Final Technical Report

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Executive Summary

This project had two main goals. The first goal was to evaluate several high yielding tropical perennial grasses as feedstock for biofuel production, and to characterize the feedstock for compatible biofuel production systems. The second goal was to assess the integration of renewable energy systems for Hawaii.

The project focused on high-yield grasses (napiergrass, energycane, sweet sorghum, and sugarcane). Field plots were established to evaluate the effects of elevation (30, 300 and 900 meters above sea level) and irrigation (50%, 75% and 100% of sugarcane plantation practice) on energy crop yields and input. The test plots were extensive monitored including: hydrologic studies to measure crop water use and losses through seepage and evapotranspiration; changes in soil carbon stock; greenhouse gas flux (CO_2, CH_4, and N_2O) from the soil surface; and root morphology, biomass, and turnover. Results showed significant effects of environment on crop yields. In general, crop yields decrease as the elevation increased, being more pronounced for sweet sorghum and energycane than napiergrass. Also energy crop yields were higher with increased irrigation levels, being most pronounced with energycane and less so with sweet sorghum. Daylight length greatly affected sweet sorghum growth and yields. One of the energy crops (napiergrass) was harvested at different ages (2, 4, 6, and 8 months) to assess the changes in feedstock characteristics with age and potential to generate co-products. Although there was greater potential for co-products from younger feedstock, the increased production was not sufficient to offset the additional cost of harvesting multiple times per year. The feedstocks were also characterized to assess their compatibility with biochemical and thermochemical conversion processes. The project objectives are being continued through additional support from the Office of Naval Research, and the Biomass Research and Development Initiative.

Renewable energy assessments included: biomass feedstocks currently being produced by Hawaiian Commercial & Sugar Co., and possibilities of producing methane from agricultural and livestock wastes and the potential of photovoltaic systems for irrigation pumping at HC&S. Finally, the impact of a micro-hydroelectric system on a small-farm economics and the local community was assessed.

Accomplishments Relative to Goals and Objectives

Objective A- Develop high yield, tropical feedstocks.

Task A.1 Genetic improvement of C4 grasses (Turano)

18 wild napiergrass and seven guinea grass accessions were collected from the islands of Oahu, Maui, Hawaii, and Kauai. A randomized complete block variety trial was conducted at Waimanalo, Oahu (elevation 65 feet) and Kula, Maui (elevation 3000 feet) with the accessions. Yield and chemical composition analyses are discussed in Task B. The genetic diversity of Hawaiian germplasm was determined with molecular markers. 59 pearl millet SSR markers were screened for production of DNA polymorphisms on napiergrass accessions. The project demonstrated that pearl millet molecular markers could be used to determine the genetic diversity of napiergrass. Eleven markers were used with all accessions. 13 SSR Guinea grass markers were screened on Guinea grass accessions. Six markers were deemed useful for genetic diversity determination. Molecular markers were used to screen additional Hawaiian and non-Hawaiian accessions, as well as pearl millet x napiergrass (PMN) hybrids acquired/developed during the course of the project. The study showed that Hawaiian accessions were genetically distinct and, in contrast to our expectation, could not be grouped by island.

Flow cytometry, stomatal guard cell size, and chromosome squash techniques and analysis were performed to characterize genome size and ploidy of napiergrass, PMN hybrids, and Guinea grass accessions. Flow cytometry and stomatal size measurements are used to determine genome size. Our results demonstrate that neither method is sufficient to distinguish between napiergrass and PMN hybrids genomes.

Crossing napiergrass accessions with cytoplasmic male sterile pearl millet varieties obtained from ICRISAT, Hyderabad, India in field and greenhouse trials, developed PMN hybrids. Ten/2000 PMN progeny were selected for additional trials. Current, post-project research is focused on the drought tolerance of PMN hybrids in comparison to best performing napiergrass accessions.

Objective B. Optimize biomass conversion of feedstocks into consumable energy.

Task B.1 Determine the effect of pretreatment on the biochemical conversion of C-4 grasses into biofuel (Khanal)

Subtask B.1.1 Apply dewatering of harvested feedstock to evaluate the potential of generating co-products and/or advanced biofuels

Aliquots of the liquid fraction for 2, 4, 6, 8 month old Napiergrass have been collected following a screw-pressing unit operation at 40 psi backpressure. Analyses of the juice for co-product potential on the basis of total Kjeldahl nitrogen (TKN) and chemical oxygen demand (COD) have been completed. The aforementioned parameters are inversely related to fungal biomass yields, which were the main co-products of interest. COD and TKN are consumed/removed from solution as fungal biomass increases. Mature napiergrass (8 months of age) was found to contain the highest concentrations of TKN and COD of 1.03 ± 0.01 g/L and 58.61 ± 1.67 g/L, respectively. However, the moisture content of mature Napiergrass was determined to be 70 ± 2 %, lower than younger (≤ 6 months old) biomass. Lower moisture contents corresponded to reduced juice recovery.

The growth of *Rhizopus oligosporus* was demonstrated in preceding experiments and reports as a potential avenue for co-product generation, however preliminary economic calculations suggested that bioreactor requirements in Hawaii for fungal growth, namely the energy intensive unit operations and high electricity costs ($0.35/kWh) of the state, limit the application of this particular species in the islands. The original intent was to cultivate *R. oligosporus* for animal/fish feed applications to improve the self-sufficiency of Hawaii's agricultural/livestock production. Because of high production costs associated with microbial cultivation, however, other microbial species of greater economic value are recommended for consideration in biorefining napiergrass (e.g., photosynthetic cultures for neutraceuticals, bioplastics, etc.).

Subtask B.1.2 Pretreatment of the residual lignocellulosic fiber to determine its feasibility for bioconversion into advanced biofuel through biochemical pathway

The dilute acid pretreatment of napiergrass, dewatered and extruded from a screw-press, was shown to be effective at releasing > 95% of the xylose and 85% of the glucose content from the biomass structure at laboratory scale under the conditions of 5% w/w sulfuric acid, 120°C, and 45 minutes residence time.

Scale-up of the dilute acid pretreatment from 30 mL to 300 mL resulted in a shift of optimal pretreatment conditions. Specifically, comparable concentrations of structural (hemicellulosic) sugars (as determined by DNS analyses) were released in the acid hydrolysate under the conditions of 2.5% w/w sulfuric acid, 130°C, and 45 minutes residence time. The increase in temperature suggested that mass transfer might be more of a limiting factor in the efficacy of pretreatment than acid concentration in the ten-fold scale-up. Future research implementing factorial design at two or more levels would produce insightful data to support or disprove this hypothesis.

Subtask B.1.3 Test butanol fermentation of the hydrolyzate to optimize biofuel yield

Pretreatment and saccharification have been scaled up accordingly to produce 900-1200 mL of acid hydrolysate (from dilute acid pretreatments). Pretreated fibers (~400 g) were neutralized, dried, and sent to our collaborators at Ohio State University (OSU) for enzymatic saccharification.

At OSU, the napiergrass hydrolysates were used as the primary substrate for biofuel fermentation and produced only 3 g/L butanol due to the combined effects of lignocellulose-derived microbial inhibitory compounds (LDMIC) and butanol (**Figure B.1.1**). To circumvent the effects of butanol toxicity to the fermentation microbes, a proof-of-concept experiment using vacuum-assisted gas stripping for acetone, butanol, and ethanol (ABE) fermentation was implemented to examine if there were any positive impacts on mixed sugar utilization and butanol yield. Preliminary results indicated that *Clostridia beijerinckii* was able to produce over 8 and 3 g/L butanol and acetone, respectively, with napiergrass hydrolysates as the primary substrate in the aforesaid vacuum-assisted gas stripping coupled fermentation (**Figure B.1.2**). In addition, pentose sugars were utilized 1.7 fold better in this process than in batch fermentation without *in situ* product recovery. The impact of this process is significant in that the technology can be used to recover fuels and chemicals from fibrous/impure substrates such as lignocellulosic biomass without clogging the system.

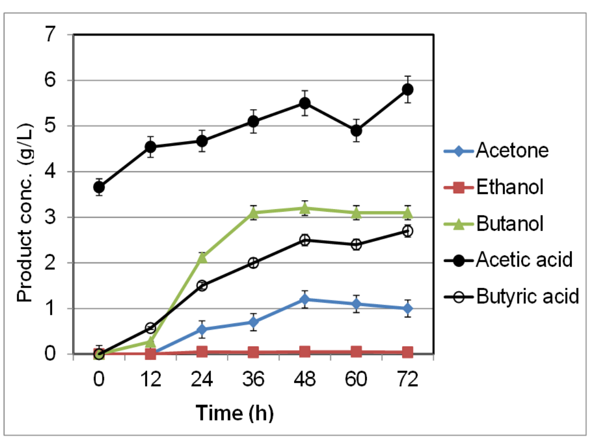


Figure B.1.1

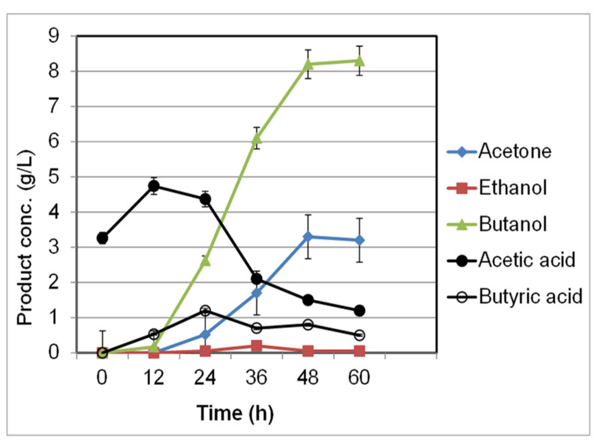


Figure B.1.2

Subtask B.1.4 Investigate impact of anaerobic digestion of the liquid stream on the feasibility of producing biogas for heat/stream and electricity generation

Analyses of the liquid stream remain contingent on the successful completion of the previous task at OSU, however, because of the time needed to address the toxicity issues, this task was not completed. Biofuel yields were low due to butanol toxicity. The fermentation setup was redesigned to mitigate butanol toxicity and improve ABE fermentation.

