PHASE II REPORT
May 1994

ASH QUANTIFICATION AND CHARACTERIZATION STUDY

CALIFORNIA INTEGRATED WASTE MANAGEMENT BOARD

R·W·BECK

ACKNOWLEDGEMENT

This report is based upon work performed pursuant to a contract with the California Integrated Waste Management Board. The contract number and dollar amount are as follows:

IWM-C081; $321,940

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DISCLAIMER

NOTE: Legislation (SB 63, Strickland, Chapter 21, Statutes of 2009) signed into law by Gov. Arnold Schwarzenegger eliminated the California Integrated Waste Management Board (CIWMB) and its six-member governing board effective Dec. 31, 2009.

CIWMB programs and oversight responsibilities were retained and reorganized effective Jan. 1, 2010, and merged with the beverage container recycling program previously managed by the California Department of Conservation.

The new entity is known as the Department of Resources Recycling and Recovery (CalRecycle).

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PHASE II REPORT ASH QUANTIFICATION AND CHARACTERIZATION STUDY

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ASH QUANTIFICATION AND CHARACTERIZATION STUDY

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Ash Quantification and Characterization Study — Phase II

1.0 INTRODUCTION

The State of California has a large urban and agricultural sector and, as a result, significant amounts of municipal solid waste (MSW), medical wastes, agricultural wastes, and municipal sewage sludge are generated. Some of these waste streams, such as agricultural waste and wood waste, are utilized as a fuel in boilers to generate steam or electricity. Other lower calorific value waste streams, such as sewage sludges, are incinerated for purposes of volume reduction prior to landfilling.

The California Integrated Waste Management Board (CIWMB) is interested in determining:

A. A list of operational waste fuel combustion facilities in the State and;

B. The characteristics of the incinerated residue ash.

Based on the characterization of the ash stream, CIWMB's ultimate goal is to determine uses for the ash product. Recycling of the ash stream may result in significant savings of valuable landfill space. Finding ways to use ash will help to reduce reliance on landfill disposal and may help to increase the use of waste-to-energy technologies.

Phase I of the Study (submitted under a different cover) provided a database of operational municipal solid waste (MSW), medical waste, and biomass (agricultural wastes, wood wastes, sludge, and others) combustion facilities in California. The database listed facility information such as location, combustion technology, fuel types, fuel volumes, ash generation and other pertinent information. It was concluded that the 76 California facilities reviewed used almost 28,000 tons of fuel per day and generated almost 2,200 tons of ash per day.

Working with the data provided in Phase I, the CIWMB staff provided a list of facilities to be sampled.

This document presents Phase II of the Ash Quantification and Characterization Study (the Study) prepared for the California Integrated Waste Management Board (CIWMB) by R.W. Beck and Associates (the Consultant). The purpose of the Study was to characterize the ash generated at several facilities. The information is intended to be used by the California Department of Transportation for assessing the adequacy of ash materials for road construction applications and by the CIWMB for exploring markets and uses for these materials. In addition, information can be used by interested parties to assess the beneficial use of ash for agricultural applications. These uses as well as landfill cover are the focus of the testing and analysis performed in this study.

This report includes the procedures used to sample, test, and analyze the ash streams of three MSW, two medical waste, and ten biomass combustion facilities in California.

2.0 STUDY OVERVIEW

The information presented in this Phase II report includes discussions of ash test results from MSW, medical waste, and biomass combustion facilities; potential useful applications for ashes; and recommendations for use and or ways to improve the usefulness of the material. Facility reports containing sampling procedures and test results from individual facilities participating in this study are provided in the appendices.

The Consultant supplied a methodology outlining the procedures used to sample the residues from the different facility types. Although a methodology was developed for each facility type, many atypical operational characteristics made it necessary to adjust the methodology at many individual facilities. The methodologies used are provided in the appendices. In general, the approach was to take representative samples by taking six samples at different times during the course of a day and make a composite of the first three and second three samples taken. The sample size was dictated by the testing requirements. Recognizing that a larger number of samples can yield more accurate results, for the purposes of this study, it was decided that sampling from many facilities using a composite sample methodology would be of greater utility than characterizing one facility's ash more thoroughly.

After sampling, three categories of tests were performed: material, analytical, and agricultural.

2.1 MATERIAL TESTS

Material tests were performed for MSW, biomass, and medical waste ash. The samples were prepared and tested by the laboratory using California Test Methods. Table 1 shows specifications for a variety of transportation related applications for ash ranging from low-end uses, such as subbase material, to more demanding applications including asphalt and concrete aggregate. For material to be considered suitable for a particular application, it must meet or exceed the corresponding CalTrans specifications for that application. However, the specifications given are only for the those tests performed in this study. Additional requirements may need to be met for a particular application. For example, Portland cement concrete aggregate requires further testing before it can be approved by CalTrans for this use.

All of the CalTrans applications require an aggregate which is free of organics and inorganic contaminants. No ash sampled in this study meets this requirement. It should be noted that an exact specification for amount of organics or inorganic contaminants is not given by CalTrans.

TABLE 1
CAL TRANS SPECIFICATIONS FOR VARIOUS APPLICATIONS

Material	Residue Sample	SPECIFICATION REQUIREMENT FOR CALIFORNIA D.O.T. TEST									
		CT 211 500r Maximum	CT 213	CT 217 Minimum	CT 229 Minimum	CT 301 Minimum	CT 303 Kc Maximum	CT 303 Kf Maximum	CT 312 Minimum	CT 515 Minimum	CT 548 Minimum
Aggregate Subbase, Class 3				18		40					
Aggregate Base				22	35	78					
Asphalt Treated Permeable Base		45%									
Asphalt Concrete and Ashphalt Concrete Base Aggregate, Type 3		50%		42			1.7	1.7			
Lean Concrete Base Aggregate				18							700 psi
Cement Treated Base Aggregate, Class A				18					750 psi		
Portland Cement Concrete Aggregate – Course		45%			60						
Portland Cement Concrete Aggregate – Fine			Satisfactory	71	60					95%	
Slurry Seal Aggregate				45	55						
Bituminous Seal Aggregate		40%									

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The following battery of tests were to be performed:

California Department of Transportation Standard Test Methods

CT 201	Method of Soil and Aggregate Sample Preparation
CT 202	Method of Tests for Sieve Analysis of Fine and Coarse Aggregates — This test determines the relative particle distribution for the ash. Results are reported by a graph which shows the percent of the material which passes through different sized screens.
CT 206	Method of Test for Specific Gravity and Absorption of Coarse Aggregate — This test measures the bulk specific gravity and absorption of moisture or water of the larger sized aggregate material in the ash.
CT 207	Method of Test for Specific Gravity and Absorption of Fine Aggregate— This test measures the bulk specific gravity and absorption of moisture or water of the smaller sized aggregate material in the ash.
CT 208	Method of Test for Apparent Specific Gravity of Fine Aggregates — This test measures the apparent specific density of the fine aggregates proposed for use in bituminous (asphalt) mixes, cement treated bases (for road support), and aggregate bases. The difference between this test and CT 207 is that this test does not account for the porosity of the aggregate, and therefore yields a lower value for fine aggregates.
CT 211	Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Rattler Machine — This test determines the amount of material which is lost due to attrition in a rotating chamber, and is an indication of the durability of the material for various applications.

CT 212	Method of Test for Unit Weight of Aggregate — This test measures the weight of aggregate in a cubic foot container.
CT 213	Method of Test for Organic Impurities in Concrete Sand — This test determines the amount of organic impurities in the sand portion of the ash.
CT 217	Method of Test for Sand Equivalent — This test indicates the amount of sand versus clay and silt in the ash. The greater the number, the more sand and less clay there is.
CT 226	Method of Determination of Moisture Content by Oven Drying — This test determines the percent moisture in the ash as received by the laboratory.
CT 229	Method of Test for Durability Index — This test measures the relative resistance of the ash in producing clay sized particles. The test generates forces between the ash particles in the presence of water to simulate wear and tear on the aggregate. A higher number indicates more durability.
CT 301	Method of Test for Determination of the Resistance "R" Value of Treated and Untreated Bases, Subbases, and Basement Soils by the Stabilimeter — The R value is an indicator of how stable a base or subbase material will be. The higher the value, the better the stability.

