Physicochemical Analysis of Selected Biomass Materials in Hawaii

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Hawaii Natural Energy Institute
School of Ocean and Earth Sciences and Technology

Scott Q. Turn
Vheissu Keffer
Keith Beers

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Abstract

Samples of eight tree species, bagasse, and cane trash were collected from across the state and subjected to proximate, heating value, and ultimate analyses. In addition, samples of the ash derived from these biomass materials were analyzed for 12 chemical species (Si, Al, Ti, Fe, Ca, Mg, Na, K, P, S, Cl, and C (as CO_2)). Ash deformation temperatures in both oxidizing and reducing environments were also measured. The particle size distribution and bulk densities of chipped wood samples were also determined.

Ash contents of the tree derived samples ranged from 0.42% to 5.32% of fuel mass with the higher value determined for bark removed from rose gum logs. Higher heating values ranged from 7,355 to 8,472 BTU per lb with the lower value determined for the rose gum bark sample and the high value measured for swamp mahogany. Ash contents for bagasse samples averaged 1.9%, whereas cane trash ranged from 5.4 to 17% on a dry basis. As with the tree species, higher heating values were inversely proportional to ash content ranging from 6,779 to 8,262 BTU per lb.

Nitrogen was present in all fuel sample at levels ranging from 0.3 to 0.7%. Sulfur concentrations were an order of magnitude lower, varying from 0.02 to 0.08%, consistent with the low sulfur quality of biomass fuels. Chlorine concentration ranged from <0.005% in bagasse and tropical ash to as high as 0.4 % in the bark from rose gum logs.

Analysis of ash derived from the biomass samples revealed a wide range of concentrations for 12 chemical elements. Tree species consistently exhibited high Ca concentrations, ranging from 18 to 44% CaO in the ash. Moluccan albizia had the highest potassium (as K_2O) concentration at 31% of ash and values in excess of 10% were common for the other tree species.

The sugar cane derived samples, bagasse and cane trash, were contaminated with soil during harvest and as a result produced ash samples with elevated concentrations of the elements Fe, Al, and Ti. Of the remaining elements, Si and K were present in highest concentrations in the ash.

Ash from the tree species proved to be highly refractory, exhibiting initial deformation temperatures in excess of 2500ºF under oxidizing and reducing environments. Six of the samples did not reach their initial deformation point at 2700ºF, the maximum temperature of the measurement device.

Ash from the sugar cane derived samples had lower deformation temperatures than the tree species. Initial deformation temperatures under an oxidizing environment ranged from 2100 to 2400ºF. Measurements in a reducing environment resulted in initial deformation temperatures of 2123 to 2262ºF.

Alkali metal mass per unit of fuel energy, an index of fuel quality, was calculated for each of the fuel samples. Three materials, rose gum bark, and cane trash from two sugar factories, exhibited

values greater than or equal to the threshold value of 0.34 kg (K_2O + Na_2O) per GJ of fuel energy. Above this value ash fouling and slagging can be expected in combustion facilities. All other fuels had values below 0.17 kg (K_2O + Na_2O) per GJ of fuel energy and would not be expected to exhibit ash slagging or fouling problems in a combustion environment.

1. Introduction

Biomass is the only renewable resource with the potential to produce power, fuels, and chemicals. Among renewable resources for energy generation, biomass is often a least cost alternative. As a fuel, biomass is highly flexible, as it can be used in direct combustion, combined heat and power (CHP) applications or it can be gasified (thermochemically or biologically) to produce a combustible gas. After appropriate processing, the combustible gas can be used in conversion technologies such as fuel cells, combustion turbines, and reciprocating engines. Biorefineries of the future will use biomass as a raw material and produce a suite of products including fuels, chemicals, and power, in much the same way that present day refineries produce an array of products from crude oil.

In a continuing effort to foster the development of biomass-based energy systems, the State of Hawaii, through its participation in the U.S. Department of Energy's, Pacific Regional Biomass Energy Program, has provided support for the physicochemical evaluation of biomass materials available in Hawaii. This evaluation includes volatile, fixed carbon, and ash content, heating value, elemental composition, and ash deformation temperatures. These data are the initial starting point from which biomass-based energy conversion systems can be designed. The data and analysis presented in this report serve to augment the previous results [1] for bagasse, sugarcane trash, macadamia nut shells, and sewage sludge. Bagasse is also included in the current report, although its source differs from that previously reported [1]. Analyses of biomass material removed by the wet cane cleaners in Hawaii's two sugar factories are also included in this report. Of particular prominence in the current report are analyses of wood samples from trees with potential for use as renewable feedstocks. A wood resource stream could be derived from timber harvesting, forest management activities, or alien species eradication efforts.

Bagasse is the fibrous plant material remaining after sugar extraction has been completed in commercial milling operations. Biomass material removed in the wet cane cleaner in a sugar factory is often referred to as trash and includes leaf and top material. Trash has little sugar content and, if not removed from the process stream, serves to increase the volumetric flow requirements of the process line and reduce sugar extraction efficiency. Wet cane cleaner trash can be reduced in particle size, dewatered, and used as fuel. Under current sugar cane production practices, a significant amount of cane trash is open burned prior to harvest. If this material could be economically collected, it would provide a biomass fiber resource roughly comparable in size to the bagasse fiber currently utilized.

Material from eight, non-native tree species was analyzed, including four species of eucalyptus, moluccan albizia, tropical ash, ironwood, and strawberry guava or waiwi. The eucalyptus species and albizia are currently growing on plantations on the islands of Kauai and Hawaii. The eucalyptus species are being grown for timber production. On one plantation, albizia, a nitrogen fixer, is intercropped with eucalyptus to enhance early growth and later culled when the eucalyptus stand is established. Tropical ash, ironwood, and strawberry guava are introduced species that are widely dispersed throughout the islands. Efforts to restore native forests seek to remove these species from targeted areas and these eradication efforts may produce a biomass supply stream.