<u>Task B.2.</u> Investigate the thermochemical conversion of C4 grasses for syngas production

Sub-Task B.2.1. Determine methods to process Napiergrass and guinea grass to improve fuel characteristics.

Tropical biomass feedstock candidates, banagrass (*Pennisetum purpureum* x *Pennisetum glaucum*), guinea grass (*Panicum maximum*), energy cane (*Sacharum spontaneum*), and sugarcane (*Saccharum officinarum L.*) were processed to improve fuel properties by removing water soluble inorganic elements, mostly alkali metals (Na and K), sulfur (S) and chlorine (Cl). At temperatures typical of gasification or combustion systems (≥800 °C) these elements can create deposits on heat exchange surface, produce slag in high temperature regions, and contribute to pollutant/contaminant formation that require active control methods. Accordingly, removal of these elements via fuel processing prior to thermochemical conversion can be an effective control measure.

A flow diagram of the process used on two varieties of banagrass (G-Bana and P-Bana), guinea grass (OG-03), and energy cane (E-cane) is shown in Figure 1. A commercial sugarcane variety was also processed as a reference material. The process utilized a screw press to mechanically dewater freshly harvested biomass materials with subsequent rehydration and mechanical dewatering. Designations for solids (S0, S1, S2, and S3) and liquids (L1, L2, and L3) at each point in the process are defined in Figure 1.

Results of fuel analyses of the S0, S1, and S3 solid material streams are presented in Tables 1 and 2. The analysis of solid fuel S1 indicates that the fuel property is upgraded with lower ash content, increased higher heating values, and higher ash deformation temperatures, when compared with the unprocessed materials. Additional improvement can be achieved by rinsing the material with water and using a secondary mechanical dewatering in the screw press. This yields a final processed fuel, S3, and two liquid streams, L2 and L3. The properties of the resulting S3 fuel have been improved over the S0 and S1 materials, and exhibit a higher ratio of VM (volatile matter) to FC (fixed carbon). The process removed about 10% of dry matter from the unprocessed banagrass or energy cane into the initial L1 liquid during the production of fuel S1, and the removal is increased to about 20% for sugar cane. An additional 10% of dry matter, based on the unprocessed fuels, was transferred to the rinse leachate L2 and the liquid L3 in the production of the final processed fuel S3. Chemical oxygen demand, sugar content, total solid content, total suspended solids, major and trace elements or heavy metal content of the liquid stream were determined to inform design of beneficial reuse or disposal processes.

Chemical equilibrium calculation showed that using a processed fuel in steam gasification can significantly reduce the concentration of elements of concern, such as potassium, sodium, chlorine, and sulfur, etc., the product gas stream.

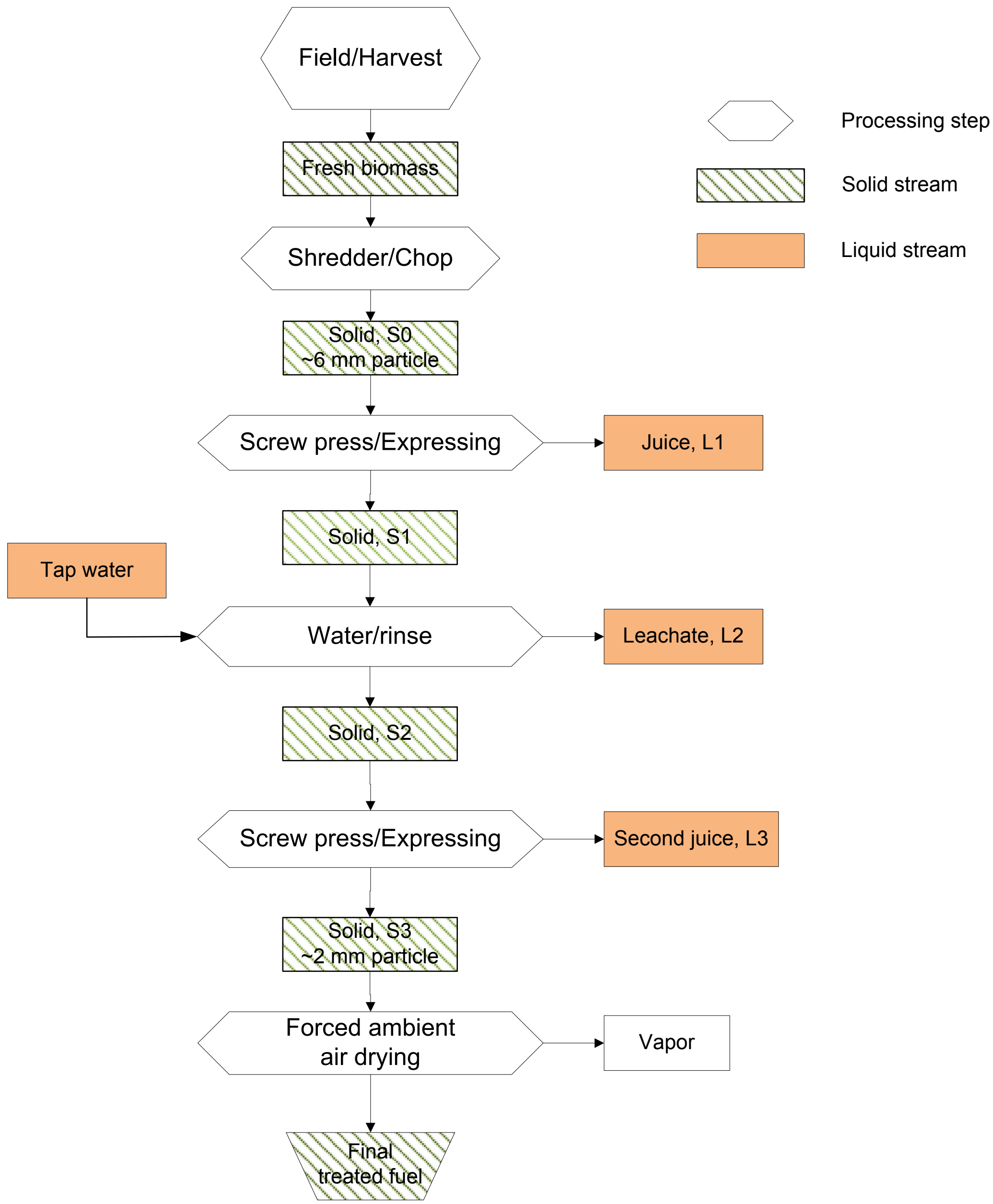


Fig. 1. Schematic of fuel processing and samples generated from banagrass (Material streams are identified as liquid (L#) or solid (S#))

Table 1. Fuel property analyses for green banagrass (G-Bana), purple banagrass (P-Bana) guinea grass (OG03), and energy cane (E-cane)

