CLOSED-LOOP BIOMASS CO-FIRING

**Quarterly Technical Progress Report
for the Period January – March 2000**

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Results Summary

- Subagreements were finalized between HC&S Co. and University of California – Davis and the University of Hawaii to perform work required in the pilot-scale and full-scale demonstration tasks
- The seed plot that contains the high-fiber cane variety is showing good growth
- A visit was made by Dr. Ralph Overend this quarter to be apprised of project progress
- Preliminary testing was performed with the “Cuba” mill at HC&S that will be used to prepare biomass samples for the pilot-scale testing
- Solid fuel feeder calibration tests were performed for one of the boilers at the Puunene factory for bagasse and coal fuel

Progress Discussion

Task 0, General and Administrative

Subagreements were finalized with the University of California – Davis and the University of Hawaii. The University of California subagreement was started December 1, 1999 and the University of Hawaii subagreement was started February 14, 2000.

Dr. Ralph Overend from NREL visited the Project Leader on January 20, 2000. Dr. Overend was given an overview of the project timetable and was shown the seed plot where the high-fiber cane variety is being grown.

A request was made by Dr. Larry Baxter of Sandia National Laboratories (a collaborator in this project) to be supplied monthly project updates. The Project Leader will try to comply with this request through more informal communication such as e-mail, fax, or telephone conversation.

Task 1, Analyze Data from Small Plot Harvests

Personnel used to maintain the sugarcane variety test plots were used to assist in performing the solid fuel feeder calibration tests and to harvest small quantities of high-fiber cane to perform the preliminary testing for the pilot-scale tests.

Analytical results from the high-fiber cane variety test plots in Field 414 were obtained and analyzed during this quarter. The harvest results obtained from this field were presented in the last quarterly report. The analytical results are provided in one of the attachments to this report. Ash percentages were determined for the stalk fraction and also for the composite sample that contained tops and leaves. The average ash percentage more than doubled when tops and leaves were included in the sample. The fiber yield per acre for variety B52298 (the sugarcane variety selected for the high-fiber cane used for this project) was 11.6 tons fiber per acre at approximately one year of age. The estimated sugar yield was quite low at 0.9 Experimental Tons Sugar per Acre (ETSA). The ash percentage for the composite sample was comparatively low at 3.68% which is desirable with respect to use as biomass fuel. The low sugar yield could actually be an advantage for this variety if the focus shifts to fiber production only as the juice fraction of sugarcane may become a disposal problem if there is no useful product from juice. A

more likely production scenario is that both the fiber and juice fractions of sugarcane will be used as are done now for the production of raw sugar.

Task 2, Large-Scale Planting of High-Fiber Cane Variety

Variety B52298 was planted for seed material last quarter and was showing good growth during this quarter (see photos in Attachments). The seed material from this plot should be nearing maturity by the end of the next quarter and be ready for large-scale planting in Field 415.

The field that is designated for the large-scale planting was not harvested this quarter due to harvest schedule changes and a later start of the grinding campaign. An area of 40 acres is being designated in Field 415 for commercial planting of this variety.

Task 3, Pilot-Scale Testing of Fuel Blends

Preliminary tests were performed using the HC&S small three-roll "Cuba" mill to measure its effectiveness for de-watering prepared cane samples. An effort is being made to utilize this mill for de-watering chopped biomass material because this should be a more productive method of processing the biomass samples for the pilot-scale combustion tests compared to preparing batch samples using a hydraulic press. Photos of this unit are provided at the end of this report. What follows is a summary of results provided by Dr. Scott Turn of the University of Hawaii, Hawaii Natural Energy Institute who supervised this testing.