Results of the analyses of the biomass resources identified above are the focus of this report. The analytical results provide a common quantitative basis for comparison of different fuels, information necessary for determining the suitability of utilizing a given fuel in a particular application, and data required for energy conversion facility design.

2. Materials and Methods

Samples of bagasse, wet cane cleaner trash, and wood were collected and analyzed as described below.

2.1 Sample Description

2.1.1 Bagasse and sugarcane trash

Samples of bagasse and trash from the wet cane cleaner were obtained from the Gay & Robinson sugar factory at Kaumakani on the island of Kauai. Bagasse was sampled as it exited the last mill and from stockpiles in the bagasse storage house. Wet cane cleaner trash was sampled from the collection pile at the exit of a discharge conveyor. Samples were place in gallon Ziplock bags and hand carried back to Oahu where they were oven dried at 103ºC until they attained constant weight [2].

Wet cane cleaner trash was also collected from the Hawaiian Commercial & Sugar Co.'s (HC&S) Puunene sugar factory on Maui. Samples were obtained from material flumed away from the wet cane cleaner exit. Samples were dried on site by HC&S personnel and provided to HNEI as oven dried material.

2.1.2 Wood Materials

Samples of wood were obtained from tree plantations on the islands of Kauai and Hawaii. On Kauai, samples of moluccan albizia (*Paraserianthes falcataria*) were obtained from slab wood derived from sawmill operations at Hawaiian Mahogany Co. Inc. Slabs were chipped and samples were collected from the resulting pile, placed in gallon ziplock bags, and hand carried back to Oahu where they were oven dried at 103ºC until constant weight was attained [2].

Samples collected on the island of Hawaii were obtained from plantations managed by Forest Solutions, Inc. Table 1 presents a listing of tree species by both common and scientific names.

One tree was selected and cut from plantation stands for each of the eucalyptus species with the exception of *E. grandis* where two trees were cut. Two ironwood, three waiwi, three tropical ash, and two moluccan albizia trees were selected and cut from volunteer stands in areas of the plantation not under cultivation. The locations where trees were sampled is shown in Figure 1. The diameter at breast height was measured for each tree before it was felled and total height was measured afterward. Trees were topped and delimbed and the remaining boles were cut into nominal 1.8 m (6 ft) bolts and trucked to a central location. The bark was removed from the bolts from one of the *E. grandis* trees by loosening it along the length with a hammer and then manually removing it. The bark and wood were separated and maintained as two distinct fractions. Each log section was chipped using a 12" (30.5 cm) disk-style chipper (Bandit Industries, Inc., Model 150, Remus, Michigan) with an 80 hp (60 kW) engine, see Figure 2. Using a five gallon bucket, subsamples were collected from the chip stream ejected from the chipper. Chip subsamples were not collected from the initial bolt of a species as it passed through the chipper to avoid contaminating the sample with chips from the preceding species.

Table 1. Tree species obtained from land managed by Forest Solutions, Inc.on the Hamakua Coast of the Island of Hawaii.

No.	Common name(s)	Scientific name
1	Rose gum	*Eucalyptus grandis*
2	Hybrid gum	*Eucalyptus grandis x urophylla*
3	Blue gum	*Eucalyptus globulus*
4	Swamp mahogany	*Eucalyptus robusta*
5	Ironwood	*Casuarina equisetifolia*
6	Waiwi or Strawberry Guava	*Psidium cattleanium*
7	Tropical ash	*Fraxinus uhdei*
8	Moluccan albizia	*Paraserianthes falcataria*

Subsamples were used in determining bulk density in a 1 ft^3 (0.028 m^3) box [3] (see Figure 3) and then transferred to 30 gallon (114 liter) plastic bags. Bagged sample weights were later determined on a balance with ±2.5 g accuracy and recorded. Three bulk density measurements were made for each wood type. Samples were air freighted to Oahu the same day they were chipped. The three bagged samples from each wood type were combined and spread on a tarp to air dry. Material from each of the wood types was sampled and oven dried at 103°C to determine moisture content [2]. The material on the tarps was mixed daily to ensure even drying and moisture was monitored periodically. After the sample moisture content reached equilibrium with ambient conditions, particle size distributions were determined for each wood type [4, 5].