Samples	G-Bana-S0	G-Bana-S1	G-Bana-S3	P-Bana-S0	P-Bana-S1	P-Bana-S3	OG03-S0	OG03-S1	OG03-S3	E-cane-S0	E-cane-S1	E-cane-S3
Proximate Analysis												
Moisture (%, wet basis)	57.7	46.7	52.9	65.0	50.9	56.6	56.9	48.6	53.8	67.3	47.9	54.8
Ash (%, dry)	6.9	5.7	4.3	7.9	5.8	5.5	8.2	7.8	5.9	5.3	4.5	4.5
VM (%, dry)	76.6	78.4	82.8	74.5	78.3	81.4	73.5	76.2	80.5	79.8	82.0	85.6
FC (%, dry)	16.5	15.9	12.9	17.6	15.9	13.2	18.4	16.0	13.5	15.0	13.5	9.9
HHV(MJ/kg, dry)	17.8	18.0	18.2	17.6	17.8	18.3	17.4	17.2	18.2	16.8	17.8	17.7
Ultimate analysis (Dry, %)												
C	48.2	48.4	49.9	47.5	48.8	48.7	47.3	47.6	48.9	46.8	47.8	48.6
H	5.56	5.56	5.69	5.53	5.63	5.58	5.42	5.54	5.56	5.71	5.77	5.71
N	0.36	0.21	0.2	0.43	0.31	0.18	0.33	0.25	0.17	0.36	0.27	0.34
S	0.07	0.04	0.01	0.06	0.03	0.03	0.06	0.02	0.02	0.30	0.13	0.05
Cl	0.62	0.38	0.07	0.83	0.49	0.08	0.86	0.65	0.09	0.41	0.17	0.02
Elements analysis of ash (%, 600 ^{o}C ash)												
SiO_2	53.5	59.7	82.7	53.9	68.1	86.1	53.0	60.3	82.1	54.4	69.5	82.4
Al_2O_3	0.4	0.75	0.4	0.54	0.41	0.61	0.41	0.55	0.68	2.31	2.47	2.88
TiO_2	2.82	0.18	0.02	0.13	0.27	0.05	0.09	0.27	0.07	0.02	0.01	0.18
Fe_2O_3	0.38	0.64	0.7	0.33	0.53	0.51	0.35	0.66	0.77	0.84	1.17	1.87
CaO	4.84	4.58	5.93	3.92	4.44	4.62	3.60	3.97	5.21	7.21	5.05	4.17
MgO	5.75	4.17	2.41	5.21	4.11	2.54	6.80	6.40	4.23	5.29	3.22	1.77
Na_2O	1.12	0.74	0.49	1.09	0.82	0.53	3.33	3.24	1.05	0.74	0.49	0.47
K_2O	18.8	16.7	4.45	20.1	12.2	4.24	19.9	15.5	4.25	15.2	8.53	2.45
P_2O_5	5.46	4.08	1	3.28	3.1	0.91	3.49	2.52	0.93	4.45	3.36	1.03
SO_3	1.86	1.45	0.54	1.47	0.81	0.4	1.39	0.87	0.51	8.04	3.43	1.70
Cl	6.31	4.61	0.36	7.58	2.53	0.35	8.97	5.89	0.31	3.14	0.79	0.02
CO_2	0.35	0.45	0.41	0.39	0.26	0.28	0.24	0.18	1.13	0.18	0.29	0.29
Total	101.6	98.1	99.4	97.9	97.6	101.1	101.6	100.3	101.2	101.8	98.3	99.2
Ash deformation temperature (^{o}C)												
Oxidizing atmosphere												
Initial	1116	1142	>1482	1131	1251	>1482	1093	1099	>1482	1123	1243	>1482
Softening	1158	1260		1274	1460		1124	1173		1166	1456	
Hemispherical	1226	1286		1299	1468		1162	1226		1216	>1482	
Fluid	1268	1337		1329	1473		1189	1268		1232		
Reducing atmosphere												
Initial	1126	1154	>1482	1086	1274	>1482	1037	1036	>1482	1029	1349	>1482
Softening	1288	1273		1260	1466		1149	1132		1116	1420	
Hemispherical	1338	1321		1337	>1482		1204	1182		1207	1465	
Fluid	1391	1374		1371			1247	1254		1261	>1482	

Table 2. Trace elements in unprocessed samples (S0) and processed samples (S1 and S3) for green banagrass (Bana-P276 and G-Bana), purple banagrass (P-Bana), guinea grass (OG03), and energy cane (E-cane) (units in mg of element/kg of dry fuel)

Name	Symbol	G-Bana-S0	G-Bana-S1	G-Bana-S3	P-Bana-S0	P-Bana-S1	P-Bana-S3	OG03-S0	OG03-S1	OG03-S3	E-cane-S0	E-cane-S1	E-cane-S3
Antimony	Sb	<0.35	<0.28	<0.22	<0.40	<0.29	<0.27	<0.41	<0.39	<0.30	NA	NA	NA
Arsenic	As	0.25	0.06	0.05	0.13	0.06	0.17	0.31	0.08	0.10	NA	NA	NA
Barium	Ba	2.07	2.16	1.25	1.98	2.03	1.80	4.81	4.00	3.54	1.46	1.42	2.18
Beryllium	Be	<0.35	<0.28	<0.22	<0.40	<0.29	<0.27	<0.41	<0.39	<0.30	NA	NA	NA
Boron	B	3.81	<2.84	<2.16	10.03	3.69	4.17	<4.08	6.77	<2.95	NA	NA	NA
Cadmium	Cd	0.46	0.41	0.29	0.45	0.35	0.27	0.49	0.52	0.38	<1.5	<1.3	<1.3
Chromium	Cr	19.21	29.14	35.38	<0.40	17.02	16.00	<0.41	37.00	44.31	<3.8	25.13	26.59
Cobalt	Co	0.69	0.57	0.43	0.79	1.16	0.49	0.82	0.78	0.59	<2.0	<1.8	<1.7
Copper	Cu	5.18	14.77	6.48	7.19	4.94	4.97	6.28	11.76	8.85	3.64	4.04	5.67
Fluorine	F	<13.82	<11.36	<8.64	<15.80	<11.62	<10.92	<16.30	<15.68	<11.80	NA	NA	NA
Germanium	Ge	<0.14	<0.11	<0.09	<0.16	<0.12	<0.11	<0.16	<0.16	<0.12	NA	NA	NA
Lead	Pb	4.91	2.78	2.46	2.37	2.32	1.64	3.83	1.49	1.06	<15.3	<13.2	<12.9
Manganese	Mn	24.19	18.18	11.66	26.07	18.59	13.65	32.60	35.28	25.96	17.90	16.47	15.39
Mercury	Hg	<0.0007	<0.0006	<0.0004	<0.001	<0.0006	<0.0005	<0.0008	<0.0008	<0.0006	NA	NA	NA
Molybdenum	Mo	2.04	1.74	1.78	0.47	6.86	9.34	0.42	1.10	0.94	<6.1	<5.3	<5.2
Nickel	Ni	8.29	15.34	18.58	2.37	9.88	9.83	1.63	21.17	23.01	<5.1	12.85	13.50
Selenium	Se	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	NA	NA	NA
Strontium	Sr	15.69	13.46	12.10	15.01	13.83	12.56	15.57	15.76	14.57	14.55	10.79	9.56
Thorium	Th	<0.35	<0.28	<0.22	<0.40	<0.29	<0.27	<0.41	<0.39	<0.30	NA	NA	NA
Tin	Sn	<6.91	6.82	<4.32	10.27	<5.81	<5.46	<8.15	<7.84	<5.90	NA	NA	NA
Uranium as U3O8	U	<0.07	<0.06	<0.04	<0.08	<0.06	<0.05	<0.08	<0.08	<0.06	NA	NA	NA
Vanadium	V	0.76	1.74	0.23	2.70	2.28	1.36	1.96	3.78	1.50	<2.6	<2.2	<2.2
Zinc	Zn	24.19	23.86	7.78	31.60	18.59	12.56	23.64	20.38	15.34	10.96	10.80	13.12

Note: NA = not available

Sub-Task B.2.2. Determine gasification characteristics of processed Napiergrass and guinea grass.

Gasification Fuel processing and gasifier tests were conducted in the research facilities of the Hawaii Natural Energy Institute at the University of Hawaii at Manoa on four biomass fuel candidates for the state of Hawaii including green and purple banagrass (*Pennisetum purpureum x Pennisetum glaucum*), guinea grass (*Panicum maximum*), and energy cane (*Sacharum spontaneum*). Fuel properties were evaluated and gasification behaviors investigated in a bench scale fluidized bed gasifier.

Prior to conducting tests in the gasifier, all biomass plants were harvested and processed to eliminate obvious contaminants that could potentially have negative impacts on the gasifier operation or product gas quality. Fuel processing consisted of pressing and leaching techniques to reduce moisture content and concentrations of alkali and alkaline earth metals, chlorine, and sulfur, as well as select trace elements and heavy metals. The processed fuels were determined to have lower ash content, improved heating value, higher ash deformation temperatures, and higher ratios of volatile matter (VM) to fixed carbon (FC) when compared to the parent material. All have implications for design of thermochemical conversion reactors.

All processed biomass materials were characterized as fuels in a steam-blown, bench scale, bubbling fluidized bed, gasifier at the same nominal test conditions with a reactor temperature of 800 °C, a steam to biomass ratio of 2, and a fuel feed rate of 1 kg hr^{-1}. In these tests, gas production yields were obtained; gas species and primary contaminants in the gas stream were sampled and analyzed. Concentrations of the primary contaminants of concern are reported, including tar compounds, sulfur compounds, ammonia, chloride, cyanide, and trace elements. Results are summarized below:

<u>*Product gas composition and yield*</u>

Product gas contained four main species, H_2, CO, CH_4, and CO_2. Their concentrations varied slightly between the four test fuels, ranging from 39 to 44% for H_2, 22 to 27% for CO, 10 to 12% for CH_4, and 19 to 23% for CO_2. C_2H_4 and C_2H_6 were present in lower concentration, ranging from 1.9 to 2.4% and 0.2 to 0.3%, respectively, for the four tested biomass fuels. Product gas yields were calculated based on the measured fuel feed rate (kg/hr, dry basis) and the measured volume of product gas exiting the reactor over the duration of the test. The four fuels have similar product gas yields calculated to be 863±35, 887±41, 971±106 and 814±122 L/kg for G-Bana, P-Bana, G-grass, and E-cane, respectively.

<u>*Water content*</u>

Water content of product gas streams from the G-Bana and P-Bana fueled tests were both measured to be 1.8 g H_2O /L (STP) dry gas on average. Measured water content from G-grass and E-cane tests, were 2.2 and 1.6 g/L (STP), respectively.

<u>*Sulfur gases species*</u>

Hydrogen sulfide (H_2S), carbonyl sulfide (COS), and thiophene (C_4H_4S) were detected with concentrations of 100 to 227 ppmv, 1 to 6 ppmv, and 7 to 11 ppmv in the dry product gas stream, respectively, for the tested fuels.

G-Bana, P-Bana and G-grass had lower sulfur contents (0.01 to 0.03% dry basis) and generated gaseous sulfur species in the product gas at concentrations of 100 to 109 ppm of H_2S, 1 to 5 ppmv of COS, and 7 to 11 ppmv of C_4H_4S. E-cane contained more S, 0.05%, that accordingly resulted in product gas with higher concentration of sulfur species, 227 ppmv of H_2S, 6 ppmv of COS, and 10 ppmv of C_4H_4S.