CT 303 Standard Method of Test for Centrifuge Kerosene Equivalent and Approximate Bitumen Ratio (ABR) — The K number for fines and coarse aggregate are determined and, in turn, used to calculate the approximate bitumen ratio which gives the asphalt needed for asphalt road applications. The lower the K_c and K_f number, the better for asphalt uses.

CT 312 Design and Testing of Classes "A and B" Cement Treated Bases — This method yields the appropriate cement and moisture contents to be combined with available aggregates for cement treated bases.

CT 515 Method of Test for Relative Mortar Strength of Portland Cement Concrete Sand — This test indirectly measures the concrete-making properties of the sand portion of the ash.

CT 548 Method of Test for Evaluation of Aggregate for Lean Concrete Base (LCB) — This test serves to determine the strength producing properties of the aggregate for this application, and the amount of cement needed for adequate compressive strength.

ASTM C-289 Standard Test Method for Potential Reactivity of Aggregate (chemical method) — This test gives an indication of whether the ash may react with cement over time and cause a network of fine cracks in the surface.

2.2 ANALYTICAL TESTS

Analytical tests were performed only for biomass and medical waste ash. The samples were prepared and processed by the laboratory and tested with the following battery:

> Waste Extraction Test, STLC, and TTLC for Inorganic Persistent and Bio-accumulative Substances only. See California Code of Regulations, Title 22, Division 4.5, Environmental Health Standards for the Management of Hazardous Wastes, Article 11, Chapter 5.
>
> Toxicity Characteristic Leaching Procedure, Method 1311 for eight heavy metals only (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver). Test Methods for Evaluating Solid Waste (Physical/Chemical Methods), SW 846. See Federal Register, Vol. 55, No. 126, P 26986, Friday, June 29, 1990.
>
> American Society of Testing and Materials (ASTM):

- Total calcium,
- Total sodium,
- Total potassium,
- Total chlorine,
- Total sulfur,
- Total moisture, and
- Loss on ignition or total volatile solids.

Testing was performed on small volumes of ash as extracted from the samples. Ash extraction for testing purposes was performed as required by each testing protocol. Rocks, nails, needles, and other visually identifiable items were not included in the tested portions of material.

The analytical tests are designed to show potential toxicity of the ashes analyzed. It should be noted that the sampling was not conducted based on regulatory requirements and hence, the results are invalid from a regulatory standpoint. The regulatory limits are given more for purposes of comparison than for assessment of toxicity. They are also useful in evaluating some of the nutrients and trace metals necessary for beneficial application of the materials for agricultural uses.

2.3 AGRICULTURAL TESTS

As part of this quantification and characterization study, the consultant evaluated the physical and chemical characteristics of ash with the intent to provide beneficial use for agriculture. The laboratory tests which were performed excluded analyses to identify potential toxicities of the materials. The consultant contacted individuals familiar with the beneficial uses of incinerated wood waste byproducts, including staff from the University of California-Davis (Department of Land, Air, and Water Resources), and the Ash Work Group of the University of California Cooperative Extension Service. In addition, a limited amount of literature pertinent to the study was reviewed and is made part of this discussion.

Agricultural tests were performed on the ash from biomass facilities only. The following characteristics were determined:

<u>Chemical Characteristics</u>:

- Macronutrients
  - Nitrogen
  - Phosphorus
  - Potassium
  - Sulfur
  - Magnesium
  - Calcium

- Micronutrients
  - Iron
  - Manganese
  - Copper
  - Zinc
- Other Characteristics
  - Aluminum
  - Sodium
  - Acid Insoluble Ash (% sand)
  - % Organic Matter
  - Calcium Carbonate Equivalent (CCE)
  - Chloride (ppm)

Physical Characteristics:

- Bulk Density (gm/cc)
- % Moisture (dry basis)
- Particle Size (% passing No. 200 sieve)

Although a great deal of research has been conducted on beneficial use of fly ash, much of the work centers around the byproduct as generated from coal-fired power plants. Bottom and fly ash from wood and coal have been found to be a useful soil amendment on acidic soils and mine spoils, to physically improve soil texture and nutrient availability, and as an additive in animal and poultry feed, among other uses. The review for this study focused upon research related to wood or wood waste fired boilers/incinerators.

Early studies by Host and Pfenninger (1978) and Master and Zellmer (1979) suggested that the ash from wood bark serves a beneficial purpose as a low-grade fertilizer. More recent field experiments have found that wood waste ash is high in potassium and naturally releases nutrients over a longer period of time than artificially designed fertilizer products (Meyer, et al, 1992). Other recent studies have found that wood waste fly ash can also be used as a daily landfill cover without the threat of groundwater contamination by heavy metals contained in the fly ash (Perkins and Dohms, 1989).

Studies have suggested that the most nutrient-rich ash materials are those that have used untreated wood chips and bark as a feedstock to the furnace (Hakkila, 1989). This is especially the case where organics are fully combusted (Meyer, 1993; personal communication). Use of elementally rich ashes may lead to excess levels of micronutrients which, if chemically available, may be detrimental to agricultural lands. Impurities in the feedstock such as nails, treated wood and painted wood, or mineral-rich rocks or soils may also contribute to elevated levels of lead and copper.

Meyer et al (1992), characterized ash from the standpoint of "high-carbon black" and "low-carbon gray" materials. High-carbon black ashes typically have high potassium concentration, while low-carbon ash tends to contain potassium, phosphorous, and calcium. Low-carbon gray ash may also offer a higher availability of micronutrients on an average basis than high-carbon ash, particularly for zinc. This trend is evident in the testing results for this study. Both materials have their advantages, as well as their limitations with regard to agricultural uses. High-carbon content may hinder nitrogen availability for plant growth and for microbial decomposition of the applied ash. Consequently, supplemental nitrogen may be needed in order to support plant growth. Conversely, addition of high organic materials to soils can improve physical soil properties, such as water infiltration, tilth, and structure. Therefore, facility operators and their agricultural end-users should work closely to ensure that the ash byproduct in use coincides with the specific nutrient needs of the agricultural crop.

Potential Uses. Research into the use of biomass ash is presently underway in California and other parts of the United States. Principal applications under evaluation include supplemental uses for dry-land and irrigated crops, eucalyptus and forest land, and rangeland. Field trials by the University of California Cooperative Extension and a number of northern California biomass combustion facilities are ongoing. The trends identified by the researchers, to date, tend to support the conclusions of early studies that application of biomass ash at varying rates can enhance plant growth, under a variety of field conditions.

Uses and applications of biomass ash are also dependent upon a number of externalities. Studies have shown that the cost-effectiveness in use of ash for agricultural or even silvicultural purposes can be maximized if hauling distances are limited to a radius of 25 miles from source to end-user. The viability of the resource as an agricultural supplement may also be limited by handling, storage, and spreading considerations. Additionally, the nutrient loading requirements of the receiving land will have bearing on the application rate of the ash and hence, its cost effectiveness. All of these limitations may result in marginal returns on investments for agricultural end-users if production yields do not increase significantly on ash-applied lands.

3.0 DATA ANALYSIS

Separate discussions of the data are provided for biomass facilities, medical waste facilities, and MSW facilities. The discussion includes an analysis of test results and of potential uses for the ash residues and recommendations for future activities.