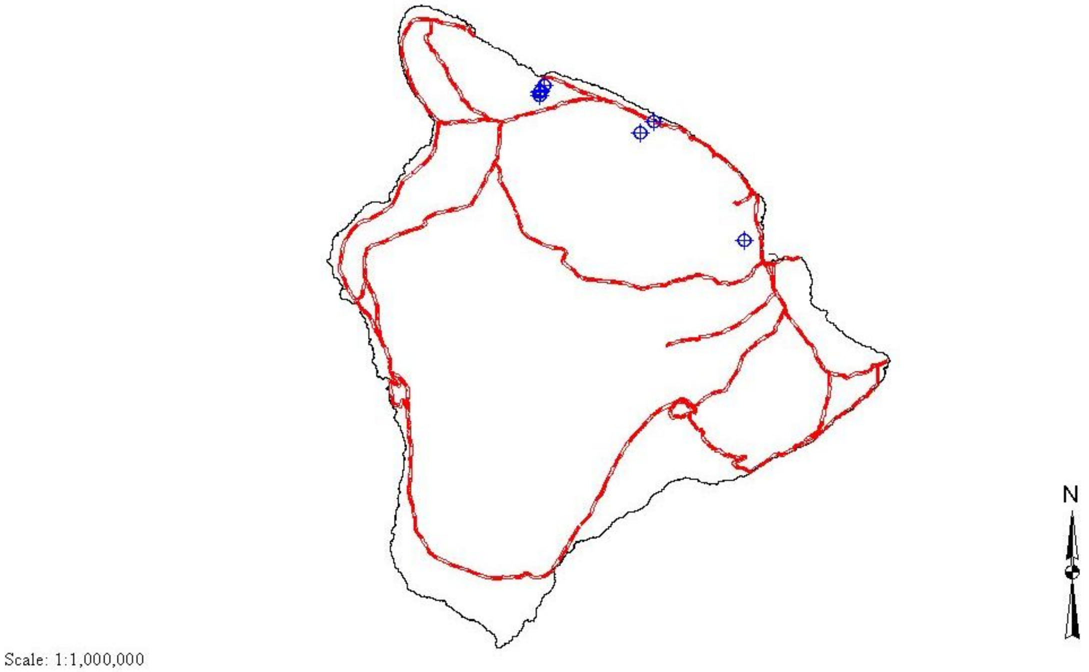

Figure 1. Locations where trees were harvested from plantations managed by Forest Solutions, Inc. to obtain samples for this study

Figure 2. Badger Model 150 chipper used to reduce bolts to chips for sampling.

Figure 3. Measurement of bulk density according to ASTM 873 [3].

2.2 Analytical Methods

Samples of the biomass materials described above were subjected to proximate, ultimate, Cl, and heating value analyses. Major ash species (Si, Al, Ti, Fe, Ca, Mg, Na, K, P, S, Cl, and C as CO_2) and ash deformation characteristics in oxidizing and reducing atmospheres were also determined. These analyses were performed by Hazen Research, Inc., Golden, CO.

3. Results and Discussion

3.1 Bulk Density

Results of the bulk density measurements are presented in Figure 4. Wet basis indicates the values derived from measurements made at the time the bolts were chipped. Dry basis values were derived from the wet basis data using the measured moisture content of each fuel. Ironwood and waiwi chips had the highest wet bulk densities with values of roughly 30 lb per ft^3 and corresponding dry bulk densities of 15.7 and 18.4 lb per ft^3, respectively. Swamp mahogany, hybrid gum, moluccan albizia, and blue gum had wet bulk densities in the range of 25 to 27 lb per ft^3 and corresponding dry bulk densities values ranging from 9.9 to 12.8 lb per ft^3. Lower wet bulk densities, in the range from 18 to 22 lb per ft^3, were determined for tropical ash, rose gum, and debarked rose gum. Dry bulk density values for these three materials ranged from 8.7 to 11.4 lb per ft^3. Note that removing the bark from rose gum bole wood resulted in lower bulk densities (dry and wet).

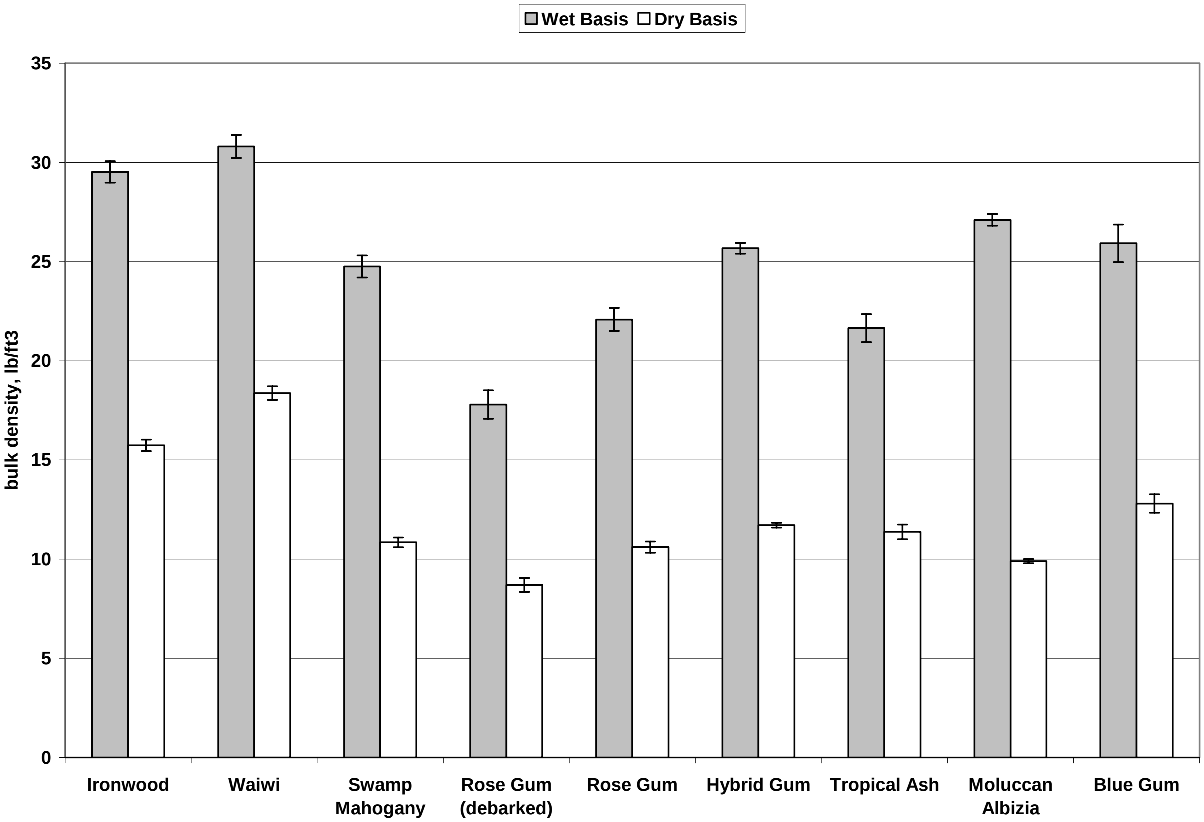

Figure 4. Bulk densities of chip samples obtained from bolts processed with a Bandit Model 150 chipper.