Ammonia (NH_3), cyanide (CN^-), and chloride (Cl^-)

Ammonia, NH_3, concentrations of 1,700±351, 1,891±17, 2,205±159 and 2,676±29 ppmv in dry product gas (STP) were measured in the product gas from G-Bana, P-Bana, G-grass, and E-cane tests, respectively.

Cyanide, CN^-, concentrations of 353±76, 179±30, 217±80 and 116±37 mg/m^3 in dry product gas (STP) produced from G-Bana, P-Bana, G-grass, and E-cane, respectively.

Measured concentrations of Cl^- in dry product gas (STP) from the gasifier tests of G-Bana, P-Bana, G-grass, and E-cane were 224±210, 99±9, 108±19 and 151±65 mg/m^3, respectively.

Tar

Tar components were identified and quantified by a gas chromatograph (GC) equipped with a flame ionization detector (FID) and by gravimetric methods.

Thirteen compounds containing six or more carbon atoms were identified by GC-FID analysis. These are principally lighter tar compounds that have boiling points at or below the operating temperature limits of a GC. Identified GC detectable tar species were determined to have total concentrations of 37.1, 33.9±2.9, 36.1±5.1 and 17.7±4.9 g/m^3 in dry product gas (STP) for G-Bana, P-Bana G-grass and E-cane tests, respectively. Benzene, toluene, and naphthalene were the three compounds present in greatest concentration, contributing more than 50% of the total mass of compounds that were identified. The GC detectable tar compounds including both those that were identified and those that were not identified totaled 60.7, 55.1±7.4, 59.1±2.9 and 32.3±10.7 g/m^3 in dry gas (STP) for G-Bana, P-Bana, G-grass, and E-cane, respectively.

By gravimetric analysis, the amounts of heavy tar compounds (boiling points higher than the operating temperature limits of a GC) were determined to be present at 9.2±0.9, 9.8±5.6, 15.9±3.1 and 6.2±3.0 g/m^3 in dry gas (STP) for G-Bana, P-Bana, G-grass, and E-cane, respectively.

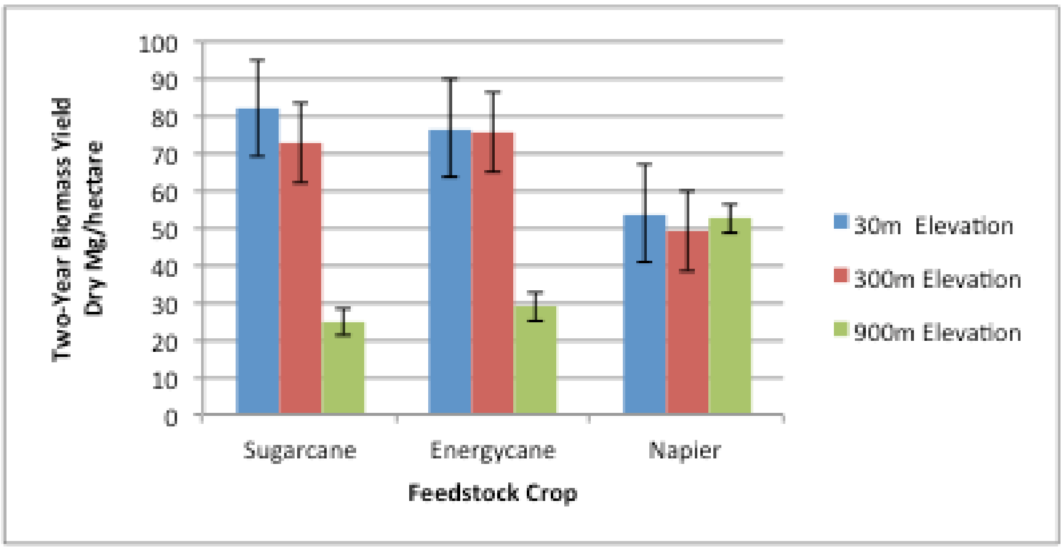
Trace elements

A total of 21 inorganic elements present in mass concentrations typically less than 1% in the processed biomass materials used as fuel were quantified in the product gas. Analyses were conducted for Al, Ca, Fe, K, Mg, Na and Si (Group 1), elements generally present in greater abundance, and Ba, Cd, Co, Cr, Cu, Mn, Mo, Ni, P, Sr, Pb, Ti, V, and Zn (Group 2), elements present in lesser abundance. Concentrations of the 21 elements in total in the dry product gas were 3.2±1.9, 12.7±10.1, 15.0±8.7, and 2.9±1.2 mg/m^3 for G-Bana, P-Bana, G-grass, and E-cane, respectively. Group 1 contributed 63-98%, alkali metals contributed 21-85%, and Group 2 contributed 2-37% to the total. For individual Group 2 elements, Ni, P, Pb, and Zn, were detected in the highest concentrations in the product gas.

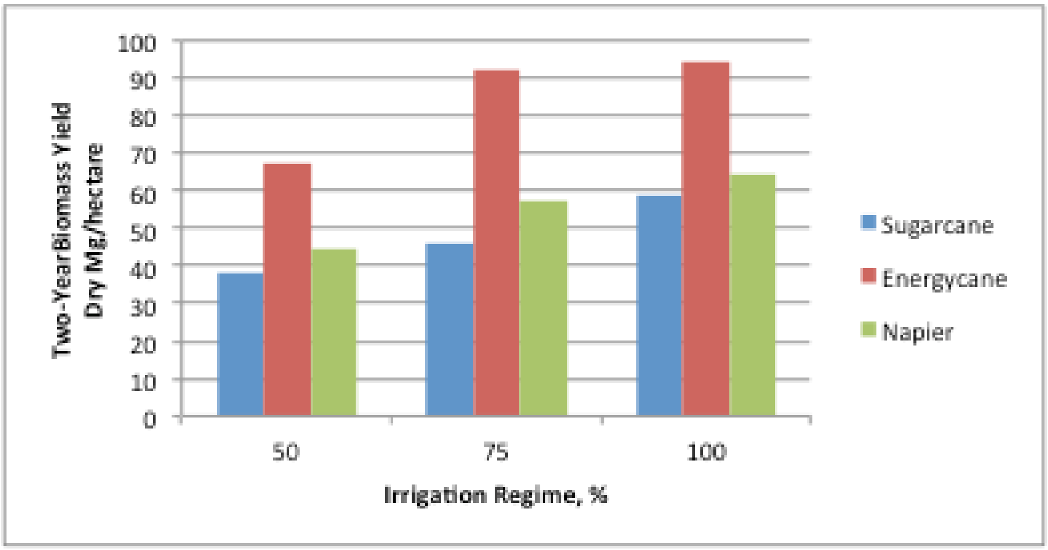
Objective C- Develop and assess the integration of bioenergy systems for Hawaii.

<u>Task C.1</u>. Determine the yield potential of C4 grasses in different agro-climatic environments and develop and validate crop simulation models. (Ogoshi)

Results from the multi-location trial showed that sugarcane and energycane produced greater yields in the lower elevations while Napier yielded well in the higher elevation. At the 30- and 300-m sites, sugarcane and energycane dry biomass yield ranged from 73 to 82 Mg hectare^{-1} over a two-year period, however at the 900-m site yields for both crops dropped to 25 to 29 Mg hectare^{-1}. Napier grass yields were relatively constant across all sites ranging from 49 to 54 Mg hectare^{-1}. Feedstock production across landscapes will need to match the plant species to the temperature characteristics of the location.



Biomass harvests were completed for the irrigation trials. Two-year yield data was collected from sugarcane, energycane, and napiergrass plots. To compare the yield among the crops, yield was calculated on a two-year basis because sugarcane is grown over a two-year cycle in Hawaii. Irrigation had a significant effect on yield, and energycane had significantly greater biomass yield than sugarcane and napiergrass, and there was no significant irrigation x species interaction.



In a small field at the Kula Research Station, Napiergrass was sprayed with glyphosate, plowed and volunteers allowed to germinate. Volunteers germinated from rhizomes that broke from the main stool. Treatments of the main trial will be based on this observation. Field observations indicated that glyphosate alone did not control napiergrass well. Another control method was implemented instead. The new method consisted of two parallel passes of a deep ripper across a field, followed by manual removal of remaining weed. Initial observations indicated good control of napiergrass.

Given the wide range of feedstock available for the production of biofuel under Hawaii's tropical climatic conditions, feedstock evaluation is a priority. Financial analysis is mainly focused on the farmer's point of view concerning potential feedstock supply for biofuel production. This information is important to biofuel producers interested in identifying least cost feedstock options for future biofuel production. Hence, a primary focus was given to the private account stance in evaluating feedstock production.

From a private accounting stance, costs and returns are measured from the producers' perspective: market or administered prices are used; externalities are usually not fully internalized; taxes are treated as a cost; and subsidies are considered a benefit. In biofuel feedstock production, the cost of producing each feedstock includes commonly used cost categories from land preparation to harvesting. The analysis assumes that feedstock production is on non-prime land under rain fed conditions. Financial analysis consists of deriving net returns on an annual equivalent basis over a 25-year project period. Feedstock cost of biofuel, breakeven price of feedstock and the breakeven price of biofuel can be calculated. Manuscript combining GIS Network Analysis with transportation and hauling costs that was submitted to a bioenergy journal is still under review. Preliminary net returns analysis for Banagrass and Energy Cane completed.

