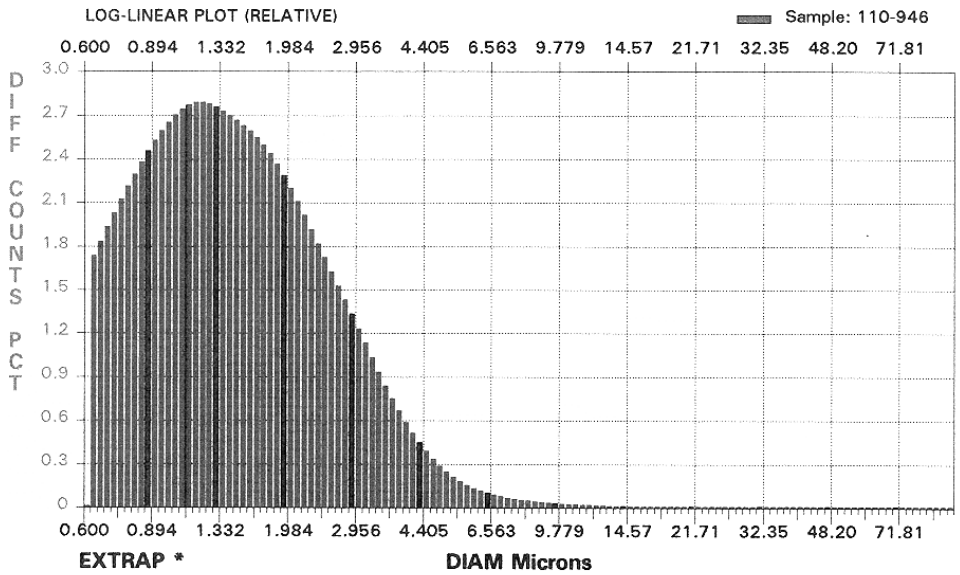

Figure 10A. Histogram of Particle Frequency Data from Large-Scale Test

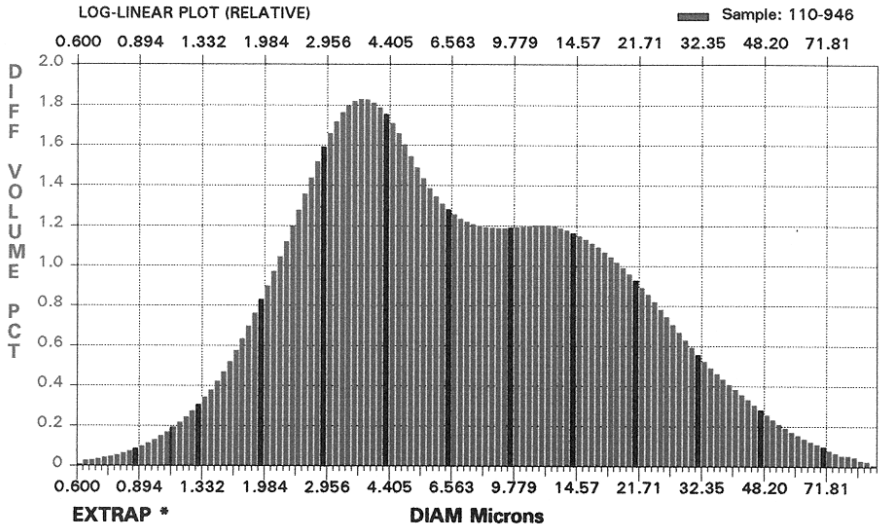

Figure 10B. Histogram Showing Particle Mass Distribution from Large-Scale Test

Emission testing was performed during the intermediate-scale test immediately downstream of the rotary hearth. EPA Methods 1, 2, 3A, 4 and 17 were used to measure or otherwise obtain gas temperature, velocity, molecular weight, moisture and quantity of filterable particulate materials. The particle size distribution was determined using University of Washington Pollution Control Systems (UW-PCS) Mark 5 cascade impactors. A summary of the particle size distribution for the ash released from the rotary hear appears in Figure 11.