3.2 Particle size distribution

Particle size distributions by weight of the chipped wood samples obtained from Forest Solution's plantings are shown in Figure 5 and 6. The geometric mean diameter and geometric standard deviation by weight were calculated for each distribution and are shown in parentheses in the figure legends. For the nine materials, geometric mean diameters by weight ranged from 4.3 mm (0.17") for moluccan albizia to 10.2 mm (0.4") for tropical ash. The geometric mean diameter by weight divides the particle distribution in half; 50% of the particles by weight will be larger than the geometric mean diameter and 50% of the particles by weight will be smaller than the geometric mean diameter. Geometric standard deviations (GSD) ranged from 2.2 mm (0.09") to 4.1 mm (0.16"). GSD describes the particle size uniformity, a small GSD indicates a higher degree of uniformity in particles size and a larger GSD indicates less uniformity.

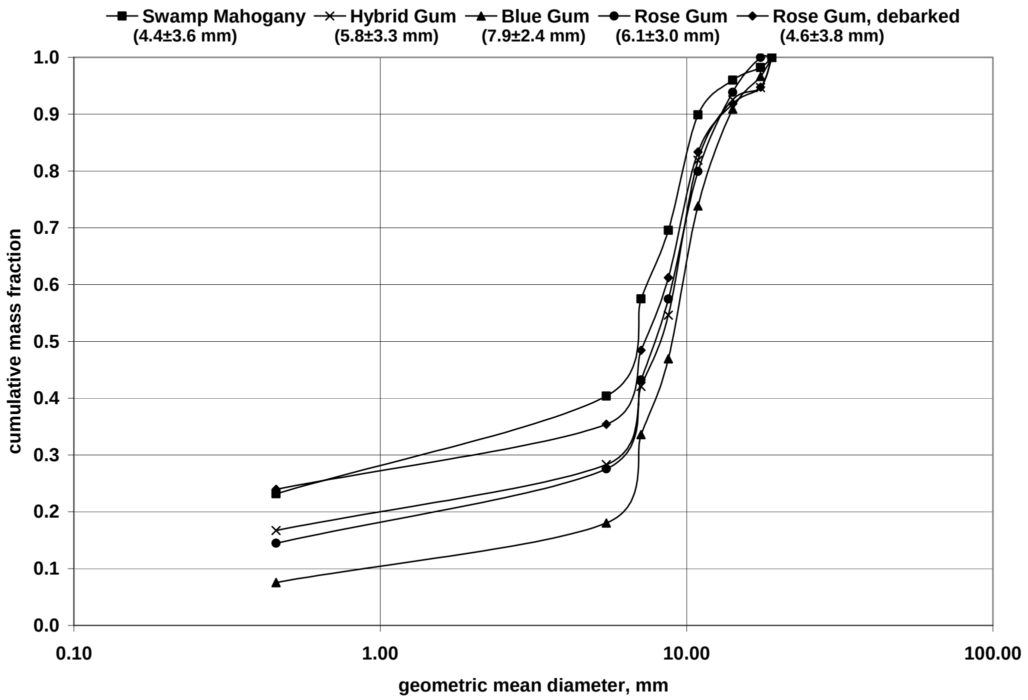

Figure 5. Particle size distributions for chips generated from bolts of eucalypts using a Badger Model 150 chipper, with geometric mean diameter and geometric standard deviation by weight in parenthesis.

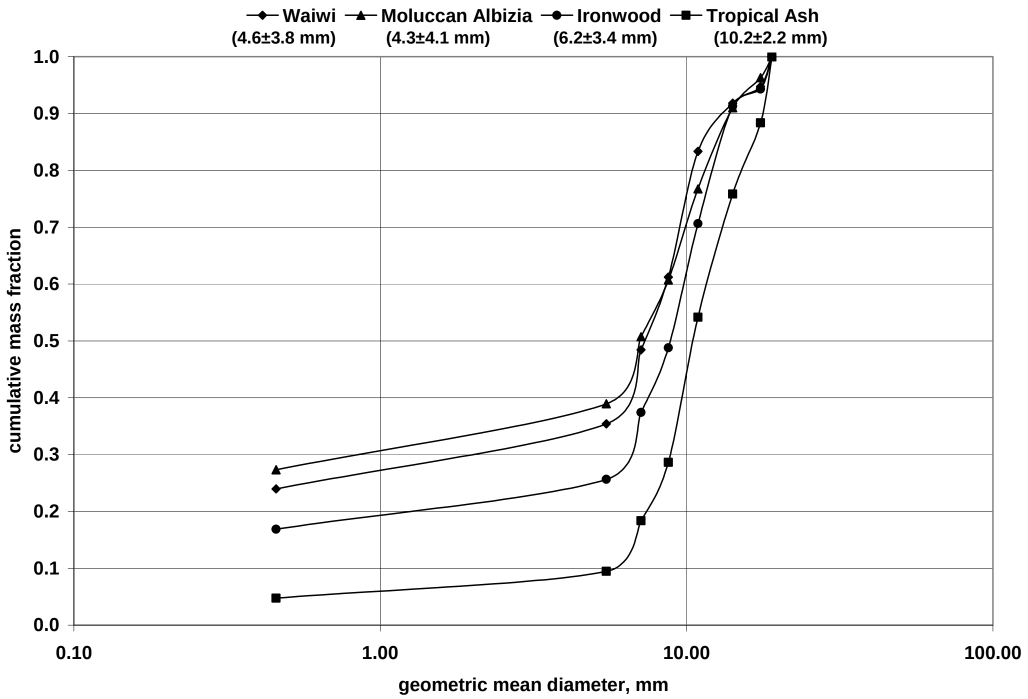

Figure 6. Particle size distributions for chips generated from bolts of waiwi, albizia, ironwood, and tropical ash, using a Badger Model 150 chipper, with geometric mean diameter and geometric standard deviation by weight in parenthesis.