Task C.2 Determine the impact of C4 grasses grown along a climate gradient on terrestrial carbon stock and dynamics. (Crow)

Baseline soil C stock was determined for the benchmark locations (HC&S Field 718, 410, and Kula) and the deficit irrigation trial (HC&S Field 609) on Maui. The change in soil C stock following plantation of ratoon (zero-tillage) harvested tropical C4 grass varieties at the benchmark locations and deficit irrigation trials was determined annually.

At Field 609, in three years of under ratoon harvest, measured soil C stocks showed a sustained 18.5% increase compared to the baseline measurement pre-planting. Flux of the greenhouse gases (GHG) CO_2, CH_4, and N_2O from the soil surface was monitored and measured extensively following targeted events such as fertilization and harvest at the deficit irrigation trial site and at key growth cycle stages for the benchmark locations. Flux of N_2O, a major contributing GHG from agricultural source, at Field 609 was very low in comparison to other large-scale agricultural areas due to efficient belowground drip irrigation and fertilizer injection system in place at HC&S. Spikes in N_2O flux were apparent in the days following fertilization, however, within three days returned to background levels.

In collaboration with USDA-ARS researchers and HC&S, these values for soil C stock and are being used to validate the ALMANAC crop simulations for projecting yield and greenhouse warming potential. Further, these simulation data were linked to economic analysis of potential C4 grass feedstocks to determine whether entering a C market or trading system would provide key viability to the economic outcome of the production system. Successful root biomass and turnover research was conducted at both the Waimanalo and Maui HC&S Field 718 site using root tissue analysis, root biomass, and decay bags to link root C inputs to the accumulation of soil C over time following the implementation of ratoon harvesting techniques. Results show that the chemistry of root tissue, such as the lignin concentration, affects the decay trajectory and accumulation of soil C under ratoon harvest of C4 grass feedstocks. Specifically, at the Waimanalo field sites on Oahu, high lignin concentration resulted in rapid decay and accumulation of soil C, as opposed to loss through CO_2 flux, providing yet another environmental benefit of this management system.

One component of the optimization of feedstock choice for an environmentally and economically viable renewable fuels system is the role that plant structural chemistry plays not only in C dynamics also in fuel conversion efficiency. The structural lignin composition was determined using cupric oxide oxidation and extraction followed by quantification by GC/MS for 25 accessions of potential C4 grass feedstocks grown in two locations (Waimanalo, Oahu and Kula, Maui). The overall lignin composition was highly variable between species (napier grass versus guinea grass) but also varied greatly based on the environmental condition for some accessions. Some of the feedstocks identified as having the greatest potential viability due to high yield also demonstrated a robust chemistry that was not affected by the growing location. If the lignin composition can be further related to the ease of conversion into biofuels by multiple pathways, then the lignin structural chemistry may provide an important index for feedstock selection.

<u>Task C.3</u> Methodology for determining net energy productivity of biomass production in Hawaii.

Life cycle analysis of biofuel feedstock can be used to determine direct and indirect (embodied) energy in crop production. Net energy balance assesses the use of energy inputs to produce energy output in all operations of the growing cycle. Direct energy is associated with fuels for propulsion and utilities. Indirect energy includes energy embodied not only in manufactured fertilizers, but also in farm machinery. This research proposes use of a net energy balance that accounts not only for direct energy but also for indirect energy use. The first task is to develop a methodology to assess net energy productivity of biomass production systems in Hawaii. Second, production data collected from Sub Task C.1.5 of Task C.1 will be used to estimate direct and indirect energy usage for selected C4 crops. The aim is to estimate a net energy value (NEV) for agricultural biomass production in Hawaii. Since C4 grass production data are not available, adaptations of NEV calculations for corn in the US are utilized to validate the embodied energy accounting procedure. Draft of manuscript based on MS thesis completed.

This research develops a linear programming (LP) model to assess cropping systems options for sugar and biofuel production from sugarcane and other selected feedstock. Gathering of Maui field data continues. Banagrass production was used as the primary feedstock to illustrate application of the Hawaii Computable General Equilibrium (CGE) model for measuring sectorial impacts from biofuel production. A working paper was completed to illustrate the Hawaii CGE model. Revised manuscript submitted to a renewable energy policy journal.

Task C.4 Investigate alternative renewable energy sources for biofuel and electric power production by identifying feedstock and energy initiative options at HC&S. (Nakahata and Jakeway)

Sub-Task C.4.1. Energy cane development (Nakahata)

The selections from the 2010 and 2011 crossing seasons were planted and evaluated.

Hawaii energy cane types proved to have significant more volume than *Spontaneum* or *Robustum* varieties. Selections were made by the local livestock industry of varieties believed to be low in lignin. These tended to be grassy and slower growing. These varieties were planted under unirrigated conditions. Other than planting under moist soil conditions no additional water was provided. The plants have taken and grazing is expected to commence. Consideration is now underway to backcross these varieties with higher yielding clones to retrieve the drought tolerant characteristic.

Sub-Task C.4.2. Alternate energy crop development (Nakahata)

Attempts to cross *Erianthus* with sugarcane (to introduce cold tolerance and hybrid-vigor) failed—DNA analysis showed that the *Erianthus* had self-pollinated and there were no evidence of sugarcane DNA. A complete year of sorghum production demonstrated its' poor potential as a feedstock. Plots were plowed out and replaced with pearl-millet crosses from USDA/NRCS Molokai Plant Material Center.

Sub-Task C.4.3. Energy farm transition investigation (Jakeway)

Collaboration continued with several renewable energy project developers proposing energy projects at HC&S. A refrigerated container of bagasse was loaded with bagged bagasse on pallets for shipment to a biofuel development company on the mainland. HC&S will be paying for the shipment and testing of bagasse for conversion into liquid biofuel. The company that was awarded the contract by Maui County to develop the Maui Resource Recovery Facility, Anaergia Services, continues to approach HC&S to collaborate on their project for additional biogas production through the use of dedicated energy crops. We will continue to collaborate on investigating the feasibility of this energy project and the value proposition for HC&S compared to current sugarcane cultivation operations.

Energy crop samples were obtained from Field 401 to obtain additional dry weight data for crop components such as tops, stalks, and attached leaves. This was the last sampling period for this sub-task, as the project funding will end this quarter.

The report "Biofuel Case Study and Biomass Feedstock Analyses for Advanced Biofuel Production at Hawaiian Commercial & Sugar Co." was produced as a deliverable for this sub-task. This report summarizes and updates all past attempts for producing biofuel at HC&S. A business model producing ethanol vs. the current raw sugar production model with sugarcane byproducts were compared. A financial analysis showed there was no economic advantage to an ethanol production model to be competitive with ethanol that is currently being imported to Hawaii. Advanced biofuel production using lignocellulosic feedstocks is still a developing technology, but if developed and competitive with fossil fuels, there would be significant volumetric markets in Hawaii in the ground transportation, airline, electric utility, and military sectors. A second part of this report presents analytical data on alternative energy crop feedstocks for advanced biofuel production that were being grown for other sub-tasks required for this project. Selected energy crops were analyzed for fuel properties combined with feed and forage analyses. Both composite and crop component samples were analyzed with the results summarized in the report.

Sub-Task C.4.4 Cane trash collection and processing (Jakeway)

This subtask is complete and the deliverable report produced by the outside consultant Chris Norris was provided during the reporting period January to March 2013. The title of this report is "Evaluation of Alternative Sugarcane Production Systems" and is listed in the Publications/Presentations section of this report.

On the basis of the analysis within this report, and based on the available information and assumptions listed, NorrisECT believe that the "best practice" for recovery and utilization of leafy cane trash for HC&S is chopper harvesting, incorporating dry trash separation at the factory. Under such a strategy, overall agricultural production, harvesting and delivery costs remain similar to the current production system, as does total sugar production. The availability of biomass for value added processes increases significantly, and is controllable to meet factory demand and to optimize agricultural benefit.

Further, chopper harvesting and dry trash separation are both established and mature technologies, with chopper harvesting the norm in nearly all large-scale advanced industries, and trash separation becoming increasingly popular. Commercial, off the shelf equipment and solutions to adopt this strategy at HC&S are readily available. This strategy requires the retirement of some land from sugarcane production as it would be uneconomic to develop it to the standard required for efficient chopper harvesting, however this loss would be significantly offset by the increased productivity from the land currently used for disposal of water from the cane washing facility. The total cost of the modification of fields, including de-rocking and strategic land smoothing would be in the order of $12M, over the phase–in period.

In addition to the cost of procurement of harvesters, a dry trash separation system would have to be installed at the mill. The operating cost of such a facility is very significantly lower than the operating cost of a wet cleaning facility, and the losses are also significantly lower.

The two-year green cane strategy involves increased production cost and reduced sugar production, and would only be considered if the biomass was of very high value to HC&S. The actual feasibility of this strategy would require careful consideration due to the significant increase in season length associated with the increase in total fiber milled, and the novelty associated with Olsen Rolls. Whilst it is understood that HC&S do have some experience with Olsen Rolls, NorrisECT do not believe it to be considered "proven" technology under the conditions and operating parameters proposed. Further, NorrisECT understand that the Hawaiian Industry did not use drip tape in fields during the previous experience with Olsen Rolls, and this may be a source of difficulty not previously evaluated. The cost of upgrading the wet cleaning plant to process "whole cane" at the maximum capacity of the milling train is in the order of twice the cost of the installation of a dry cleaning facility for chopper harvested cane.