De-watering tests using the HC&S Co. Cuba mill were conducted on March 30 and 31. Intentions are to use this mill to process fuel samples for the multi-fuel combustor (MFC) tests at Sandia National Laboratories. Each roll of the three-roll Cuba mill is a cylinder 30.5 cm diameter and 30.5 cm width with a circumferentially grooved surface. The groove dimensions for the bottom front feed roller are 12.7 mm deep and 12.7 mm width and for the other two rollers are 6.3 mm deep and 6.3 mm in width. The top roller has grooves milled across the face of the roll to aid in the feeding of material to the roller set. All three rolls are oriented with parallel axes of rotation and roll ends aligned in two common vertical planes. Axes of the two bottom rolls are located in a horizontal plane. The third, upper roll is located above the bottom rolls with its axis at roughly the midpoint between the two bottom roll axes. Thus the three axes lie at roughly the vertices of an isosceles triangle. Material enters the mill by passing between the top roll and one of the bottom rolls (the feed opening) and then exits between the top roll and the other bottom roll (the delivery opening). When viewed from the left side of the direction of travel for material flow through the mill, the top roll rotates in a clockwise fashion and the two bottom rolls in a counter clockwise direction. The distance for the feed opening is normally greater than the delivery opening, and as a result, the setting for the delivery opening has influence over juice expression. The locations of the rolls are adjustable with respect to one another within design limits. The bottom rolls may be independently moved horizontally to change the distance between the face of each and the top roll. The top roll floats in a vertical guide under the force of an adjustable compression spring. The mill is powered by a single electric motor/gear reduction unit and all rolls rotate at the same angular velocity. The unit does not permit roll speed to be adjusted. Juice expressed from the milled material is collected in a catchment located beneath the rolls and directed by gravity flow through a pipe to a collection vessel.

The Cuba mill at HC&S is currently used by the Crop Control ripening crew to extract juice from stripped cane stalks for analysis and assessment of ripeness. As such, the settings of the mill (feed and delivery opening and top roll pressure) were not established to process

chopped material. Other parameters can affect the mill performance, but within the capabilities of the existing equipment, these parameters are readily controlled. Beyond the limitations of the mill, the degree to which the feedstock has been reduced in particle size also has an effect on mill performance. Mill performance within the context of the current study is largely quantified as the ability of the milling process to reduce the moisture content of the feedstock. The purpose of this shakedown testing was to (1) evaluate the performance of two machines available for feedstock particle size reduction, (2) obtain preliminary information on the performance of the Cuba mill, and (3) design a method of feeding chopped material to the mill with minimal equipment modification and disruption of scheduled use by the HC&S Crop Control ripening crew.

Cane variety B52298 has been selected for high fiber production by HC&S personnel and was used for these shakedown tests. The harvest crew provided one lot of whole cane (stalks, leaves, and tops) and a second lot of stripped cane with leaf and top material removed. Two machines were used to chop the feedstock; a conventional forage chopper used to process agricultural materials and a conventional brush chipper designed to chip wood or tree prunings. The forage chopper has knives mounted on a drum rotating at high speed. The knives are mounted on the drum at an angle to the axis of rotation to provide uniform torque during cutting as the material is cut by the rotating knife drum that works in conjunction with an anvil. As a result, the material is cut into a uniform particle size. The brush chipper cuts and smashes material by knives mounted on the outside edge of a flywheel. As the material goes through the feeding mechanism, the swinging knives mounted on the edge of the flywheel have very high tip speed to chop and pulverize the material being presented to it. The difference in the chopped material produced by the two machines was assessed by visual inspection. Sugar cane stalks are composed of a pithy core and a tough outer rind. The brush chipper produced a wider range of particle sizes than the forage chopper, including 15 to 20 cm pieces of rind and a very fine, disintegrated pith fraction. By comparison, the forage chopper produced a relatively uniform particle size distribution, an observation similar to that reported in earlier work (Turn, 1997). An attempt to feed the processed material produced by the brush chipper through the forage chopper to produce greater particle size reduction met with limited success because the feeding unit on the forage chopper is not designed for chopped material. As a result of these tests, it was concluded that the forage chopper would provide the simplest means to prepare the harvested material for processing. The particle size distribution of the forage chopped material was not determined during the shakedown testing, but will be included when the fuel lots for the MFC tests are processed.

The chopped fuel lots were subsequently processed using the Cuba mill. As noted earlier, the mill is normally used for processing whole cane material by the HC&S Crop Control harvest crew. As such, the feed opening of the mill was set at approximately 20.7 mm and the delivery opening was set at about 3.2 mm with a nominal roll face velocity of 4.3 m/min. In addition, the stripped canes or stalks are fed by hand, four to six canes at a time, through a slot at the end of a 15 to 20 cm horizontal guide chute. Initially, a vertical rectangular chute was improvised to feed the chopped material to the mill but the material did not easily flow and was found to bridge, causing an irregular feed. A second inclined chute was devised with a bottom that was approximately the width of the rollers and sides 15 cm high. This is shown in the photos at the end of this report. A uniform mat of material was placed in the chute at a depth of ~7 cm and the mat was moved into the feed opening at a rate equivalent to the roll surface speed. This was found to work quite well and a longer chute of this design will be used in future tests.