3.3 Fuel analyses

Results of the analyses described above are presented in Table 2-A through 2-B. Characteristics of the different materials are discussed below.

3.3.1 Wood fuels

Results of the proximate analyses indicate that samples of bole wood that included bark generally had ash contents in the range of 0.7% for moluccan albizia to 2.0% for ironwood. The eucalypts fell in the lower end of this range with ash contents less than 1.25%. The sample of debarked rose gum (*E. grandis*) had a lower ash content (0.42%) compared to the sample with bark (0.72%). This is explained by the higher ash content (5.3%) of the rose gum bark analysis. The sample of slab wood from moluccan albizia obtained from Hawaiian Mahogany exhibited a higher ash content than the bole wood sample from Forest Solutions as would be expected due to the higher ratio of bark to bole wood.

Volatile matter content of bole wood samples that included bark ranged from 79.8% (swamp mahogany) to 86.5% (blue gum). The moluccan albizia slab wood sample also fell within this range. The rose gum bark and debarked bole wood had volatile matter content outside of this range, with the bark value being lower (75.8%) and the debarked bole being higher (87.3%). Fixed carbon values for all woody fuel samples ranged from 12 to 19% and varied inversely with volatile matter content.

Heating values of the samples of whole bole wood ranged from 8,000 BTU/lb for blue gum to 8,472 BTU per lb for swamp mahogany. A heating value of 8,237 BTU/lb was measured for the debarked rose gum sample, not substantially different than the value of 8,289 BTU/lb determined for the rose gum sample that included the bark. A bark sample was also analyzed and a heating value of 7,355 BTU/lb was determined. The moluccan albizia slab wood from Hawaiian Mahogany was found to have a heating value of 8,373 BTU/lb, slightly higher than the bole wood sample from Forest Solutions (8,207 BTU/lb).

Results of the ultimate analyses reveal that nitrogen levels in the wood samples were in the range of 0.3 to 0.7%. The two samples of moluccan albizia, a nitrogen fixing tree, were at the high end of this range (0.66% and 0.71%) with the remaining samples generally less than 0.5% N. Rose gum bark contains 0.5% N suggesting that debarking at the point of harvest could aid in soil fertility maintenance.

Sulfur levels in the wood samples were all less than 0.07% and are typical of biomass. Chlorine was present at similar concentrations, less than 0.09%, with the exception of the rose gum bark sample that contained 0.43% Cl. The elevated Cl measured in the bark fraction is supported by the measured difference between the debarked rose gum bole wood (0.01% Cl) and the rose gum bole wood containing bark (0.042% Cl).

Results of the analysis of the ash component of the wood fuels show that in most cases the largest fraction of the ash is CaO, ranging from 18 to 44%. C measured as CO_2 is also present, accounting for up to 31% of the ash content. Combined CaO and CO_2 concentrations are 30 to 72% of the wood ash. K_2O contributes more than 10% to the total ash weight with the exception of the blue gum sample. The highest levels of K_2O measured in the ash were in mollucan albizia (31.4%) and tropical ash (22.5%) samples collected from Forest Solutions. With a few exceptions, MgO, Na_2O, P_2O_5 were present in the ash at levels less than 10%. The elements Al, Fe, and Ti are normally associated with the soil contamination of biomass materials and their oxides were present in the wood samples at levels of less than 5%. The Cl and SO_3 fractions of the ash were generally less than 3%, the exceptions being Cl levels in ash from hybrid gum and the bark of rose gum. The latter is consistent with the high Cl levels in the parent bark material as noted above.

Ash deformation temperatures indicate the range over which ash may be expected to melt and form slag. Data for oxidizing and reducing environments relate to combustion and gasification applications, respectively. The ash from the wood samples is highly refractory, with the lowest initial deformation temperature measured to be 2487ºF (1364ºC). In an oxidizing environment, six of the samples did not attain a state of initial deformation at the maximum furnace temperature of 2700ºF (1482ºC). Under reducing conditions, an equal number did not reach the initial deformation point at 2700ºF (1482ºC). Under either oxidizing or reducing conditions, the largest difference between the initial deformation point and the point where the ash became fluid was 83ºF (46ºC).

3.3.2 Sugar cane derived fuels

Results of the analysis of samples of bagasse and sugar cane trash from Hawaiian Commercial & Sugar Co. (HC&S) and Gay & Robinson (G&R) are discussed below.

At the G&R mill, bagasse samples were obtained from the exit of the last mill in the sugar factory and from the exit of the conveyor delivering material to the bagasse storage house. Both samples were analyzed and the results are presented in Table 1-B. Analyses of the two materials are in close agreement. Ash content was about 2%. Volatile matter and fixed carbon fractions were about 85% and 13%, respectively. The higher heating values of the two samples were 8,138 and 8,262 BTU/lb, with the higher value determined for the sample with the lower ash content. Nitrogen, sulfur, and chlorine concentrations in the two samples were ~0.45%, 0.03%, and ≤0.007% for the two samples. All are comparable with the values determined for the wood fuels discussed above.

At both HC&S and G&R, cane trash samples were obtained from the conveyor removing material extracted from the cane wet cleaner. This material consists of a mixture of dried and green leaf material, the top or growing point, and short pieces of cane. Samples exit the conveyor with free water from the washing process. The wash water is high in suspended solids, primarily soil incorporated with the cane during the harvest process. Trash often has a high ash content as a result of mixing with the contaminated wash water. Note that the cane trash from the G&R factory has an ash content of 17% whereas the bagasse ash content was ~2%. Higher ash contents result in reduced heating values of the samples and this is evident when comparing bagasse (8,200 BTU/lb) to cane trash (6,779 to 7,692 BTU/lb).