The analysis within this report has been conducted without detailed knowledge of the actual value of sugar and biomass production to HC&S, and without definitive knowledge of the current losses between pre-harvest and the factory shredder. NorrisECT strongly recommend that this analysis be re-visited with knowledge of product values prior to any investment decision being made. Further, NorrisECT very strongly recommend further investigation and quantification of sucrose and mass losses between pre-harvest and milling in the current production system. This is essential because of the very limited data on mass flow within the harvest and processing system currently available. Initial steps to significantly enhance the understanding of the current product mass flow could include strategies such as weighing a sample of the cane delivery vehicles.

Sub-Task C.4.5 Landfill gas utilization with supplemental biomethanation from agricultural/livestock waste (Jakeway)

The consulting firm CH2M HILL completed the report "Pu'unene Mill Landfill Gas Utilization Evaluation Report" for HC&S. The report was forwarded to the Project Leader at UH-CTAHR as a deliverable for this task. The options evaluated were a) LFG piped to HC&S and used as supplemental fuel in HC&S boilers, b) LFG piped to HC&S and used in a CHP scenario, and c) a stand-alone engine gen-set at the Maui County landfill site selling power directly into the MECO electric grid. The last option was viewed as the most straightforward option to implement with a minimum of permitting requirements and produced favorable revenue with lowest capital cost.

Sub-Task C.4.6. Alternate energy sources for irrigation pumping (Jakeway)

Review comments were provided to the consultant working on this sub-task so the final report could be completed. The final report was produced during this quarter, which was a deliverable for this sub-task. Highlights of the report showed that a 3 MW (AC) PV system could be installed on fallow agricultural land and would provide a simple payback period of less than 7 years with all available state and federal tax credits applied. The amount of energy the PV system could provide would be approximately 5000 MWh per year, which is equivalent to electrical energy produced from about 5000 tons of coal. This amount of energy was also nearly enough to offset the energy usage the deep-well irrigation pumps that are located nearby the proposed PV site. The wind generator system proposed was a 500 kW system. Analysis of available wind regime data showed that annual energy production could be about 935 MWh, which is equivalent to electrical energy produced from about 935 tons of coal. The simple payback period with all tax credits included for the wind system would occur just after the 10th year.

<u>Task C.5.</u> Economic impact of low-cost energy source to increase food production and employment opportunities- Hamakua Springs Water LLC (Ha, Chiang, Shimizu)

The goals of this project are to measure the effects of installing a small-scale hydroelectric plant on:

A) The economic viability of coordinated agricultural operations to stream-line distribution, production and consolidation of resources to its maximum efficiency and;

B) Carbon emissions of a coordinated agricultural operation versus a traditional large scale operation.

Hamakua Springs Water LLC installed a hydroelectric plant to provide all the electricity that the farm presently uses and allow for increased use of current facilities – resulting in a cost savings that could be passed on to participating farmers by lowering some of their operating costs. For example, the excess electricity could be used to increase refrigeration capacity to help area farmers maintain and prolong produce quality. The expanded capacity would allow additional farmers to piggy-back onto the HS distribution system, assisting them by consolidating and shipping to markets throughout the state.

Data to measure the financial impact of the facility and the change in carbon emissions of a coordinated agricultural operation versus a traditional large scale operation was to be collected prior to the implementation of the hydro facility and 4-5 years after activation of the facility.

Due to unforeseen delays in the construction of the facility and difficulties faced in getting the approvals to get the completed facility "on-line," the project was not completed in time to allow for an adequate length of time to pass between the activation date and the project end date. As a result, the post activation data is not sufficient to provide a definitive measurement of the goals stated at the beginning of this project.

However, initial results are promising and the theory that a coordinated agricultural operation utilizing power generated from a hydro facility would have a greater chance at economic viability than individual small farms due to the ability to streamline the distribution chain, share resources and expenses and take advantages of economies of scale appears feasible. It also appears that such an operation would appear to have a positive impact on the carbon emissions of the community.

Establish baseline for quality of life and community stability. (DeBaryshe/Stern)

The hydropower project was intended to demonstrate how a renewable energy source can support farm profitability and increased local food production. This project provided a unique opportunity to explore the potential impacts of on-farm renewable energy on a variety of related sustainability issues (e.g., energy and food systems, economic development). The Center on the Family (COF) was asked to assess the impact of this micro hydroelectric project from the perspective of the social sciences. Our four objectives and the associated evaluation methods were as follows:

Provide baseline data on the population, employment patterns, and agriculture for the Hāmākua region of the Big Island. We identified an existing set of indicators regarding population size, age distribution, and mobility; employment in agriculture and related fields of work; farm size and acreage; and the material living conditions of agricultural workers. These indicators are collected by federal and local agencies on an ongoing basis. Unfortunately, not all of the desired data are collected at the sub-county level. This set of indicators may be tracked over time to describe trends in the size and wellbeing of the agricultural workforce and to examine whether these trends appear to be influenced by the development of new on-farm renewable energy projects.

Evaluate the impact of the micro hydroelectric power plant on the direct beneficiaries and assess its potential to serve as a model for other on-farm renewable energy projects in the state To assess the impact of the micro hydroelectric power plant on the direct beneficiaries, we conducted interviews with the tenant farmers on the land where the plant was constructed. To gather perspectives on the potential macro-level impact of this and other forms of on-farm renewable energy sources for agriculture and economic development in Hawaiʻi, we conducted interviews with key informants representing a mix of nonprofit and government leaders in the agriculture and sustainable and renewable energy fields.

Describe public attitudes towards renewable energy. We administered a statewide survey to capture data on the degree of public support for renewable energy in general and the relative acceptability of different renewable and conventional energy sources. In addition to state estimates, results were compared for Honolulu, Maui, and Kauaʻi Counties and the Hāmākua region vs. the rest of Hawaiʻi County. These results contribute to the community assessment of the Hāmākua region and may be used to guide public education efforts relating to future renewable energy projects.

Describe public perceptions of personal and community quality of life. A premise guiding the Hāmākua project is that less expensive, cleaner, and more reliable energy sources have the potential to stabilize food production costs and increase local food production. More affordable, varied, and higher quality food could then influence the wellbeing of residents across the region, county, and perhaps even the state. We used an existing methodology for collecting data on four aspects of quality of life. Data were collected at the state and county levels.

Findings

Population, Agriculture, and Related Employment Indictors

The region's recent population growth appears to be in formerly non-residential lands within Hāmākua. These shifts provide some evidence to support local concerns about residential encroachment into the region's former agricultural lands.

The Hāmākua region also seems to have an older and aging population. This trend requires attention, as efforts to increase local food production are likely to require a supply of younger workers in the region.

In Hawaiʻi County and the Hāmākua region, agricultural jobs account for a slightly higher proportion of all jobs (4.6% and 5.3% respectively) compared to the state (2%).

Hawai‘i farms are especially small, with the average sized farm less than 150 acres, and the median in the range of five to six acres. Almost two-thirds of all farms in the state are less than 10 acres in size.

For a large proportion of farm operators in the state, the income from their farming activities constitute only a portion of their household income. This suggests that for many farmer operators significant non-farm income is required to support their household.

Qualitative Study: The Potential of Micro Hydroelectric Power for Local Food Production

While they had very limited knowledge of the hydropower plant at baseline, the tenant farmers at Hāmākua Springs expressed the expectation that they might benefit from the renewable energy source, perhaps through reduced operational costs. With stabilized operational costs, farmers could then explore opportunities to diversity and expand their crop production. Unfortunately, at the time of the follow-up interviews with participating farmers in May 2014, the hydro plant had not been operational long enough for them to experience any impact. Farmers, nevertheless, believe that renewable energy technologies are important for managing farm expenses and reducing a dependency on imported energy.

Interviews with key informants revealed that the project at Hāmākua Springs is an important one being watched by agriculturalists and other key stakeholders throughout the state. The farm serves as a model for sustainable agriculture by driving the conversation on what other agriculturalists through the state should be doing to explore renewable energy on their sites and by demonstrating how farmers can support one another through collaborative structures.

Renewable energy sources on farm sites was viewed by informants as having the potential to strengthen the viability of small farms and increase local food production. Informants, however, also indicated that renewable energy on farm sites is perhaps not as widespread in local agriculture as it was in the past, as it is in other sectors, or as one would expect, and that more can be done to effectively promote adoption.

A key finding that emerged from the qualitative inquiry is the importance of the cooperative farming business structure (or more informal collaborative structures) to the survival of the small farmer and also as a strategy to increase local food production and develop regional economies. Both farmers and key informants discussed a vision of a local food system that would be characterized by a greater sharing of resources and skills among agriculturalists. A new generation of farmers may be turning to such business structures both out of economic need and an interest in creating value-added products that enhance the local food system. These types of supportive structures could better position Hawai‘i’s smaller agriculturalists for success, contribute to an increase in regional local food production, and encourage a new approach to rural economic development.

Public Attitudes Towards Renewable Energy

We examined the acceptability of nine different forms of energy generation—six renewable sources and three conventional sources. The overall level of support for renewable energy was very high and there was close to universal support for at least some forms of renewable energy.

The vast majority of the public favored solar and wind sources (92% and 86% respectively). Three quarters of the public was favorably inclined toward hydropower and geothermal power. Slightly more than half of respondents supported the two incineration options and conventional forms of power generation (fossil fuels and nuclear plants) were favored by only 10-20% of respondents.