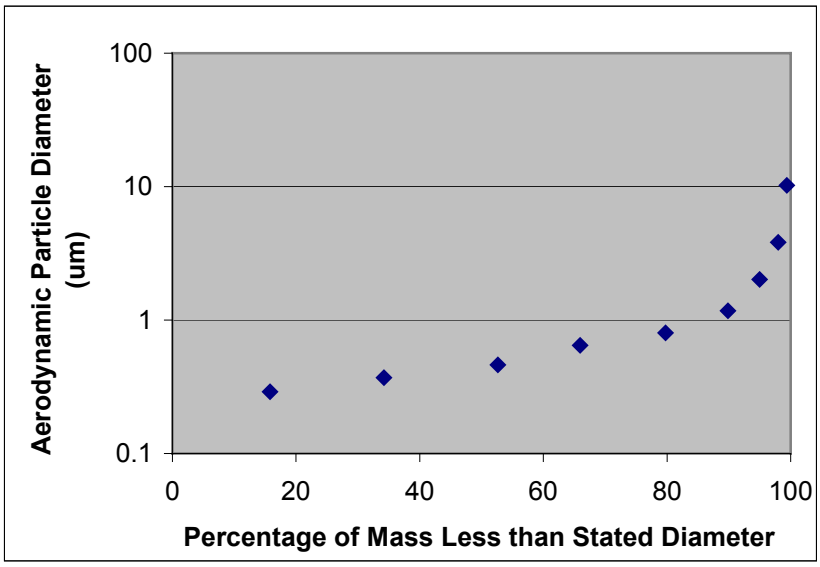

Figure 11. Particle Size Distribution for Intermediate Scale Test

The data in Figure 11 shows that most of the particulate matter escaped the hearth exhibited an aerodynamic diameter greater than 1 micron. The particles collected in the off-gas from the intermediate-scale test are significantly smaller than those collected during the large-scale test because of the lower off-gas velocity and the lower level of turbulence in the hearth. Consequently, the relative quantity of particles released from the hearth is also correspondingly smaller. The less energetic processing conditions prevalent during the intermediate-scale test are considered more representative of the conditions that would be typical of field processing. Thus, the particle size distribution is also considered more representative of field conditions.

6.0 COST ASSESSMENT

The cost of the system is broken into two parts including the estimated capital cost and the project operating costs. The estimated capital cost includes engineering, design, fabrication, functional testing and delivery. It does not include testing to demonstrate compliance with regulatory standards. For the operational costs, assumptions have been made with respect to energy costs, labor costs, and system utilization and processing rate. Operational costs include burdened labor rates and reasonable overhead costs but do not include profit, permitting costs,

analytical costs, mobilization and/or other fees that have not been foreseen. Table 11 summarizes the basis upon which operational costs have been estimated and presents the estimated capital cost as well.

Significant portions of the operational costs shown in Table 11 are "fixed". In other words, this portion of the cost of operation does not change with a moderate increase or decrease in processing scale. The Army has expressed an interest in the difference in capital and operational cost between the system depicted in Table 11 and a system with a lower throughput capacity because the system described may be larger than necessary for the anticipated workload.

Table 11. Summary of Operational Cost Estimate, 1.5 ton/hour System

Item/Task	**Description/Assumption**
Labor	Assumes 24-hr/day operations with crew of 3 per shift and Project Manager.
Production	Assumes 7500 operation hours/year processing 8450 tons/year of waste
Fuel	Assumes $4.00/MMBTU with 28,848 MMBTU/year
Overtime	Assumes 10%
Annual Operational Cost	$987,000/year
Estimated Per Ton Operating Cost	$117.00/ton
Estimated Capital Cost for System	$1,950,000

A detailed engineering and cost analysis of a smaller system is outside the scope of this project but reasonable estimates can be made based upon the estimates provided for the larger system above. An estimate was performed for a system with half the capacity of the system above (i.e., 0.75 ton/hr). Using the same assumptions stated above, the capital cost for a system with this capacity would be approximately $1,350,000 and processing costs would be approximately $175/ton.