3.1 BIOMASS COMBUSTION FACILITIES

3.1.1 *Introduction*

Using data collected in Phase I of this study, the CIWMB staff identified biomass facilities to be sampled. The facilities were chosen with consideration to fuel (type and quantity), air pollution control equipment, and combustion technology. After contacting several facilities and advising the facility's management about the Study's purpose and procedures, ten biomass facilities agreed to participate in the study. Table 2 shows the names, locations, and

TABLE 2
BIOMASS FACILITY CHARACTERISTICS

Facility Name	Sample Date	Feedstock	Technology
Burney Forest Products	06/10/92	Wood waste from lumber	Fixed grate
El Nido Biomass Power Plant	01/29/93	Almond trees, walnut shells, grape pomace	Fluidized bed
Fairhaven Power Company	04/30/93	Wood waste from redwood lumber operations	Fixed grate
Hudson Lumber Company	05/08/93	Wood chips from lumber	Fixed grate
Mendota Biomass Power, Ltd.	04/08/93	Urban wood waste and prune pits	Fluidized bed
Operational Energy Company — Williams	01/08/93	Rice hulls	Moving grate
Pacific Lumber Company — Scotia	05/06/93	Redwood scrap	Moving grate
Sierra Pacific — Burney	06/11/92	Wood waste from lumber operations	Fixed grate with after-burner for bottom ash
Soledad Energy Partnership	08/12/92	Half almond, pine and eucalyptus trimmings and half urban wood waste	Fluidized bed
Wheelabrator Shasta Energy Co. — Anderson	05/07/92	Wood waste from timber/ lumber operations.	Moving grate

sample dates for the participating biomass facilities, along with information on the feedstock combusted during our sampling and the technology category of the furnace.

3.1.2 *Biomass Sampling Procedures*

As described in section 2.0 Study Overview, samples were taken from each of the facilities listed above. A standard protocol was developed outlining sampling procedures at the biomass facilities. This protocol required the removal of ferrous metals and materials over two-inches in diameter (overs) from each sample taken. This removal of material was performed as a part of field sample preparation prior to shipping and laboratory testing.

Please note that because facility operations differed, actual protocols differed slightly; however the field sample preparation used to remove the ferrous metals and "overs" was performed for all samples at each facility. See the appendix for detailed sampling protocols.

Table 3 provides the proportion of ferrous and "overs" for each facility sampled. The facilities are classified by the combustion technology used.

3.1.3 *Test Results for Transportation Uses*

Many of the results of physical testing performed on the various samples of ash can be compared directly to the specifications set by CalTrans. These results are shown in Table 4, and can be compared with the specifications of Table 1.

A number of tests could not be run successfully for some samples due to organic contaminants. The organics either led to an inability to perform the test or results which were indeterminable. Samples from Burney Forest, Sierra Pacific, and Soledad Energy had few successfully performed tests due to organics or other contaminants.

Tests were performed to characterize the aggregate in the ash. CT 202, 206, 207, 208, and 212 characterize the size distribution and density of the ash. ASTM C-289 is not a standard CalTrans test but is important in concrete surface applications nonetheless. Results of CT 206, 207, 208, 212, 226, and ASTM C-289 are shown in Table 5. CT 202 results are given in Appendix A.

TABLE 3
FERROUS AND MATERIAL OVER TWO-INCHES IN DIAMETER
REMOVED FROM THE SAMPLES PRIOR TO LABORATORY TESTING
(Provided as a Proportion of the Total Sample Taken)

Facility	Ash Type	Ferrous	Material Over 2"	Samples	Observed Ash Characteristics	Comments
Fluidized Bed Facilities						
El Nido Biomass Power	Bottom/Fly Ash Combined	0 - 0%	0 - 0%	2	Fine, brown material; nothing over 2 inches.	Two - 600+ pound samples were taken as compared to six 200 pound samples taken at other facilities.
Mendota Biomass Plant	Bottom Ash Fly Ash	0 - <1% 0 - 0%	0 - 0% 0 - 0%	3 3	Bottom ash mostly sand, nails, rocks, some unburned material; fly ash fine, brown/black material.	
Soledad Energy Partnership	Bottom Ash Fly Ash	0 - 0% 0 - 0%	0 - 0% 0 - 0%	3 3	Bottom relatively homogeneous, coarse gravel in texture and color; fly fine, black.	
Fixed Grate Facilities						
Burney Forest Products	Bottom Ash Fly Ash	0 - 0% 0 - 0%	0 - 6% 0 - 0%	3 3	No ferrous; slag and rock present over 2 inches, consistent size otherwise.	The "overs" were mainly slags and inerts
Fairhaven Power Company	Bottom Ash Fly Ash	0 - <1% 0 - 0%	0 - <1% 0 - 0%	3 3	Fly was black and fine; bottom consistent except for some nails and rocks.	
Hudson Lumber Company	Bottom Ash	0 - <1%	0 - 34%	6	Coarse; some nails, rocks and slag over 2 inches.	One daily sample contained 34% slags/inerts. All other samples contained less than 1% "overs."
Sierra Pacific Industries	Bottom Ash Fly Ash	0 - 0% 0 - 0%	0 - 0% 0 - 0%	3 3	Bottom similar to fly - no ferrous, organics, or slag seen.	
Moving Grate Facilities						
Operational Energy Company	Bottom/Fly Ash Combined	0 - 0%	0 - 0%	6	Homogeneous, light weight, very fine, black; no slag, inerts, organics or ferrous noticed.	
Pacific Lumber Company	Bottom Ash Fly Ash	0 - <1% 0 - 0%	0 - 6% 0 - 0%	3 3	Bottom over 2 inches rock, slag, and unburned wood chips, nail; fly-fine,black.	Overs were mainly slags/inerts with some unburned organics.
Signal Wheelabrator	Bottom Ash	0 - <1%	0 - 5%	6	Some nails, slag, rock and partially burned fuel; over 2-inch rocks and slag.	Only bottom ash was sampled at this facility.

TABLE 4
PHYSICAL TESTING RESULTS OF BIOMASS ASH

Biomass Waste Source		Residue Sample	CALIFORNIA D.O.T. TEST									
			CT 211 500r	CT 213	CT 217	CT 229	CT 301	CT 303 Kc	CT 303 Kf	CT 312	CT 515	CT 548
Burney Forest												
Sample 1	Fine/Coarse	Fly	*	Unsat.	*	*/*	*	*	*	*	*	*
Sample 2	Fine/Coarse	Bottom	*	Unsat.	95	*/*	70	*	*	*	*	*
El Nido Power Plant												
Sample 1	Fine/Coarse	Mixed	*	Satisfactory	51	27/*	88	*	2.7	*	40	*
Sample 2	Fine/Coarse	Mixed	*	Satisfactory	49	32/*	82	*	2.6	*	45	*
Fairhaven Power Plant												
Sample 1	Fine/Coarse	Fly	*	Satisfactory	25	*/*	62	*	>3	*	*	*
Sample 2	Fine/Coarse	Bottom	*	Satisfactory	70	*/*	71	*	>3	*	7.7	*

NOTES:

* Unable to determine
** Unable to test

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TABLE 4 (Continued)
PHYSICAL TESTING RESULTS OF BIOMASS ASH

Biomass Waste Source		Residue Sample	CALIFORNIA D.O.T. TEST									
			CT 211 500r	CT 213	CT 217	CT 229	CT 301	CT 303 Kc	CT 303 Kf	CT 312	CT 515	CT 548
Hudson Lumber												
Sample 1	Fine/Coarse	Mixed	44	*	93	88/87	70	*	*	*	*	*
Sample 2	Fine/Coarse	Mixed	46	*	89	87/85	70	*	*	*	*	*
Mendota Power Plant												
Sample 1	Fine/Coarse	Fly	*	Satisfactory	32	84/*	86	*	2.0	*	*	*
Sample 2	Fine/Coarse	Bottom	*	Satisfactory	92	25/*	69	*	1.4	*	81.7	*
Operational Energy Company												
Sample 1	Fine/Coarse	Mixed	*	Satisfactory	63	66/*	70	*	>3	*	*	*
Sample 2	Fine/Coarse	Mixed	*	Satisfactory	59	79/*	69	*	>3	*	*	*