When asked to comment in more detail on their reasons for supporting (or not supporting) renewable energy, the major themes included concern for the natural environment, the need to reduce dependence on imported fossil fuels, and concern with the current high cost of energy in Hawaiʻi. The state was seen as both uniquely vulnerable due to our geographic isolation and imbalanced reliance on oil-based power generation. At the same time, respondents saw Hawaiʻi as uniquely advantaged with the potential for abundant power from solar, wind, wave, and geothermal sources. The general sentiment towards renewable energy may be summarized in two short quotations: “It’s the right thing to do” and “We can’t afford not to.”

Subjective Wellbeing

The general tone was one of optimism and satisfaction. Fifty percent (50%) of respondents were satisfied with their current overall quality of life, 42% were very or extremely satisfied, and only 7% were at the negative end of the satisfaction scale. In terms of seven specific aspects of personal wellbeing, satisfaction was highest for family life and spirituality, and lowest for educational attainment and financial status.

We measured 11 different components of subjective community wellbeing. The highest evaluations were given for items reflecting shared values in the community, i.e., respect among neighbors for privacy, cultural diversity, and religious diversity. The lowest ratings were given for the quality of the public schools.

Wellbeing was generally higher for those who were older, more affluent, and more highly educated. Men and women did not differ, however. Controlling for gender, age, income, and education, residents of Honolulu County reported higher levels of community wellbeing than did residents of Hawaiʻi County.

Products Developed:

<u>Journal Publications:</u>

Takara D., and S.K. Khanal. 2011. Green processing of tropical banagrass into biofuel and biobased products: An innovative biorefinery approach. *Bioresource Technology*. 102 (2): 1587-1592.

Tran, N., P. Illukpitya, J.F. Yanagida, and R. Ogoshi. 2011. "Optimizing biofuel production: An economic analysis for selected biofuel feedstock production in Hawaii", *Journal of Biomass and Bioenergy*, 35: 1756- 1764.

Illukpitiya, P., J. F. Yanagida, R. Ogoshi and G. Uehara. 2013. Sugar-ethanol-electricity co-generation in Hawaii: An application of Linear Programming (L.P.) for optimizing strategies. *Journal of Biomass and Bioenergy* 48: 203-212.

Mochizuki, J., J.F. Yanagida, D. Kumar, D. Takara, and G.S. Murthy. 2014. Life Cycle Assessment of Ethanol Production from Tropical Banagrass (Pennisetum purpureum)

Using Green and Dry Processing Technologies in Hawaii. *Journal of Renewable Sustainable Energy*. 6, 043128-1 – 043128-18.

Mochizuki, J., M. Coffman, and J.F. Yanagida. 2014. Market, Welfare, and Land-Use Implications of Lignocellulosic Bioethanol in Hawai`i. *Renewable Energy*, (under review).

Mochizuki, J., J.F. Yanagida, R. Ogoshi, T. Miura, and PS Leung. GIS Analysis of an Optimal Plant Location – the Case of Banagrass-based Bioethanol Production in Hawai`i. *Biomass and Bioenergy* (under review).

Ma, S., M. Karkee, P. Scharf, and Q. Zhang, 2014. Sugarcane harvester technology: a critical overview. *Applied Engineering in Agriculture*. (Under review).

Conference Proceedings:

Hashimoto, A., J. Arnold, J. Ayars, S. Crow, T. Eggeman, L. Jakeway, M. Karkee, S. Khanal, J. Kiniry, J. Matsunaga, N. Meki, G. Murthy, M. Nakahata, R. Ogoshi, B. Turano, S. Turn, J. Yanagida, Q. Zhang. High-Yield Tropical Biomass for Advanced Biofuels. Sun Grant National Conference, New Orleans, LA, October 3-5, 2012. (http://sungrant.tennessee.edu/NR/rdonlyres/3880A277-C502-4EC9-9DEB-C385186A5C85/3706/214Hashimoto_Andy.pdf).

Takara, D., A.G. Hashimoto, S.K. Khanal. Green processing: a biorefinery perspective. In conference proceedings of Sun Grant National Conference: Science for Biomass Feedstock Production and Utilization, New Orleans, LA, Oct. 2-5, 2012. (http://sungrant.tennessee.edu/NR/rdonlyres/DDF120E1-C312-4065-B095-6EC87BD11DA8/3650/317Khanal_Samir.pdf).

Abstracts, Books, Reports and Theses:

Ogoshi, R., Yanagida, J., Turn, S., Illukpitiya, P., Uehara, G., Turano, B., Brewbaker, J., Carpenter, J., and Kinoshita, C. "Biofuels and Crop Assessment Report," Prepared for Dole Foods and Castle and Cook, 2008.

Turano, B., Ogoshi, R., and Uehara, G., "Can Biofuels from Non-food Sources End the Food Versus Fuel Debate," Solicited paper for the Hawaii Energy Policy Forum, 2008.

Ogoshi, R., B. Turano, Uehara, G., Yanagida, J., Illukpitiya, P., Brewbaker, J., and Carpenter, J. 2010. Evaluation of cellulosic feedstocks for biofuel production. In Khanal, S.K., R.Y. Surampalli, T.C. Zhang, B.P. Lamsal, and R.D. Tyagi (eds.) Biofuel and bioenergy from biowastes and biomass. ASCE, Reston, VA.

CH2MHill. Puunene Mill Landfill Gas Utilization Evaluation Report, prepared for Hawaiian Commercial & Sugar Company. Final Report. November 2011.

Sakuda, Merissa H. Estimating a Net Energy Value for Biofuel from Agriculture Biomass Production in Hawaii, M.S. Thesis, Department of Natural Resources and Environmental Management, University of Hawaii at Manoa, December 2011.

HNU-ENERGY, Evaluation of Alternative Energy Generation for Hawaiian Commercial & Sugar Company. Final Report. October 17, 2012.

Takara, D., *Green Processing of Napier Grass for Generation of Biofuel and Biobased Products*. PhD dissertation, University of Hawaii at Manoa. Ann Arbor: ProQuest/UMI. 2012.

Yudai Sumiyoshi, M.S. Plan A, Thesis option, "Belowground carbon cycle of Napier and Guinea grasses grown for sustainable biofuel feedstock production", degree awarded December 2012.

Hironao Yamazaki, M.S. Plan B, Capstone Project Title "Alteration in soil carbon pools following land use and management change for bioenergy feedstock production," degree awarded December 2013.

Meghan Pawlowski, M.S. Plan A, Thesis option, "Greenhouse gas flux and fine root dynamics of sugarcane and Napier grass under deficit irrigation," degree awarded May 2013.

Mochizuki, Junko, John Yanagida, and Makena Coffman. 2013. Market, Welfare and Land-use Implications of Lignocellulosic Bioethanol in Hawaii, UHERO Working Paper No. 2013-10, November, 2013.

Norris Energy Crop Technology. Evaluation of Alternative Sugarcane Production Systems – Strategies for Trash Recovery in Both One Year and Two Year Cane in Hawaii. Final Report, January 2013.

Shaochun Ma, Manoj Karkee, and Qin Zhang. 2013. Sugarcane harvesting system: a critical review, ASABE Paper No. 131574361. ASABE St. Joseph, Mich.

Sierra Research. Evaluation of Alternative Renewable Biomass Fuels for HC&S Boilers. Final Report, April 2013.

Jakeway, Lee A., Biofuel Case Study and Biomass Feedstock Analyses for Advanced Biofuel Production at Hawaiian Commercial & Sugar Co. HC&S Report. September 22, 2014.

McDaniel, A., Murthy, G.S. and Hashimoto, A. 2014. Development of An Life Cycle Impact Assessment Method Based on GBEP indicators. ASABE Abstract No. 1909170. ASABE St. Joseph, Mich.

McDaniel, A., Murthy, G.S. and Hashimoto, A. 2014. Evaluation of Environmental Impacts of Biofuels from Sugarcane and Napier Grass Produced in Hawaii. ASABE Abstract No. 1909313. ASABE St. Joseph, Mich.

Mochizuki, J., Kumar, D., Yanagida, J.Y., Hashimoto, A., and Murthy, G.S. 2014. A. Life cycle assessment of tropical banagrass (Pennisetum purpureum) derived ethanol as transportation fuel in Hawaii. ASABE Abstract No. 1909948. ASABE St. Joseph, Mich.

Stern, I.R., and B. DeBaryshe. On-farm Renewable Energy and Sustainable Local Food Production: A Case Study. University of Hawaii, Center on the Family, Honolulu, HI. 2014.
(http://uhfamily.hawaii.edu/publications/brochures/bb683_14101001_COF_ResearchReport-FINAL%20(Jan%2021%202014).pdf)

Presentations and Posters:

Cui, H., S.Q. Turn, and T. Tran. 2010. Biomass pretreatment for gasification. Presented at the 8th International Symposium on Gas Cleaning at High Temperature, August 23-25, 2010 – Taiyuan, Shanxi, People's Republic of China.

Hashimoto, Andrew, Steven Chiang, Susan Crow, Samir Khanal, Charles Kinoshita, Richard Ogoshi, Wei Wen Su, Gordon Tsuji, Brian Turano, Scott Turn, Goro Uehara, and John Yanagida. 2010. Development of High-yield Tropical Feedstocks and Biomass Conversion Technologies. World Congress on Zero Emissions Initiatives, Honolulu, Hawaii, September 13-17, 2010.

Hashimoto, Andrew. 2010. "High Yield Tropical Biomass Feedstock and Renewable Energy for Rural Economic Development." Presented at the BIO Pacific Rim Summit on Industrial Biotechnology & Bioenergy, December 11-14, 2010. Honolulu, Hawaii.