The composition of the ash from sugar cane derived samples clearly indicates the incorporation of soil biomass. All have elevated concentrations of the soil elements Al, Ti, and Fe, totaling from 38 to 50% of the ash mass. SiO_2 accounts for more than 30% of the ash and K_2O is present at levels from 4 to 11%. Most of the remaining ash elements are present at concentrations less than 5%.

Initial ash deformation temperatures under oxidizing environments for the cane derived fuel samples ranged from 2100 to 2400ºF. The temperatures at which the ash became fluid were all above 2400ºF for the samples collected at G&R whereas the HC&S sample became fluid at 2183ºF.

Initial and fluid deformation temperatures for ash in reducing environments ranged from 2120 to 2260ºF and 2160 to 2300ºF, respectively. The samples from the HC&S factory represented the lower end of these ranges.

Table 2-A. Analyses of biomass materials found in the State of Hawaii.

	Mollucan Albizia	Swamp Mahogany	Hybrid Gum	Blue Gum	Ironwood	Tropical Ash	Rose Gum	Rose Gum	Rose Gum	Waiwi	Mollucan Albizia
Source*	F.S.	F.S.	F.S.	F.S.	F.S.	F.S.	F.S.	F.S.	F.S.	F.S.	H.M.
Plant Component	Bole w/ bark	Bole w/ bark	Bole w/ bark	Bole w/ bark	Bole w/ bark	Bole w/ bark	Bole w/out bark	Bole w/ bark	Bark	Bole w/ bark	Slab Wood
Moisture Content (% wet basis when sample collected)											
	63.5	56.2	54.4	50.6	46.7	47.5	51.1	51.9	64.3	40.4	56.3
Proximate Analysis (%, dry basis)											
Ash	0.68	1.26	0.84	1.1	2.05	1.44	0.42	0.72	5.32	1.05	1.38
Volatile	82.19	79.85	82.68	86.51	83.18	83.47	87.34	84.81	75.85	82.02	81.32
Fixed C	17.13	18.89	16.48	12.39	14.77	15.09	12.24	14.47	18.83	16.93	17.3
Higher Heating Value (dry basis)											
BTU/lb	8207	8472	8323	8003	8335	8394	8237	8289	7355	8240	8373
MJ/kg	19.1	19.7	19.4	18.6	19.4	19.5	19.2	19.3	17.1	19.2	19.5
Ultimate Analysis (% dry basis)											
C	50.47	52.57	51.96	51.95	50.5	51.15	51.12	51.26	48.85	51.81	51.48
H	5.97	5.81	5.86	5.96	6.21	5.98	5.72	5.76	5.35	5.90	5.83
N	0.71	0.35	0.31	0.30	0.48	0.49	0.33	0.30	0.51	0.45	0.66
S	0.02	0.03	0.02	0.02	0.03	0.05	0.02	0.02	0.04	0.02	0.07
Ash	0.68	1.26	0.84	1.10	2.05	1.44	0.42	0.72	5.32	1.05	1.38
O (by diff)	42.10	39.89	40.92	40.61	40.64	40.89	42.38	41.90	39.50	40.77	42.10
Cl	0.05	0.088	0.093	0.062	0.087	<0.005	0.010	0.042	0.434	0.005	0.079

* F.S. = Forest Solutions, Hawaii County
H.M. = Hawaiian Mahogany, Kauai County

Table 2-A (continued). Analyses of biomass materials found in the State of Hawaii.

	Mollucan Albizia	Swamp Mahogany	Hybrid Gum	Blue Gum	Ironwood	Tropical Ash	Rose Gum	Rose Gum	Rose Gum	Waiwi	Mollucan Albizia
Source*	F.S.	F.S.	F.S.	F.S.	F.S.	F.S.	F.S.	F.S.	F.S.	F.S.	H.M.
Plant Component	Bole w/ bark	Bole w/ bark	Bole w/ bark	Bole w/ bark	Bole w/ bark	Bole w/ bark	Bole w/out bark	Bole w/ bark	Bark	Bole w/ bark	Slab Wood
Elemental Analysis of Ash (% dry basis)											
SiO_2	0.65	10.79	2.31	2.35	2.85	1.17	3.25	1.09	1.49	1.82	3.34
Al_2O_3	1.02	3.05	1.41	1.16	1.19	1.37	1.89	1.13	1.53	0.96	4.26
TiO_2	0.07	0.17	0.07	0.07	0.06	0.02	0.16	0.05	<0.01	0.02	0.73
Fe_2O_3	0.39	1.17	0.43	0.43	1.20	1.49	1.07	0.52	0.25	0.61	3.80
CaO	18.90	28.00	24.70	35.60	38.50	30.30	23.30	44.30	36.80	41.80	39.00
MgO	14.40	7.86	9.99	9.89	4.33	6.19	4.85	5.03	3.55	2.20	3.47
Na_2O	1.10	3.59	15.60	8.50	2.43	0.73	11.00	6.53	6.58	1.22	0.71
K_2O	31.40	18.40	11.00	7.71	12.10	22.50	14.50	10.10	10.10	11.20	14.30
P_2O_5	9.57	5.29	3.33	7.06	0.43	0.92	19.79	8.50	8.45	4.40	4.72
SO_3	1.74	2.48	1.14	1.46	1.45	2.62	2.67	1.17	0.70	1.42	2.36
Cl	2.84	1.74	4.25	0.83	2.13	0.17	0.88	0.36	5.26	0.24	2.06
CO_2	11.30	13.21	25.47	17.67	25.25	21.24	9.98	4.31	0.72	30.92	19.41
Undetermined	6.62	4.25	0.3	7.27	8.08	11.28	6.66	16.91	24.57	3.19	1.84
Ash Fusion Temperature (ºF), Oxidizing Atmosphere											
Initial	2700+	2525	2647	2700+	2570	2700+	2700+	2700+	2668	2700+	2487
Softening		2539	2655		2579				2688		2543
Hemispherical		2555	2666		2586				2682		2550
Fluid		2581	2678		2596				2690		2570
Ash Fusion Temperature (ºF), Reducing Atmosphere											
Initial	2700+	2700+	2658	2700+	2669	2700+	2700+	2668	2700+	2680	2653
Softening			2689		2675			2700+		2683	2668
Hemispherical			2693		2682					2685	2679
Fluid			2698		2686					2688	2688

[*] F.S. = Forest Solutions, Hawaii County
H.M. = Hawaiian Mahogany, Kauai County

Table 2-B. Analyses of biomass materials found in the State of Hawaii.