NOTES:

* Unable to determine
** Unable to test

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TABLE 4 (Continued)
PHYSICAL TESTING RESULTS OF BIOMASS ASH

Biomass Waste Source		Residue Sample	CALIFORNIA D.O.T. TEST									
			CT 211 500r	CT 213	CT 217	CT 229	CT 301	CT 303 Kc	CT 303 Kf	CT 312	CT 515	CT 548
Pacific Lumber												
Sample 1	Fine/Coarse	Fly	*	Satisfactory	93	42/*	66	*	>3	*	*	*
Sample 2	Fine/Coarse	Bottom	49	Satisfactory	88	84/85	71	1.8	1.3	*	75	*
Sierra Pacific												
Sample 1	Fine/Coarse	Fly	*	Unsat.	45	*/*	78	*	*	*	*	*
Sample 2	Fine/Coarse	Bottom	*	Unsat.	15	*/*	75	*	*	*	*	*
Signal Wheelabrator												
Sample 1	Fine/Coarse	Bottom	49	Unsat.	73	74/74	57	1.9	1.8	*	105	*
Sample 2	Fine/Coarse	Bottom	50	Unsat.	87	76/73	68	2.0	1.9	*	120	*

NOTES:

* Unable to determine
** Unable to test

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TABLE 4 (Continued)
PHYSICAL TESTING RESULTS OF BIOMASS ASH

Biomass Waste Source		Residue Sample	CALIFORNIA D.O.T. TEST									
			CT 211 500r	CT 213	CT 217	CT 229	CT 301	CT 303 Kc	CT 303 Kf	CT 312	CT 515	CT 548
Soledad Energy												
Sample 1	Fine/Coarse	Fly	*	Usat.	44.3	50/*	82	*	*	*	*	*
Sample 2	Fine/Coarse	Bottom	43	Satisfactory	97.7	74/73	*	*	*	*	*	*

NOTES:

* Unable to determine
** Unable to test

[F:\WK1889.DA1\ASH2]

TABLE 5
CHARACTERIZATION OF BIOMASS ASH

Biomass Waste Source		Residue Sample	CALIFORNIA D.O.T. TEST							
			CT 206 SG	CT 206 ABS %	CT 207 SSD	CT 207 ABS %	CT 208	CT 212	CT 226 %	ASTM C-289
Burney Forest										
Sample 1	Fine/Coarse	Fly	*	*	*	*	*	13.0	91.3	*
Sample 2	Fine/Coarse	Bottom	2.20	5.78	*	*	2.53	38.8	4.0	*
El Nido Power Plant										
Sample 1	Fine/Coarse	Mixed	*	*	2.25	10.6	2.66	72.7	1.4	Innocuous
Sample 2	Fine/Coarse	Mixed	*	*	2.25	10.4	2.66	71.5	0.9	Innocuous
Fairhaven Power Plant										
Sample 1	Fine/Coarse	Fly	*	*	1.76	15.1	2.00	17.7	157.9	Innocuous
Sample 2	Fine/Coarse	Bottom	*	*	1.78	11.6	2.03	36.3	82.2	*
Hudson Lumber										
Sample 1	Fine/Coarse	Mixed	2.05	5.64	*	*	2.21	76.8	22.2	Innocuous
Sample 2	Fine/Coarse	Mixed	2.13	5.34	*	*	2.27	69.8	22.9	Innocuous

NOTES:

* Unable to determine
** Unable to test

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TABLE 5 (Continued)
CHARACTERIZATION OF BIOMASS ASH

Biomass Waste Source		Residue Sample	CALIFORNIA D.O.T. TEST							
			CT 206 SG	CT 206 ABS %	CT 207 SSD	CT 207 ABS %	CT 208	CT 212	CT 226 %	ASTM C-289
Mendota Power Plant										
Sample 1	Fine/Coarse	Fly	*	*	2.19	4.8	2.67	76.9	Negative	Deleterious
Sample 2	Fine/Coarse	Bottom	*	*	2.47	1.7	2.57	93.3	Negative	Deleterious
Operational Energy Company										
Sample 1	Fine/Coarse	Mixed	*	*	1.94	2.4	2.08	20.2	0.1	Innocuous
Sample 2	Fine/Coarse	Mixed	*	*	1.91	7.3	2.17	20.5	0.2	Innocuous
Pacific Lumber										
Sample 1	Fine/Coarse	Fly	*	*	1.69	7.5	1.97	12.8	0.03	Innocuous
Sample 2	Fine/Coarse	Bottom	2.20	5.55	2.24	2.4	2.51	92.5	10.1	Innocuous
Sierra Pacific										
Sample 1	Fine/Coarse	Fly	*	*	*	*	2.48	25.3	14.7	*
Sample 2	Fine/Coarse	Bottom	*	*	*	*	2.24	22.8	64.1	*

NOTES:

* Unable to determine
** Unable to test

[F:\WK1889.DA1\ASH1.WK1]

TABLE 5 (Continued)
CHARACTERIZATION OF BIOMASS ASH

Biomass Waste Source		Residue Sample	CALIFORNIA D.O.T. TEST							
			CT 206 SG	CT 206 ABS %	CT 207 SSD	CT 207 ABS %	CT 208	CT 212	CT 226 %	ASTM C-289
Signal Wheelabrator										
Sample 1	Fine/Coarse	Bottom	2.28	5.35	2.34	6.2	2.40	87.4	19.7	Innocuous
Sample 2	Fine/Coarse	Bottom	2.24	5.34	2.30	6.4	2.47	96.6	14.3	Innocuous
Soledad Energy										
Sample 1	Fine/Coarse	Fly	*	*	*	*	2.34	92.1	4.1	Deleterious
Sample 2	Fine/Coarse	Bottom	2.27	2.27	2.48	3.9	2.62	154.9	1.2	Innocuous

NOTES:

* Unable to determine
** Unable to test

[F:\WK1889.DAT\ASH.WK1]

Discussion

None of the results was favorable in terms of using the ash for aggregates to be mixed with concrete. For asphalt aggregate, the bottom ash sample from Pacific Lumber appeared to meet the CalTrans requirements, although it was just out of specification for the Kc determination in CT 303. For the asphalt treated permeable base, the CalTrans specification was met only by the bottom ash sample of Soledad. None of the samples met the bituminous Seal Aggregate specification of 40 percent maximum attrition for CT 211.

As an aggregate subbase, all the samples with the exception of Sierra Pacific bottom ash and Burney Forest fly ash, met the specifications. Base applications are slightly more stringent and were met by Hudson Lumber and Signal Wheelabrator.

From the results above, there does not appear to be any clear correlations between feedstock and technology on the ash utilization characteristics. Additional factors which confound correlations include boiler operation conditions and feedstock moisture.

3.1.3 *Test Results for Agricultural Uses*

Results

Results of the agricultural and toxicity analyses are shown on Tables 6 and 7. The toxicity analyses shown do not represent the full number of tests that were run. The intent is to present those that are more critical for agricultural applications. TCLP results were acceptable based on federal regulations and are not shown here. The TCLP and California toxicity tests results are given in the appendix for each facility.