Several lots of feedstock were processed using the two chutes. Samples of the juice and the milled material were collected and analyzed. Electrical conductivity (EC) measurements of the juice were made to serve as a relative assessment of the concentration of potassium and chloride ions. Removal of these two species is of primary importance in improving fuel quality. EC measurements from an earlier fuel processing study of banagrass were available as a relative standard for comparison. Processed cane samples were dried to constant weight to determine moisture content and to assess the degree of moisture removal by the mill. Two samples were also processed using a bench-top hydraulic press commonly used in the sugar industry to extract juice from chopped cane samples for laboratory analysis of sugar yield. EC of the expressed juice and moisture content of the pressed fiber were measured to serve as a baseline for comparison of Cuba mill data. A summary of results for forage chopped, stripped cane (leaves and tops removed) are provided in Table 1. The moisture content of the fresh, forage chopped material was determined to be 73% (wet basis). Juice from 1.3 kg of fresh forage chopped material was expressed using the bench-top hydraulic press. The resulting fiber moisture content was determined to be 54% and the EC of the expressed liquids was 13.12 mS cm⁻¹. Fresh forage chopped material was also processed by passing it through the Cuba mill several times and the EC of the expressed liquid and moisture content of the fiber were measured after each pass. Moisture content of the material was found to decrease by 2.5 to 3.5% with each successive milling. After the third milling, the fiber moisture was still about 10% higher than the material processed with the hydraulic press. The EC of the expressed juice from the initial pass was lower than the juice resulting from the hydraulic press treatment by ~3 mS cm⁻¹, but subsequent passes yielded juices with EC values comparable to that of the hydraulic press juice. Additional measurements should be made to determine whether initial extractions generally contain fewer ions. A possible phenomenological explanation for this trend would be that initial extracted juices consist primarily of extracellular or vascular fluids and subsequent pressings release intracellular fluids that contain higher ion concentrations.

Table 1. Summary of preliminary results from fiber processing trials of stripped stalks of cane variety B52298 using a forage chopper for particle size reduction and a bench-top hydraulic press and Cuba mill for juice extraction.

Sample Treatment*	Fiber Moisture Content (% wet basis)	EC of Expressed Juice (mS cm ⁻¹)
FC	72.7	—
FC-HP	54.0	13.12
FC-CM-1P	69.2	10.82
FC-CM-2P	66.6	12.89
FC-CM-3P	63.8	13.27
* FC – forage chopped HP – bench-top hydraulic press CM – Cuba mill #P – number of passes through the Cuba mill		

It is evident from the data that the degree of moisture reduction obtained using the Cuba mill with its current settings is inadequate. The EC values of the liquids expressed using the Cuba mill are comparable to those measured in the juice from the hydraulic press, indicating adequate ion removal. The volume of juice expressed per mill pass should be increased in order to use the Cuba mill to process material for the MFC tests. This can be accomplished

by adjusting the settings of the mill rolls. During the shakedown tests, several roll adjustment mechanisms were found to be “frozen” from lack of use and as a result, no attempt was made to improve mill performance. In the period since the shakedown tests, problems with the adjusting mechanisms have been corrected and additional tests to assess mill performance are being scheduled. A set of chutes have been designed and are being fabricated to facilitate consistent delivery of chopped material to the mill.

Task 4, Procuring Harvest Equipment

A visit was made to the former Waialua Sugar Company who at one time were using a conventional forage harvester to harvest biomass for fuel to run their power plant which had previously used bagasse fuel for its sugar manufacturing operation. The type of harvester used here was a John Deere forage harvester, Model 6810, equipped with a row-independent Kemper head that was approximately 12 feet width. The Kemper head was problematic for maintenance as it was required to harvest several biomass crops such as banagrass, volunteer sugarcane, and guinea grass. There was no problem chopping the material with the forage chopper once the material was presented to the feeder going to the chopping knives. The cutter head had to cut the biomass at a relatively high distance from the ground to avoid hitting surface rocks. Wet fields were a problem for equipment operation. Harvesting operations could have been more productive with a better planting configuration suited to the harvester and with sufficient turn-around area at the end of rows.