Source[*]	G&R	G&R	G&R	HC&S
Material	Wet Cleaner Cane Trash	Bagasse from Last Mill	Bagasse from Bagasse House Conveyor	Wet Cleaner Cane Trash
Moisture Content (% wet basis when sample collected)				
	77.2	53.1	51.1	72.2
Proximate Analysis (%, dry basis)				
Ash	17	2.03	1.75	5.36
Volatile	69.38	84.51	85.35	79.96
Fixed C	13.62	13.46	12.9	14.68
Higher Heating Value (dry basis)				
BTU/lb	6779	8138	8262	7692
MJ/kg	15.8	18.9	19.2	17.9
Ultimate Analysis (% dry basis)				
C	42.94	50.46	50.15	47.85
H	4.98	5.79	5.66	5.64
N	0.66	0.48	0.44	0.45
S	0.05	0.03	0.03	0.08
Ash	17	2.03	1.75	5.36
O (by diff)	34.24	41.20	41.97	40.34
Cl	0.128	0.007	<0.005	0.281

[*] G&R = Gay and Robinson, Kauai County
HC&S = Hawaiian Commercial & Sugar Co. Inc., Maui County

Table 2-B (continued). Analyses of biomass materials found in the State of Hawaii.

Source*	G&R	G&R	G&R	HC&S
Material	Wet Cleaner Cane Trash	Bagasse from Last Mill	Bagasse from Bagasse House Conveyor	Wet Cleaner Cane Trash
Elemental Analysis of Ash (% dry basis)				
SiO_2	34.24	36.04	36.65	36.89
Al_2O_3	24.5	19.54	17.74	15.38
TiO_2	2.14	2.97	3.26	2.19
Fe_2O_3	23.45	16.48	15.83	10.75
CaO	2.7	2.41	2.94	6.46
MgO	1.18	2.1	2.46	5.26
Na_2O	0.27	0.48	0.52	2.49
K_2O	3.74	11.1	10.7	8.68
P_2O_5	0.97	3.12	3.63	2.43
SO_3	0.66	0.91	1.01	2.26
Cl	0.12	0.06	0.12	1.33
CO_2	0.48	0.65	0.91	2.29
Undetermined	5.55	4.14	4.23	3.59
Ash Fusion Temperature (ºF), Oxidizing Atmosphere				
Initial	2234	2413	2346	2104
Softening	2425	2424	2411	2149
Hemispherical	2456	2435	2421	2157
Fluid	2481	2440	2428	2183
Ash Fusion Temperature (ºF), Reducing Atmosphere				
Initial	2164	2262	2237	2123
Softening	2214	2294	2252	2134
Hemispherical	2254	2299	2259	2143
Fluid	2303	2303	2266	2161

*G&R = Gay and Robinson, Kauai County
HC&S = Hawaiian Commercial & Sugar Co. Inc., Maui County

3.4 Comparison of fuel alkali concentrations

The mass of fuel alkali on a unit fuel energy basis can be used as an indicator of fuel quality. In a combustion or gasification environment, the alkali metals, K and Na, present in the fuel may vaporize or melt. Melted ash constituents, or slag, can impact the operation of the energy conversion device by solidifying on combustor grates or causing loss of fluidization in fluidized bed units. Vapor phase alkali metals may condense when the flue or product gases are cooled, forming deposits and fouling working surfaces of the energy conversion device. Sulfur and chlorine participate in deposit formation by reacting with alkali species to form sulfates and chlorides. Figure 7 presents a comparison of the fuels based on their element masses of total alkali as oxides, sulfur as SO_3, and Cl, per unit of fuel energy. The wet cane cleaner trash samples and the rose gum (*E. grandis*) bark samples exhibit the highest total alkali concentrations, ranging from 0.33 to 0.52 kg ($K_2O + Na_2O$) per GJ of fuel energy. In a combustion environment, fuels containing greater than 0.34 kg ($K_2O + Na_2O$) per GJ of fuel energy are certain to cause slagging or fouling problems [6]. Those falling in the interval from 0.17 to 0.34 kg ($K_2O + Na_2O$) per GJ of fuel energy have an increased probability and those below 0.17 kg ($K_2O + Na_2O$) per GJ of fuel energy are predicted to be free of ash related slagging and fouling issues. Other than the cane trash and bark samples, all fuels fall into the latter region, indicating that their use as fuels would not be expected to present ash related problems in a combustion system. Two species, tropical ash and ironwood, exhibit values approaching the 0.17 kg ($K_2O + Na_2O$) per GJ of fuel energy benchmark and should be investigated further.

4. Summary and Conclusions

Samples of eight tree species, bagasse, and cane trash were collected from across the state and subjected to proximate, heating value, and ultimate analyses. In addition, samples of the ash derived from these biomass materials were analyzed for 12 chemical species (Si, Al, Ti, Fe, Ca, Mg, Na, K, P, S, Cl, and C (as CO_2)). Ash deformation temperatures in both oxidizing and reducing environments were also measured. The particle size distribution and bulk densities of chipped wood samples were also determined.