Of the facilities sampled, El Nido Biomass and Sierra Pacific Industries had higher levels of macronutrients than the other facilities included in the testing. This translates into a greater level of macro nutrients per ton of material applied per acre than the other ashes. Conversely, the micronutrient availability of these materials was indistinguishable from the

TABLE 6

SUMMARY OF AGRICULTURAL ANALYSIS RESULTS
BIOMASS COMBUSTION FACILITIES

	Burney Forest Products	El Nido Biomass Plant	Fairhaven Energy Company	Hudson Lumber Company	Mendota Biomass Power	Operational Energy Co.	Pacific Lumber Co.	Sierra Pacific Industries	Signal Wheelabrator	Soledad Energy Partnership
Sample Type	Fly/Bottom	Bottom Only (2 Samples)	Fly/Bottom	Bottom Only (2 Samples)	Fly/Bottom	Combined Ash	Fly/Bottom	Fly/Bottom	Bottom Only (2 Samples)	Fly/Bottom
Chemical Characteristics										
Macronutrients (%)										
• Nitrogen	0.01/<0.01	0.27/<0.01	0.11/0.14	0.07/0.68	0.01/0.01	0.31/<0.01	0.14/0.07	<0.01/0.28	0.09/0.07	0.05/0.07
• Phosphorus	0.30/0.51	0.80/0.68	0.40/0.15	0.46/0.43	0.23/0.40	0.22/0.43	0.29/0.05	2.11/2.15	0.41/0.42	0.64/0.16
• Potassium	1.39/2.04	2.52/2.50	2.38/0.98	1.45/1.35	0.76/1.84	2.25/2.25	2.31/0.22	2.74/2.76	1.44/1.53	2.01/1.40
• Sulfur	0.03/0.04	0.29/0.21	1.15/0.23	0.07/0.12	0.08/0.24	0.11/0.23	0.82/0.09	0.45/0.71	0.31/0.32	0.46/0.08
• Magnesium	0.60/0.97	0.93/0.86	0.83/0.42	0.90/0.91	0.41/0.74	0.16/0.17	0.80/0.39	1.65/1.30	0.82/0.76	0.71/0.68
• Calcium	1.77/2.77	4.74/4.36	5.95/2.33	2.46/2.72	4.34/39.51	0.10/0.13	3.10/0.84	29.72/33.11	3.21/3.30	23.64/2.16
Micronutrients (ppm)										
• Iron	36,200/46,700	20,300/14,700	24,100/21,100	29,000/34,600	6,400/17,200	394/510	24,400/9,400	19,600/18,800	28,100/23,000	28,600/24,400
• Manganese	1,720/3,070	590/630	1,870/970	2,150/2,030	490/410	386/410	1,100/325	13,300/13,500	2,340/2,280	117/69
• Copper	70/90	450/420	90/38	390/380	220/260	10/14	70/20	200/200	80/80	310/160
• Zinc	162/194	298/265	297/174	229/358	245/333	42/85	225/62	910/912	451/308	2,580/530
Other Characteristics										
• Aluminum	18,103/22,414	21,250/15,000	13,000/9,000	24,138/22,414	10,000/23,750	284/371	12,300/4,180	18,965/18,965	23,276/17,241	21,551/17,240
• Sodium	0.25/0.42	0.49/0.44	0.23/0.16	1.1/1.2	0.20/0.44	0.03/0.03	0.16/0.08	0.39/0.40	0.85/0.97	0.75/0.49
• Acid Insoluble Ash (% sand)	87.14/85.12	72.59/74.56	31.41/44.61	76.04/74.04	86.56/63	91.59/88.65	54.82/96.05	5.92/5.57	35.58/44.72	56.31/90.49
• % Organic Matter	2.72/2.21	2.36/2.12	44.23/26.20	8.44/8.95	0.16/0.66	6.91/6.53	45.85/2.09	33.77/33	43.82/45.67	5.86/0.64
• Calcium Carbonate Equivalent (CCE)	9.76/16.34	20.43/18.91	17.72/8.38	13.97/14.63	13.76/42.47	1.99/2.02	11.59/3.68	48.38/49.09	15.01/15.82	30.23/9.0
• Chloride (ppm)	1,206/496	1,454/1,312	2,482/355	496/532	426/13,475	4,610/5,851	2,305/355	11,879/11,879	4,255/5,496	7,269/638
Physical Characteristics										
• Bulk Density (gm/cc)	1.27/1.25	1.12/1.07	0.25/0.60	0.94/0.96	1.50/1.30	0.31/0.34	0.28/1.35	0.44/0.42	0.25/0.26	0.96/1.37
• % Moisture (dry basis)	2.42/2.52	9.23/10.38	60.78/44.46	43.00/40.36	0.16/NR	0.41/0.36	1.21/7.69	56.72/56.84	55.8/55.88	3.21/0.18
• Particle Size (% retained by No. 200 sieve)	43/97	72/68	32/90	92/89	56/100	83/84	51/95	22/41	97/98	58/97

ppm = parts per million
gm/cc = grams per cubic centimeter

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SUMMARY OF RESULTS FOR TOTAL THRESHOLD LIMIT CONCENTRATIONS (TTLC) AND SOLUBLE THRESHOLD LIMIT CONCENTRATIONS (STLC)

Analytical Parameters	Burney Forest Products	El Nido Biomass Plant	Fairhaven Energy Company	Hudson Lumber Company	Mendota Biomass Power	Operational Energy Co.	Pacific Lumber Co.	Sierra Pacific Industries	Signal Wheelabrator	Soledad Energy Partnership
Sample Type	Fly/Bottom	Bottom Only	Fly/Bottom	Bottom Only	Fly/Bottom	Fly & Bottom Mixed	Fly/Bottom	Fly/Bottom	Bottom Only	Fly/Bottom
	TTLC	TTLC	TTLC	TTLC	TTLC	TTLC	TTLC	TTLC	TTLC	TTLC
Cadmium	1.3/4.5	ND/ND	ND/ND	8.0/7.6	ND/ND	ND/ND	ND/ND	2.9/6.9	8.0/5.3	6.1/ND
Chromium	6.9/19	19/16	21/16.4	42/45	38.1/16.6	ND/ND	27.7/27.7	15/37	56/51	100/84
Beryllium	ND/0.74	ND/ND	ND/ND	ND/ND	ND/ND	ND/ND	ND/ND	ND/0.97	ND/ND	ND/ND
Arsenic	ND/10	22/33	ND/ND	25/19	ND/ND	ND/ND	12.6/11.5	24/78	18/20	130/53
Lead	9.2/20	24/17	36/ND	31/29	79.3/ND	ND/ND	13.7/13.2	64/35	29/30	1100/21
Mercury	ND/ND	ND/ND	ND/ND	ND/ND	0.09/ND	ND/ND	ND/ND	ND/ND	ND/ND	3.8/ND
	STLC	STLC	STLC	STLC	STLC	STLC	STLC	STLC	STLC	STLC
Cadmium	0.02/0.03	ND/0.03	ND/ND	0.05/0.04	ND/ND	ND/ND	0.06/ND	0.02/0.03	0.04/0.04	ND/0.02
Chromium	0.12/0.13	0.42/0.30	0.36/0.15	0.19/0.23	.38/.20	ND/ND	0.19/0.09	0.36/0.14	0.25/0.18	2.5/1.8
Beryllium	ND/0.01	ND/ND	ND/ND	0.01/0.01	ND/ND	ND/ND	ND/ND	ND/ND	0.01/0.01	ND/ND
Arsenic	0.23/0.37	ND/ND	ND/ND	0.37/0.26	ND/ND	ND/ND	ND/ND	0.40/0.25	0.51/0.25	1.5/1.3
Lead	ND/0.67	ND/0.11	1.37/0.60	0.23/0.22	ND/ND	ND/ND	0.04/0.49	0.11/ND	0.94/0.48	0.68/0.20
Mercury	ND/ND	ND/ND	ND/ND	ND/ND	ND/ND	ND/ND	ND/ND	ND/ND	ND/ND	0.0004/ND

(1) *TTLC reported in milligrams per kilogram (mg/kg); STLC reported in milligrams per liter (mg/L).*
ND = not detected.

Limit Concentrations for Persistent and Bioaccumulative Substances		
	TTLC (mg/kg)	STLC (mg/L)
Cadmium	100	1.0
Chromium (VI/III and other)	500/2,500	5.0/560
Beryllium	75	0.75
Arsenic	500	5.0
Lead	1,000	5.0
Mercury	20	0.2

other facilities sampled. Burney Forest Products and Hudson Lumber Company samples typically exceeded the other facilities in pounds of available micronutrients per ton of material applied (per acre basis).