Observations were made of a conventional one-year cane harvester for tests performed by HC&S in Field 212. This particular harvester is manufactured by CAMECO Industries and is designed to harvest only one row of cane at a time at 5 ft. row spacing. The harvester was used to harvest commercial one-year cane that HC&S has been trying to incorporate into its operations. The harvester trials were performed both with and without the trash extraction fans operating. Results from these trials showed that when the fans were operating, the harvester collected an equivalent of 64.1 tons/acre of mostly cut cane stalks and when the fans were turned off, the harvester collected 97.0 tons/acre of cut cane stalks with tops and leaves included. From this result, one can infer that the increased biomass tonnage for the run performed with the fans off was from the tops and leaves that were collected with the stalks. The harvester did not experience any difficulty in collecting the additional biomass from the tops and leaves although its field operating speed was slower.

Task 5, Perform Harvest and Co-Firing Trials for Full-Scale Demonstration

In the previous quarter, it was reported where a bagasse feeder calibration test was performed on the boiler that operates at the Paia sugar factory. Methodology was developed and described for this calibration test. In this quarter, actual bagasse fuel usage for the Paia boiler was compared against the calibration test result. Additionally, the methodology developed for the calibration test was applied to calibrate feed rates for the feeding mechanism on one of the boilers that will eventually be used for the co-firing test at Puunene. Feed rate calibration tests were performed for both bagasse and coal fuel on Puunene boiler 1.

Results for bagasse feed rates are summarized in Table 2 comparing the results obtained from the feeding mechanisms used for both the Paia and Puunene boilers. The bagasse feeder design should be the same for the Paia and Puunene boilers. The Paia boiler is not equipped to use coal fuel. As the results show, there were differences in the average amount of fuel metered per revolution of the bagasse feeder. The difference between the Paia calibration test result and the

result from actual fuel use can be explained by the high moisture recorded for the bagasse fuel at the time the calibration test was performed. The significant variance between the Paia actual bagasse use result and the result obtained for Puunene boiler 1 cannot be explained by moisture difference alone as the bagasse moisture values were very close. Some difficulty was experienced to obtain a constant rotational speed while the tests were being performed with the Puunene boiler. It was discovered afterwards that there was a time delay function programmed into the variable speed drives which affected the instantaneous RPM of the bagasse feeder. This should not have affected the amount of fuel dispensed per revolution of the feeder though. The large difference in fuel feed per revolution may be explained by a different design of picking roll used in the Puunene bagasse feeders compared to the Paia bagasse feeders. An attempt will be made to perform another bagasse feeder calibration test for the Puunene boiler to generate a calibration curve for a range of operating speeds.

Table 2. Comparison of Bagasse Feeder Rates

Location and Date	Pounds Bagasse Fuel per Feeder Revolution	Bagasse Moisture
Paia calibration test conducted 12/15/99	47.4	57.0
Paia actual bagasse use from 2/13 to 3/14/00	43.3	46.4
Puunene boiler 1 calibration test conducted 3/7/00	34.2	45.6

A calibration test performed for the coal feeding mechanism that works in conjunction with the bagasse feeder gave more consistent results over the range of feeder speeds used in the test. These results are shown in the figure below. The results obtained for the three different RPM settings actually corresponded to 25%, 50%, and 75% of the maximum speed setting of 60 Hz for the coal feeder variable speed motor. The average amount of coal delivered per revolution was determined to be 19.2 lbs coal per feeder revolution. Once the calibration curve is determined for the bagasse feeding mechanism over a range of speeds, it should then be possible to generate a set of curves for both coal and bagasse fuel for each of the feeder mechanisms used for the boiler. Knowing the steam produced from each fuel, projections can be made for total steam production over a range of fuel feed rates for the fuel mixes being considered in the co-firing tests.

Figure 1. Feed rates for coal fuel at different speed settings.

References

Turn, S.Q., C.M. Kinoshita, and D.M. Ishimura. 1997 Removal of inorganic constituents of biomass feedstocks by mechanical dewatering and leaching. *Biomass and Bioenergy*. 12(4), pp. 241-252.