The cost for land disposal of the chipped wood siding as exempt household hazardous waste (X008 waste designation) at Waste Management's disposal facility in Arlington, Oregon is $88/yd^3 plus transportation. Considering the low density of the waste, one ton of waste occupies a volume of 7 yd^3. Thus, the cost for disposal of this material as an exempt waste is about $625/ton. If the waste is generated from a non-residential source, the cost for stabilization (stabilization is required since the wood waste fails TCLP criteria) and disposal at the same facility was quoted at $150/yd^3. Therefore, it appears that the cost of processing this material thermally is significantly less expensive (perhaps 1/3 to 1/5) than land disposal with the added benefit of recycling the lead.

7.0 PERFORMANCE ASSESSMENT

Three thermal treatment tests were conducted on wood siding from Ft. Ord contaminated with LBP. The tests included a small-scale test conducted with a tube furnace, an intermediate-scale test conducted with a small rotary hearth and a large-scale test conducted using a large rotary hearth. The purpose of these tests was to determine:

1. The throughput capacity attainable using the proposed system for the subject waste,
2. The actual volume and mass loss resulting from treatment,
3. The chemistry of the treated waste and determination if the product can be recycled,
4. Regulatory classification of the treated product,
5. Off-gas composition and processing parameters necessary to operate within air discharge restrictions,
6. Wastewater characteristics and treatment/discharge requirements,
7. Projected operational economics for deployment of the technology for a large project,
8. Distribution of ash throughout the system,
9. Fuel consumption/energy requirements.

7.1 Throughput Capacity

The maximum throughput capacity attainable for a system that is easily transportable using the process design proposed is 3,000 lb/hr. This throughput capacity is probably in excess of what actually may be required but it represents the highest rate attainable while maintaining a system that is easily transportable and mobilized. A smaller transportable unit can be designed and built. A smaller unit would cost less to build but have higher per-ton processing rates.

7.2 Volume and Mass Loss

The volume losses that were measured from the intermediate-scale test and calculated from the large-scale test were between 96.35% and 96.97% for un-compacted ash. Further reductions can be realized by compacting the ash, especially the bag house ash.

7.3 Chemistry and Recyclability of the Ash

The ash produced consisted of two predominant phases best characterized by the hearth ash and bag house ash. Concentrations of metals were much higher in ash produced from the paint shavings than the ash produced from processing whole boards. Paint shavings ash contained about 25% lead represented as oxide with high concentrations (>10%) of iron, zinc, & titanium. The ash from whole boards contained higher concentrations of silicon, calcium and aluminum and lower concentrations of other metals and about 8% lead oxide. A subcontractor examined the data and ash samples from this project. They expressed a willingness to receive the ash and process it to recover the contained lead. They did not foresee any difficulties in processing this material. Due to the low value of lead (about $0.19/lb.), a processing fee of 250/ton was required. The ash only represents 10% of the weight of the material processed so this recycling fee equates to an increase in the cost of processing by about $25 per U.S. ton. It is important to note that other organizations are likely to be identified who can also recycle the ash and who may require a smaller processing fee.

7.4 Regulatory Classification of Ash

By finding a facility that is willing to take the ash and recover the lead, it can be legitimately re-processed as a "recyclable material" to recover the contained lead and perhaps the zinc. There are special rules that apply to residues or ash resulting from thermal treatment of "hazardous waste" under 40 CFR Part 266.112. While the wood from Ft. Ord is considered a Dangerous Waste in Washington, from a Federal perspective, it is not hazardous if the wood comes from a residential structure. Thus, regulations may vary from state to state but from a federal perspective the demonstrated process can be considered a legitimate recycling operation. Individual state regulations would need to be reviewed but typically, if a hazardous material can be legitimately recycled, the less stringent regulations simplify the process.