A comparison of fly ash to bottom ash analyses indicated a small difference in average elemental concentrations for both macro- and micronutrients. Except for phosphorus, potassium, and zinc, elemental concentrations were often higher on average for bottom ash samples as compared to the fly ash samples.

Organic matter in the ash samples was low for Burney Forest Products, El Nido Biomass Plant, Mendota Biomass Power, Ltd., and Soledad Energy Partnership. Micronutrients were especially low for Operational Energy Company, as were calcium and magnesium. Calcium carbonate equivalent was significantly higher for Sierra Pacific Industries; chloride also followed this trend. Physical characteristics varied widely.

Discussion

In reviewing the results of the analyses, three key variables may influence the results. These variables are: (1) feedstock; (2) type of technology used; and (3) residue type (fly versus bottom ash) as are shown on Table 2.

Feedstock. The type of feedstock incinerated strongly influences the quality of the ash material produced. From the facilities sampled in this study, several biomass feedstocks were employed including:

- Wood waste and/or chips from lumber;
- Agricultural waste (shells, pomace, rice hulls, etc.);
- Urban wood waste;
- Redwood scraps; and
- Tree trimmings.

The total and leachable metal levels in samples from facilities accepting urban wood waste were generally higher than the others. One sample from the Soledad Energy Partnership was high in the total lead (TTLC), but not the leachable lead (STLC). The other Soledad sample was 50 times lower, showing the high variance in the material. It should be noted that the sampling was not designed based on regulatory requirements and hence, the results are invalid from a regulatory standpoint. The regulatory limits are given more for purposes of comparison than for assessment of toxicity.

Ash samples collected from the El Nido, Hudson, Sierra Pacific, and Soledad facilities contained levels of copper and zinc which could be harmful to soils already enriched with reasonably balanced micronutrients. The rice hull ash from Operational Energy was significantly lower in some metals and calcium than the other feedstocks.

Combustion Technology. Some ash differences can be attributed to the combustion technology employed. The high calcium and chloride in the Sierra Pacific Facility samples may be a result of the use of an after burner, perhaps lowering overall carbon in the ash and subsequently raising concentrations of other elements. The expected high combustion efficiency of the fluidized bed units lead to lower organics in the ash. High burnout was also achieved for the fixed grate incinerator at Burney Forest Products.

Differences in Ash Type. A third factor influencing nutrient value is the type of ash. All combustors sampled generated two separate ash types: fly ash, which is captured downstream of the furnace, and bottom ash, which drops beneath the furnace grate. The chemical and physical characteristics of bottom ash and fly ash are markedly different. Generally, fly ash contains higher levels of leachable metals than bottom ash.

3.2 MEDICAL WASTE INCINERATION FACILITIES

3.2.1 *Introduction*

Using data collected in Phase I of this study, the CIWMB staff identified medical waste facilities to be sampled. The facilities were chosen with consideration to waste, air pollution control equipment, and combustion technology. The amount of waste incinerated was the key criteria in identifying which facilities' ash would be sampled. The facilities eligible to be sampled had to generate more that one ton of ash per day. Only eight of 72 facilities met this criterium.

After two of the eight medical waste facilities were chosen and briefed about the Study's purpose and procedures, both facilities agreed to participate in the study. Table 8 shows the names, locations, sample dates, and "overs" for each facility sampled.

TABLE 8
MEDICAL FACILITIES SAMPLED

Name/Location*	Sample Date	Ash Type	Ferrous	Material Over 2"	Daily Samples
American Environmental Management Corporation, Sacramento	04/22/92	Bottom/Fly Ash Combined	2 - 5%	1 - 14%	6
Integrated Environmental Systems, Inc., Oakland	01/29/93	Bottom/Fly Ash Combined	1 - 4%	1 - 14%	6

* All Facilities are located in the State of California

Six daily samples and composites performed from the three morning and three afternoon samples were analyzed individually for toxicity. Physical tests were performed on the composites only.

3.2.2 *Physical Results*

Two medical waste incinerators were sampled in this study, American Environmental Management Corporation (American Environmental) and Integrated Environmental Systems, Inc. (Integrated Environmental). Results from the testing are shown in Tables 9 and 10, with Table 9 giving results to compare against the CalTrans specifications of Table 4 and Table 10 giving additional testing results. Results of CT 202 are given in Appendix B.

3.2.3 *Analytical Results*

Table 11 shows results of the six daily samples from each facility analyzed by the Toxicity Characteristic Leaching Procedure. The composite samples' TCLPs fall within the ranges in the table. The average lead leachate concentration from the Integrated Environmental Systems ash was 37 mg/liter. The regulatory limit for lead is 5 mg/liter. The results for lead in the ash sampled from this facility ranged from below detection level (0.10 mg/L) to 140 mg/L. No correlation with time of sampling was evident. Lead levels were also higher than limits established for State of California Total Threshold Limit Concentration (TTLC) and Soluble Threshold Limit Concentration (STLC) tests. These data are given in the appendix.

Samples collected from the American Environmental facility indicated high TTLC levels for copper. TTLC results are provided in the appendices.

Table 11 is a summary of the TCLP toxicity results. As with the biomass ash toxicity testing, it must be noted that our sampling protocol was not designed based on regulatory requirements.

TABLE 9
PHYSICAL TESTING RESULTS OF MEDICAL WASTE ASH

Medical Waste Source		Residue Sample	CALIFORNIA D.O.T. TEST									
			CT 211 500r	CT 213	CT 217	CT 229	CT 301	CT 303 Kc	CT 303 Kf	CT 312	CT 515	CT 548
American Environmental												
Sample 1	Fine/Coarse	Mixed	50	Unsat.	34	60/59	70	*	*	*	*	*
Sample 2	Fine/Coarse	Mixed	51	Unsat.	42	62/60	69	*	*	*	*	*
Integrated Environmental												
Sample 1	Fine/Coarse	Mixed	*	Unsat.	69	*/*	76	*	*	*	*	*
Sample 2	Fine/Coarse	Mixed	*	Unsat.	65.3	*/*	75	*	*	*	*	*

NOTES:

* Unable to determine
** Unable to test

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TABLE 10
CHARACTERIZATION OF MEDICAL WASTE ASH

Medical Waste Source		Residue Sample	CALIFORNIA D.O.T. TEST							
			CT 206 SG	CT 206 ABS %	CT 207 SSD	CT 207 ABS %	CT 208	CT 212	CT 226 %	ASTM C-289
American Environmental										
Sample 1	Fine/Coarse	Mixed	*	*	*	*	2.22	54.6	18.6	Innocuous
Sample 2	Fine/Coarse	Mixed	*	*	*	*	2.28	48.4	21.2	Innocuous
Integrated Environmental										
Sample 1	Fine/Coarse	Mixed	1.79	*	*	*	2.03	71.1	7.5	*
Sample 2	Fine/Coarse	Mixed	1.94	*	*	*	2.11	68.0	4.6	*

NOTES:

* Unable to determine
** Unable to test

[F:\WK1889.DA1\ASH1.WK1]

TABLE 11
TCLP TOXICITY TESTING RESULTS
MEDICAL WASTE FACILITIES

Analytical Parameters (mg/L)	American Environmental	Integrated Environmental	Regulatory Limit	Detection Limit (mg/L)
Arsenic	ND	ND	5.0	.200
Barium	*0.05 - 0.76	*0.05 - 13.00	100.0	.050
Cadmium	ND	*0.02 - 0.06	1.0	.02
Chromium	ND	*0.01 - 0.11	5.0	.05
Lead	ND	*0.10 - 140.00	5.0	.1
Mercury	ND	ND	.2	.0002
Selenium	ND	ND	1.0	.3
Silver	ND	ND	5.0	.02

Notes:

mg/L = Milligrams per liter
ND = Not detected
* = Low range estimate is equivalent to the minimum detection limit.