Ash contents of the tree derived samples ranged from 0.42% to 5.32% of fuel mass with the higher value determined for bark removed from rose gum logs. Higher heating values ranged from 7,355 to 8,472 BTU per lb with the lower value determined for the rose gum bark sample and the high value measured for swamp mahogany. Ash contents for bagasse samples averaged 1.9%, whereas cane trash ranged from 5.4 to 17% on a dry basis. As with the tree species, higher heating values were inversely proportional to ash content ranging from 6,779 to 8,262 BTU per lb.

Nitrogen was present in the fuel sample at levels ranging from 0.3 to 0.7%. Sulfur concentrations were an order of magnitude lower, varying from 0.02 to 0.08%, consistent with the low sulfur quality of biomass fuels. Chlorine concentration ranged from <0.005% in bagasse and tropical ash to as high as 0.4 % in the bark from rose gum logs.

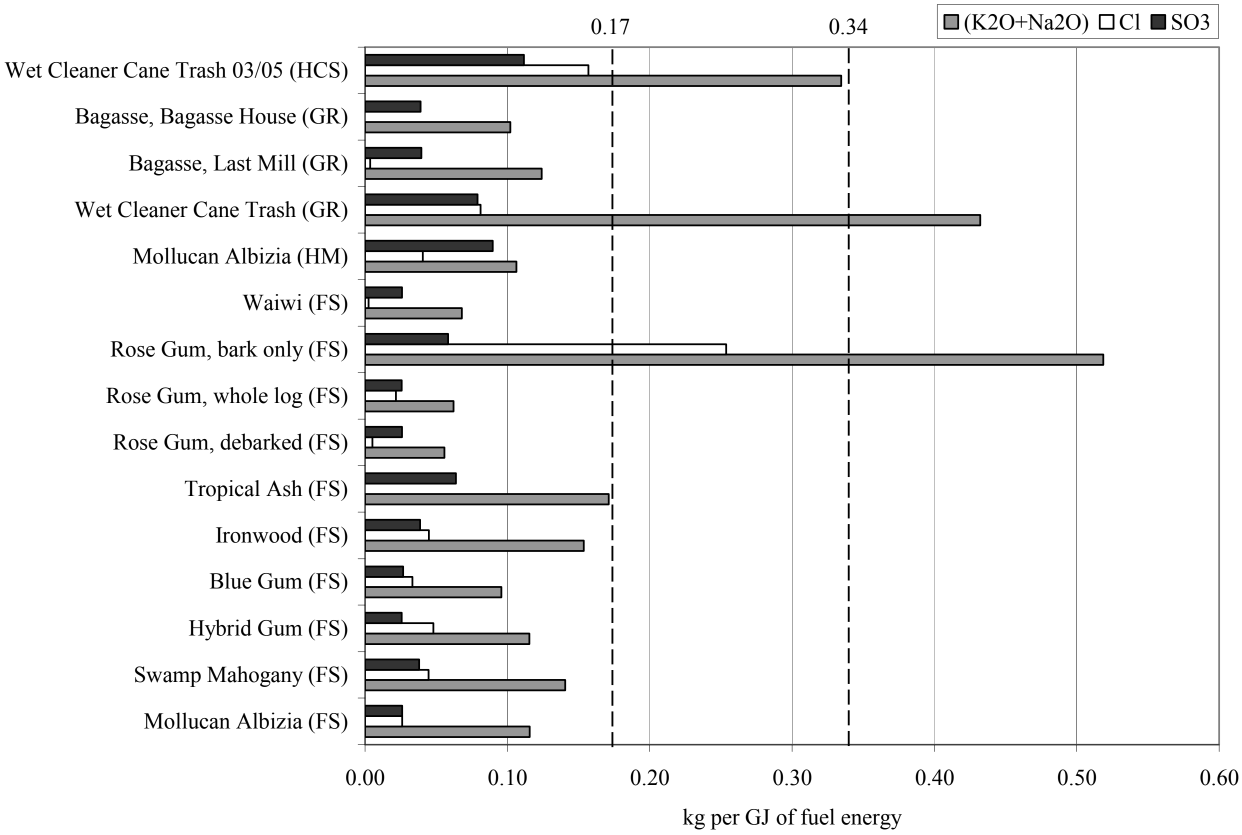

Figure 7. Summary of occurrence of selected ash elements on a unit energy basis for each fuel. Source of fuel sample is indicated by FS – Forest Solutions, HM – Hawaiian Mahogany, GR – Gay & Robinson, and HCS – Hawaiian Commercial & Sugar.

Analysis of ash derived from the biomass samples revealed a wide range of concentrations for 12 chemical elements. Tree species consistently exhibited high Ca concentrations, ranging from 18 to 44% CaO in the ash. Moluccan albizia had the highest potassium concentration at 31% of ash and values in excess of 10% were common for the other tree species.

The sugar cane derived samples, bagasse and cane trash, were contaminated with soil during harvest and as a result produced ash samples with high concentrations of the elements Fe, Al, and Ti. Of the elements that were plant, rather than soil, derived, Si and K were present in highest concentrations in the ash.

Ash from the tree species proved to be highly refractory, exhibiting initial deformation temperatures in excess of 2500ºF under oxidizing and reducing environments. Six of the samples did not reach their initial deformation point at 2700ºF, the maximum temperature of the measurement device.

Ash from the sugar cane derived samples had lower deformation temperatures than the tree species. Initial deformation temperatures under an oxidizing environment ranged from 2100 to 2400ºF.

Measurements in a reducing environment resulted in initial deformation temperatures of 2123 to 2262°F.

Alkali metal mass per unit of fuel energy, an index of fuel quality, was calculated for each of the fuel samples. Three materials, rose gum bark, and cane trash from two sugar factories, exhibited values greater than or equal to the threshold value of 0.34 kg (K_2O + Na_2O) per GJ of fuel energy. Above this value ash fouling and slagging can be expected in combustion facilities. All other fuels had values below 0.17 kg (K_2O + Na_2O) per GJ of fuel energy and would not be expected to exhibit ash related problems in a combustion environment.

5. References

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