7.5 Off-gas composition and System Processing Parameters

Off-gas sampling results showed that the wet scrubber without HEPA filtration provided 73.4% removal efficiency and the lead emission rate was 0.138 lb/hr. This release rate is probably not low enough for production processing. But the data collected provided the information required to design a system that would meet air discharge standards. A detailed analysis of the off-gas particulates shows that a combination of bag house and HEPA filtration in a dry off-gas system will be capable of meeting or exceeding federal off-gas emission requirements and most likely most state requirements including California.

7.6 Wastewater Characteristics and Treatment/Discharge Requirements

Blowdown water from the large-scale test exhibited 0.85 ppm of dissolved lead and 250 ppm total suspended solids. The intermediate-scale test utilized a dry off-gas system so there was no process water. The proposed system will also utilize a dry off-gas system with only a partial water quench so process wastewater will not be generated. Therefore, wastewater discharge requirements are not a consideration.

7.7 Operational Economics for Deployment of the Technology for a Large Project

The operational economics of the proposed system were evaluated. These evaluations indicate that the cost of a new transportable system specifically designed to process the wood waste to produce an ash that can be recycled would fall between \$1.3 and \$2.0 million depending upon the size of the system. Processing costs would be in the range of \$100 to \$200 per ton depending upon the scale of processing. This cost is significantly less (1/3 to 1/5) the cost of land disposal of this material as an exempt household hazardous waste (X008 waste designation) at Waste Management's disposal facility in Arlington, Oregon (Waste Management quoted \$88/yd^3 or \$625/ton). The cost for stabilization and land disposal of this material at RCRA hazardous waste is far greater at \$150/yd^3 or \$1,050/ton. Thus, the process appears to be highly economical when compared to the cost of land disposal.

7.8 Distribution of Ash

It is clear from the results of the intermediate-scale test that the ash is segregated into two major phases including coarse ash that remained on the hearth and finer-grained bag house ash that became airborne and was captured by the bag house. The bag house ash represents about 7% of the total mass of ash and the hearth ash comprises the remainder of the ash. Both ashes contain about the same concentration of lead. The concentrations of other metals differ between the two

types of ash. The bag house ash contains small quantities of chlorine presumably due to exposure to salt air near the ocean over a period of decades.

7.9 Fuel Consumption/Energy Requirements

The fuel consumption for the large-scale test is not representative of actual fuel consumption rates for a system specifically designed to process wood waste. Because oxidation of wood is an exothermic reaction most of the fuel consumption is for warming up the system. Very small quantities of fuel would be consumed with a properly designed operating system. Fuel consumption for the proposed system is estimated to be 15 lb. of kerosene per ton of wood waste.

8.0 CONCLUSION

Thermochemical conversion technology was demonstrated through full-scale processing on asbestos and PCBs during testing programs at the Puget Sound Naval Shipyard (PSNS) and at the Department of Energy Hanford Reservation. Due to the successful results from these programs, the US EPA determined that this technology is an alternative method for asbestos disposal under 40 CFR 61 Subpart M, Section 152. In addition, the EPA office of Toxic Substances issued a TSCA National Operating Permit for mobile treatment of PCBs in November 2000. The inherent difficulty of destroying PCBs and the stringent destruction and removal efficiency (DRE) requirements that are required demonstrate that thermochemical conversion is capable of addressing waste contaminated with a wide range of organic compounds. The technology is also capable of immobilizing certain metals and surrogate radionuclides including lead.

9.0 KEY PERSONNEL

The principal investigator who conducted this study is a Registered Professional Geologist, has B.S. and M.S. degrees in Geology, and over 19 years experience in the environmental remediation field, most involving thermal treatment of waste. He has conducted treatability tests and managed the cleanup of hazardous and radioactive sites throughout the U.S. and in Australia using thermal treatment. He has extensive experience in conducting treatability tests using thermal technology on a wide variety of wastes contaminated with metals and radionuclides including lead.

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