Results are based on 8 samples and given in a minimum/maximum range.

Discussion

The American Environmental ash satisfied CalTrans specifications for aggregate base and subbase. Integrated Environmental ash met the specifications for aggregate subbase only. These two ashes did not meet specifications for other applications due to unburned organics and inorganic debris.

Both facilities used fixed grate technology and a mixed ash was sampled. The ash sampled had a significant over two-inch fraction and some unburned material and sharps which will require screening and proper handling before use.

high concentrations of lead or other toxics can be handled with several options. Chemical additives can be applied to fix the metals in the ash to prevent them from leaching out. Alternatively, the ash could be intentionally leached and the leachate treated. It has generally been accepted that fly ash contains a greater degree of leachable metal than bottom ash; therefore, keeping the two streams separate and utilizing only the bottom ash may prevent higher concentrations of metals in the utilized ash.

3.3 MUNICIPAL SOLID WASTE-TO-ENERGY FACILITIES

3.3.1 *Introduction*

The consultant sampled the three facilities shown in Table 12, including the Stanislaus Refuse-to-Energy Facility twice. Only material testing was performed on the ash samples from the MSW facilities.

The Commerce facility ash treatment system separates the ash into an under 1" bottom and fly ash and an over 1". The unders are mixed with 10 to 12 percent Portland cement in a cement mixer. This is discharged into a 40 cubic yard roll-off lined with plastic. The mixture is allowed to cure for at least a day before being transported to the landfill for temporary road use there. The sampling protocol for Commerce differed greatly from the other facilities. For this site, the ash/cement mixture was shoveled into forms, allowed to cure for 24 hours, and then broken up into pieces less than 2" in size.

The South East Resource Recovery Facility (SERRF) also applies cement to the ash, but this is done in a proprietary way within the facility. The cement added is presumably less than used at Commerce and the ash sampled was not thoroughly cured before it was packaged and sent to the laboratory for physical testing.

TABLE 12 MSW FACILITIES SAMPLED					
Name/Location	**Sample Date**	**Ash Type**	**Ferrous**	**Material Over 2"**	**Daily Samples**
Commerce Refuse-to-Energy Facility, Commerce	10/05/92 to 10/08/92	Bottom/Fly Ash Combined	0 - <1%	0 - 0%	9
SouthEast Resource Recovery Facility, Long Beach	12/01/92 to 12/03/92	Bottom/Fly Ash Combined	7 - 17%	4 - 15%	9
Stanislaus County Resource Recovery Facility, Crows Landing *Event #1*	06/03/92 to 06/05/92	Bottom/Fly Ash Combined	3 - 8%	6 - 15%	9
Stanislaus County Resource Recovery Facility, Crows Landing *Event #2*	02/04/93 to 02/04/93	Bottom/Fly Ash Combined	3 - 12%	6 - 14%	9

At each facility, composite samples were taken for each of three consecutive days and a fourth sample was taken randomly from among the three days of sampling. As each daily composite sample was tested upon receipt at the laboratory, the fourth sample was held for thirty days before analysis. Testing of the random samples after the 30-day holding period provided comparative results used to indicate any bonding or other chemical reactions that might occur in the ash over time.

All three facilities used moving grate combustion technology, and added lime in their air pollution control which will end up in the ash.

3.3.2 *Results*

Results from the testing are shown in Tables 13 and 14, with Table 14 giving results to compare against the CalTrans specifications of Table 5, and Table 13 giving additional testing results. Results of CT 202 are given in Appendix C. The 30-day sample is the random sample in the tables.

3.3.3. *Discussion*

Commerce and SERRF ash satisfied the specifications for subbase aggregate. Base material specifications were not reached, nor were other application specifications attained. No trends were obviously correlated with sampling time. The 30-day samples for Commerce and SERRF were not significantly different that the other samples taken there.

Tests on samples from Stanislaus were successfully performed for most of the tests. The second visit's samples were particularly low in contaminants. The material, though, was still limited to meeting specifications for aggregate subbase and possibly asphalt-treated permeable base, asphalt concrete, and asphalt concrete base aggregate. The first visit's samples were significantly different than the second visit. In fact, the mortar compressive strength from the first visit was three times higher, and the durability from CT 229 was much better. This points to the variability of the ash over time due to differences in MSW, operation, and perhaps boiler condition.

The Stanislaus 30-day samples were not able to be tested for many of the tests. This suggests a time dependence which is difficult to explain. The organic contamination was somehow increased over time. This may be caused by a reduction in bonding of organics in the ash over time.

TABLE 13
CHARACTERIZATION OF MSW ASH

MSW Waste Source		Residue Sample	CALIFORNIA D.O.T. TEST							
			CT 206 SG	CT 206 ABS %	CT 207 SSD	CT 207 ABS %	CT 208	CT 212	CT 226 %	ASTM C-289
Commerce Refuse										
Sample 1	Fine/Coarse	Mixed	1.55	22.6	*	*	2.25	64.4	29.8	Innocuous
Sample 2	Fine/Coarse	Mixed	1.32	30.2	*	*	2.50	65.7	29.3	Innocuous
Sample 3	Fine/Coarse	Mixed	1.37	29.1	*	*	2.56	69.3	27.7	Innocuous
Random Sample	Fine/Coarse	Mixed	1.46	27.4	*	*	2.42	***	27.5	Innocuous
SERRF										
Sample 1	Fine/Coarse	Mixed	1.23	17.8	*	*	2.48	62.5	23.3	*
Sample 2	Fine/Coarse	Mixed	1.47	10.3	*	*	2.54	65.4	29.8	Innocuous
Sample 3	Fine/Coarse	Mixed	1.5	9.3	*	*	2.57	82.7	23.7	*
Random Sample	Fine/Coarse	Mixed	1.33	13.9	*	*	2.56	78.9	27.4	*

NOTES:

* Unable to determine
** Unable to test

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TABLE 13 (Continued)
CHARACTERIZATION OF MSW ASH

MSW Waste Source		Residue Sample	CALIFORNIA D.O.T. TEST							
			CT 206 SG	CT 206 ABS %	CT 207 SSD	CT 207 ABS %	CT 208	CT 212	CT 226 %	ASTM C-289
Stanislaus RRF – 1st visit										
Sample 1	Fine/Coarse	Mixed	2.06	6.4	2.83	9.2	2.45	91.5	20.4	Innocuous
Sample 2	Fine/Coarse	Mixed	2.06	6.1	2.82	8.7	2.55	81.6	14.6	Innocuous
Sample 3	Fine/Coarse	Mixed	2.09	7.7	2.81	8.8	2.52	77.0	18.4	Innocuous
Random Sample	Fine/Coarse	Mixed	1.99	7.9	**	**	2.55	**	16.5	**
Stanislaus RRF – 2nd visit										
Sample 1	Fine/Coarse	Mixed	2.15	8.6	2.25	15.2	2.58	85.5	17.4	Innocuous
Sample 2	Fine/Coarse	Mixed	2.09	8.4	2.24	9.0	2.56	93.0	17.4	Innocuous
Sample 3	Fine/Coarse	Mixed	2.19	7.4	2.15	13.7	2.58	93.8	16.0	Innocuous
Random Sample	Fine/Coarse	Mixed	1.96	11.1	**	**	2.57	**	16.4	**

NOTES:

* Unable to determine
** Unable to test

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TABLE 14
PHYSICAL TESTING RESULTS OF MSW ASH