Upcoming Quarter Events

Task 1, Analyze Data from Small Plot Harvests

- Activity for this task should be completed

Task 2, Large-Scale Planting of High-Fiber Cane Variety

- Continue maintenance of seed plot area
- Finalize field layout for large-scale planting

Task 3, Pilot-Scale Testing of Fuel Blends

- Conduct more biomass preparation tests using the Cuba mill
- Collect and prepare fuels for pilot-scale tests performed at the MFC facility at Sandia National Laboratory

Task 4, Procuring Harvest Equipment

- Observe forage harvest equipment operating in alfalfa forage harvest operation
- Confirm the make of mechanical cane harvester that will be used by HC&S next year

Task 5, Perform Harvest and Co-Firing Trials for Full-Scale Demonstration

- Repeat the bagasse feeder calibration test on one of the Puunene boilers

ATTACHMENT A
High Fiber Cane Analytical Results

Field 414 High Fiber Cane Analytical Results

No.	Variety ID	Plot No.	RFSOL	POL	PURITY	F/C	TCA	ETSA	TFA	Ash%Stalk	Ash%Comp
1	75-6028	21	12.5	8.9	71.3	15.8	106.3	6.4	16.8	1.91	3.37
2	78-8963	1	8.4	4.6	54.0	13.8	68.8	1.4	9.5	2.19	4.73
3	78-9218	2	11.4	7.1	62.1	21.4	39.2	1.5	8.4	2.18	3.62
4	80-8890	3	11.5	6.7	58.5	22.8	74.9	2.4	17.1	1.70	4.51
5	80-8893	4	8.6	3.8	43.9	24.0	32.2	0.3	7.7	2.54	4.89
6	80-8896	5	9.6	4.5	46.3	23.9	49.7	0.6	11.9	2.86	4.81
7	80-8897	6	7.9	2.7	33.6	22.7	46.2	0.0	10.5	3.46	6.47
8	80-8910	7	9.4	4.9	52.8	19.2	35.7	0.7	6.9	2.83	6.41
9	81-9495	8	8.4	3.2	38.8	22.9	39.2	0.1	9.0	3.73	4.88
10	83-6179	18	13.4	10.4	77.1	15.0	63.6	4.8	9.5	1.35	3.04
11	83-9222	10	8.4	4.5	53.4	15.2	49.7	1.0	7.6	2.22	5.32
12	83-9901	9	12.1	8.1	67.4	15.8	78.4	4.0	12.4	1.43	3.81
13	83-9985	11	11.4	8.2	71.6	14.9	37.5	2.1	5.6	2.37	3.92
14	83-9986	12	8.8	3.7	42.4	23.0	44.4	0.3	10.2	2.17	5.33
15	85-4106	19	9.6	5.9	61.4	14.1	49.7	1.7	4.2	1.94	4.55
16	88-9808	13	7.3	3.0	41.0	18.5	49.7	0.2	9.2	3.10	5.28
17	88-9812	14	8.6	3.7	43.1	24.6	37.5	0.3	9.2	3.47	5.49
18	88-9820	15	8.8	2.7	30.8	28.4	41.8	0.0	11.9	2.36	4.07
19	88-9823	16	13.4	10.3	77.1	19.5	49.7	3.6	9.7	1.95	3.12
20	88-9824	17	10.9	7.4	67.4	17.0	60.1	2.8	10.2	1.72	3.53
21	B52298	20	10.9	5.5	50.5	24.3	47.9	0.9	11.6	1.57	3.68
									Avg.	2.34	4.52

Terminology Legend:

RFSOL	Refractometer Solids
POL	An indicator of the potential percentage of sucrose solids in cane
PURITY	The ratio of units of POL to units of RFSOL
F/C	Fiber percentage in sample
TCA	Tons cane per acre
ETSA	Experimental Tons Sugar per Acre
TFA	Tons fiber per acre
Ash%Stalk	Ash % in stalk fraction only of cane variety
Ash%Comp	Ash % in composite sample of stalks, tops, and leaves for cane variety

ATTACHMENT B
Selected Project Photos

Photo 1. Growth of high-fiber cane variety at 5 months crop age

Photo 2. Side view of HC&S Cuba mill

Photo 3. Front view (feed side) of Cuba mill showing rolls, feed chute, and catchment beneath the rollers

Photo 4. Improved feed chute used for Cuba mill tests