Hashimoto, Andrew. 2010. "University of Hawaii Bioenergy Program." Presented at the BIO Pacific Rim Summit on Industrial Biotechnology & Bioenergy, December 11-14, 2010. Honolulu, Hawaii.

Khanal, S.K. 2010. **"Biomass conversion to biofuels."** Chonnam National University, May 4, 2010, Gwanju, South Korea.

Illukpitiya, P. Economic competitiveness of biofuel feedstock production in Hawaii. Presented at the Dalian Nationalities University, Jinzhou, Dalian, Liaoning, People's Republic of China (October 25 - 26, 2010).

Ogoshi, Richard. 2010. Biofuel crop evaluation. Presented at the Waimanalo Field Day, November 19, 2010, Waimanalo Research Station, Waimanalo, Hawaii.

Reeves, Mataia and Susan Crow. 2010. Carbon sequestration in soils: Assessing the potential for offsetting CO2 emissions through soil conservation. The World Congress on Zero Emissions Initiatives: Launching the "Blue Economy". Honolulu, HI. September 2010.

Reeves, Mataia and Susan Crow. 2010. "Assessing the Potential Carbon Sequestration of Hawai'i's Soils Used for Bioenergy Feedstock Production: An Investigation of Soil Fractionation Methods". CTAHR Student Research Symposium, University of Hawaii, Honolulu, HI.

Smith, Leanna and Scott Turn. 2010. "Net energy analysis of bioenergy feedstock production of Eucalyptus" CTAHR Student Research Symposium, University of Hawaii, Honolulu, HI

Sumiyoshi, Y. and S. E. Crow. Estimation of spatial, diurnal, and species/varietal differences in soil CO_2 efflux from biofuel feedstock plots. Soil Science Society of America Annual Meeting, Long Beach, CA, October 2010. (Contributed poster)

Sumiyoshi, Yudai, S. Crow, B. Turano, and R. Ogoshi. 2010. "Estimation of Spatial, Diurnal, and Species/Varietal Differences in Soil CO_2 Efflux from Biofuel Feedstock Plots", CTAHR Student Research Symposium, University of Hawaii, Honolulu, HI

Takara, Devin and Samir Khanal. 2010. "Wet processing of adolescent Pennisetum purpureum for enhanced sugar release and co-product generation", CTAHR Student Research Symposium, University of Hawaii, Honolulu, HI

Tome, Maria, Cecily Barnes, Andrew Hashimoto. 2010. "Why Biomass & Biofuels for Hawaii?" Panel presentation at the Hawaii Biomass and Bioenergy Workshop, Sep. 24, 2010. Honolulu, Hawaii.

Hashimoto, Andrew. 2011. "Sustainable Bioenergy Systems for Hawaii." Presented at the World Congress of Bioenergy, April 25-30, 2011. Dalian, China.

Khanal, S.K. 2011. "Green processing of a tropical grass for advanced biofuel and biobased products." New Horizons in Biotechnology, Mini Symposia in **Biofuels - Current perspectives and challenges for commercialization**, November 21-24, 2011, Trivendrum, India.

Khanal, S.K. 2011. "Biorefinery for Hawaii." NC 1023: Engineering for Food Safety and Quality, USDA Multi-state Committee Meeting, October 3, 2011, Honolulu, HI.

Ogoshi, Richard, and Joshua Neipp. 2011. Power Plants. CTAHR Agriculture Awareness Day for Elementary School Students, February 17, 2011, Pearl City Urban Garden Center, Pearl City, Hawaii.

Pawlowski, M., S. E. Crow, Y. Sumiyoshi, J. Wells, and H. Kikkawa. Greenhouse gas flux under warm-season perennial C_4 grasses across different soil and climate gradients on the Islands of Hawaii. American Geophysical Union Annual Meeting, San Francisco, CA, December 2011. (Contributed abstract)

Sumiyoshi, Y., S. E. Crow, C. M. Litton, and J. L. Deenik. Belowground carbon cycle of Napier and Guinea grasses. American Geophysical Union Annual Meeting, San Francisco, CA, December 2011. (Contributed abstract)

Takara, D. and S.K. Khanal. Wet processing of banagrass: A biorefinery perspective. American Society of Agricultural and Biological Engineers (ASABE) 2011 Annual International Meeting, Louisville, KY, USA, August 7-11, 2011.

Hashimoto, A. G. Farming and Energy: Sustainability in America. National Association of State Energy Officials, Minneapolis, MN, September 10-12, 2012.

Hashimoto, A.G. and G. S. Murthy. Biofuels Sustainability Assessment. S-1041-The Science and Engineering for a Biobased Industry and Economy Annual Meeting and Symposium, Waterfront Center (USDA), Washington, DC, August 6-7, 2012.

Meki, M., J. Kiniry, A. Youkhana, M. Nakahata, S. Crow, R. Ogoshi, and J. Steiner. ALMANAC model parameterization for high biomass bioenergy crops. American Society of Agronomy Annual Meeting, Cincinnati, OH, October 21-24, 2012.

Pawlowski, M., S. E. Crow, J. L. Deenik, C. Evensen. Linking soil and water conservation practices to greenhouse gas flux and fine root dynamics: A comparison of sugarcane and Napier grass grown for bioenergy production. ASA, CSSA, and SSSA International Annual Meetings, Cincinnati, OH, October 2012.

Robertson, N., Turano, H., and Turano, B. Genetic Characterization of Hawaiian Napiergrass. CTAHR Student Research Symposium, April 17, 2012. *Poster presentation won CTAHR Merit Award (3rd place out of 65).

Sumiyoshi, Y., S. E. Crow, C. M. Litton, J. L. Deenik, B. Turano, and A. Taylor. Belowground carbon cycle of Napier and Guinea grasses grown for biofuel feedstock

production. ASA, CSSA, and SSSA International Annual Meetings, Cincinnati, OH, October 2012.

Takara, D., A. G. Hashimoto, and S.K. Khanal. Green processing of dedicated energy crops for biofuel and biobased products. International Conference on Challenges in Environmental Science and Engineering (CESE) 2012, Melbourne, Australia, September 9-13, 2012.

Takara, D., A.G. Hashimoto, and S. K. Khanal. Green processing of high yield tropical grass for biofuel and biobased products. S-1041-The Science and Engineering for a Biobased Industry and Economy Annual Meeting and Symposium, Waterfront Center (USDA), Washington, DC, August 6-7, 2012.

Takara, D. and S.K. Khanal. Green processing of tropical feedstocks for biofuel and biobased products. College of Tropical Agriculture and Human Resources Research Symposium, Honolulu, HI, April 13-14, 2012.

Hashimoto, A. High-Yield Feedstock and Biomass Conversion Technology for Renewable Energy and Economic Development. U.S. Department of Energy Bioenergy Technologies Office Project Peer Review, Alexandria, VA, May 20, 2013.

Hashimoto, A. University of Hawaii BRDI Project. S-1041-The Science and Engineering for a Biobased Industry and Economy Annual Meeting. Kahului, Maui. June 17, 2013.

Hashimoto, A. Conversion of High-Yield Tropical Biomass into Sustainable Biofuels. Green Initiative for Fuels Transition Pacific (GIFTPAC, working group of the U.S. Department of Defense Joint Forces Pacific Command) working group meeting. Honolulu, HI. June 21, 2013.

Jakeway, Lee. 2013. “Biofuel Outlook at HC&S Co.” Presented at the Asia Pacific Clean Energy Summit and Expo, September 9-11, 2013. Honolulu, Hawaii.

Meki, M. N., J. R. Kiniry, A. Youkhana, M. Nakahata, R. Ogoshi, and S. E. Crow. Key crop parameters for ALMANAC modeling of high biomass energy sorghum growth and productivity. ASA, CSSA, and SSSA International Annual Meetings, Tampa, FL, November 2013. (Contributed poster)

Mochizuki, Junko, John F. Yanagida, Richard Ogoshi, Tomoaki Miura, and PingSun Leung. “GIS analysis of an optimal plant location—the case of Banagrass-based bioethanol production in Hawaii.” Paper presentation, College of Tropical Agriculture and Human Resources, Student Research Symposium, University of Hawaii, April 12-13, 2013.

Mochizuki, Junko, John F. Yanagida, Devin Takara, Deepak Kumar, and Ganti S. Murthy. “Life cycle assessment of ethanol production from tropical Banagrass (Pennisetum purpureum) using green and non-green processing technology in Hawaii.” Poster presentation, College of Tropical Agriculture and Human Resources, Student Research Symposium, University of Hawaii, April 12-13, 2013.

Ogoshi, R., A. Youkhana, L. Jakeway, M. Nakahta, and P. Shingaki. Feedstock Crop Trials for Hawaii and the Tropics. S-1041-The Science and Engineering for a Biobased Industry and Economy Annual Meeting, Kahului, Maui, HI, June 17-18, 2013.

Youkhana, A., S. E. Crow, M. N. Meki, J. R. Kiniry, R. Ogoshi, and M. Nakahata. Belowground biomass and C dynamics in sugarcane and ratooning energycane cultivated as biofuel production in Hawaii. ASA, CSSA, and SSSA International Annual Meetings, Tampa, FL, November 2013. (Contributed poster)

Hashimoto, Andrew, Richard Ogoshi, Devin Takara, Samir Khanal, Susan Crow. High-Yield Tropical Feedstocks for Bioenergy Production. European Biomass Energy Conference, Hamburg, Germany, June 23-26, 2014.