MSW Waste Source		Residue Sample	CALIFORNIA D.O.T. TEST									
			CT 211 500r	CT 213	CT 217	CT 229	CT 301	CT 303 Kc	CT 303 Kf	CT 312	CT 515	CT 548
Commerce Refuse												
Sample 1	Fine/Coarse	Mixed	*	Unsat.	62	14/*	85	*	*	*	*	*
Sample 2	Fine/Coarse	Mixed	*	Unsat.	62	14/*	89	*	*	*	*	*
Sample 3	Fine/Coarse	Mixed	*	Unsat.	68	13/*	84	*	*	*	*	*
Random Sample	Fine/Coarse	Mixed	*	Unsat.	63	14/*	81	*	*	*	*	*
SERRF												
Sample 1	Fine/Coarse	Mixed	48.6	Unsat.	34	*/*	84	*	*	*	*	*
Sample 2	Fine/Coarse	Mixed	43.8	Unsat.	48	*/*	81	*	*	*	*	*
Sample 3	Fine/Coarse	Mixed	*	Unsat.	54	30/*	81	*	*	*	*	*
Random Sample	Fine/Coarse	Mixed	50.2	Unsat	42	16/*	83	*	*	*	*	*

NOTES:

* Unable to determine
** Unable to test

[F:\WK1889.DA1\ASH2]

TABLE 14 (Continued)
PHYSICAL TESTING RESULTS OF MSW ASH

MSW Waste Source		Residue Sample	CALIFORNIA D.O.T. TEST									
			CT 211 500r	CT 213	CT 217	CT 229	CT 301	CT 303 Kc	CT 303 Kf	CT 312	CT 515	CT 548
Stanislaus RRF – 1st visit												
Sample 1	Fine/Coarse	Mixed	48	Unsat.	60	44/67	73	2.6	1.5	*	105	*
Sample 2	Fine/Coarse	Mixed	48	Unsat.	53	24/63	82	2.2	2.1	*	105	*
Sample 3	Fine/Coarse	Mixed	49	Unsat.	55	28/62	75	2.3	2.5	*	105	*
Random Sample	Fine/Coarse	Mixed	**	**	49.5	**	**	**	**	**	**	**
Stanislaus RRF – 2nd visit												
Sample 1	Fine/Coarse	Mixed	42	Satisfactory	51	22/10	74	2.1	2.1	*	35	340/375/400
Sample 2	Fine/Coarse	Mixed	33	Satisfactory	54	23/17	79	2.0	>3	*	35	185/270/320
Sample 3	Fine/Coarse	Mixed	29	Satisfactory	57	25/23	81	1.8	1.0	*	40	300/540/570
Random Sample	Fine/Coarse	Mixed	**	**	54	**	**	**	**	**	**	**

NOTES:

* Unable to determine
** Unable to test

[F:\WK1889.DA1\ASH2]

4.0 CONCLUSIONS

For this study, an emphasis was placed on identifying beneficial uses for these ashes. The ash from the three categories of facilities, biomass, medical waste, and MSW, show distinct differences. These differences were generally a function of feedstock characteristics, technology, operating conditions, and whether the ash was bottom ash, fly ash, or mixed.

In order to recommend a suitable use, the toxicity characteristics of the ash were assessed. In the case of the biomass facilities, only one sample (Soledad Partnership) was found to have significant levels of lead based on a single toxicity test. Soledad combusted urban wood waste for half of its fuel, excessive lead may come from paint. One of the medical waste facilities, Integrated Environmental, averaged relatively high in lead, while the other, American Environmental, was high in leachable copper. Further testing of samples from these facilities is recommended before moving forward on ash utilization. The MSW facilities were not tested for toxicity of the ash.

The biomass sample results showed that in general, a lower carbon ash was attained with the fluidized bed facilities. These facilities tend to burn particles more completely due to the mixing action of the incinerator, and the use of a more consistently sized feedstock. The extent of burnout affected other ash characteristics such as a higher concentration of macronutrients. Micronutrients do not seem to be influenced strongly by extent of burnout. Soil application needs will influence the amount of burnout desired in a given ash.

CalTrans specifications for various transportation applications were met by many of the samples. For the biomass, nearly all the ashes sampled met specifications for a subbase aggregate. Base applications were met by samples from two of the facilities, and an additional facility was close to meeting the specification for asphalt aggregate.

The ash from medical waste facilities met specifications for subbase; one facility's ash met specifications for base aggregate. In general, the medical waste ash was less homogeneous than the biomass ash, as would be expected from the diverse medical waste being incinerated. Due to the toxicity testing results, applications of this material for base and subbase may require more extensive testing before treatment is considered to stabilize the metals.

The MSW facilities show differing levels of ash utilization potential. The Commerce facility's ash treatment program adds a substantial quantity of Portland cement to the ash, making it a different starting material than the other facilities. SERRF also added cement but at a lower rate. The ash from Stanislaus proved to be the most free of contamination and, therefore, most useful for transportation applications. This ash, despite the feedstock's diverse nature, competed well in terms of specifications for road base and asphalt aggregate materials with the best biomass ash. However, its characteristics changed over time, which is a threat to its marketability unless steps are found to eliminate this change, such as controlling the moisture in the ash in order to avoid adverse reactions in the ash.

In comparing the biomass, medical waste, and MSW ash, it is difficult to draw consistent conclusions. It is interesting that useful ashes seem to cross boundaries of technology, feedstock, and ash type. There was not a strong correlation between good char burnout and the lowering of organic contaminants which leads to inability to run many of the tests for the biomass ash samples. Because operating temperatures, residence times, air/fuel ratios, and other furnace conditions were not recorded for this study, many important factors have not been included. These factors, along with feedstock composition, influence ash characteristics.

Although some ashes may meet specifications for a given CalTrans application, it is important to note that not all tests have been performed relative to each application. Also, the material may require some fractionation to attain the required particle distribution. Organic and inorganic contaminants may present a problem even though specifications are met otherwise. In fact, all of the applications require a material free of organics and inorganic debris. Inorganics may be removed by screening or magnetic removal. Organics are probably more of a problem if in the form of putrescibles, which can decompose and leach out. Only a demonstration through field testing can conclusively assess the utilization of an ash in a base application.

5.0 RECOMMENDATIONS FOR FUTURE WORK

This study was intended to be a first step towards potential utilization of ash materials in various applications. It is useful in giving a baseline against which future testing and demonstrations can be gauged. There are many paths that can be taken to promote and implement the use of these materials.

For materials which have been shown to meet specification for a particular application, additional testing will be necessary to fully prove their effectiveness. Screening to change the particle size distribution to the appropriate range may be required for a given use. A demonstration project, such as a section of road, or farm land would be useful in proving the concept under practical conditions. This would also serve to evaluate economics and convenience for the user.

Contribution of this report to the research presently underway by University of California-Davis and the Ash Work Group of the University of California Cooperative Extension Service is recommended as a way to demonstrate useful applications for biomass combustion ash for agriculture. Research work might focus on two areas: the producer end and the agricultural user end. At this time, much of the research is focusing on application methods for varying types of agricultural land. Operators that may desire to find agricultural uses for their ash may want to consider the recommended refinements to their processes. A more thorough linkage between combustion processes, feedstock type, and land application techniques is recommended in order to gain a better understanding of the beneficial use of ash on agricultural lands.

For those materials lacking in quality due to excessive organics, changes in operation may lead to cleaner ash. If an emphasis is placed on operating to more fully combust the ash, it is likely that organics can be removed. Additional screening and ferrous recovery may also be required. A study of operations at various facilities could provide insight into the differences in ash characteristics seen.

It may also be useful to run different feedstocks through the same facility and sample and analyze the resulting ash. This could aid understanding of the effect of feedstock on ash quality.

It may be beneficial to create a forum with CalTrans to discuss the issues of organic and inorganic debris in the ash. While these present a barrier to ash use in road uses, the specifications may need to be expanded to allow for a new material like ash to be used. This could accelerate the use of ash materials in road applications, without significantly affecting the final product's quality.

Other uses for which biomass ash may be considered include: dietary supplement for livestock and poultry, or as a daily cover for landfills if texturally appropriate. Use of any ash as a final vegetative cover is not recommended, as a number of studies have indicated that ash alone is not a sustainable growing medium unless allowed to leach soluble alkaline oxides and stabilize (Meyer, et al, 1992).

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