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CANE ENERGY UTILIZATION SYMPOSIUM
A REPORT FROM THE 2nd PACIFIC BASIN BIOFUELS WORKSHOP

VOLUME II : PRESENTED PAPERS

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CANE ENERGY UTILIZATION SYMPOSIUM
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KAUAI, HAWAII

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Office of Energy
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and

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*Volume I : Summary

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CHAPTER I

MULTI-PURPOSE CANE/BIOMASS IN DEVELOPMENT STRATEGY

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The Traditional Sugar Industry

The traditional sugar industry is a one-product, bulk-commodity type of industry. It is based on permanent mass markets for a homogeneous, standardized, and storable good, with a low value per unit of weight and no meaningful distinctions between cargos meeting trade norms for a given level of quality. Overproduction and "dump" pricing are chronic. Competition from other sweeteners is fierce and increasing, both on a calorie and price basis. Revenues from the sale of raw sugar account for 90% or more of the typical processor's gross income. In many growing and processing operations unit costs are also low, but this is not necessarily the result of advanced technology. Frequently it reflects a combination of cheap labor and ancient machinery (e.g., boilers and cane mill tandems over 60 years old).

Although sugar, in physical terms, is an ideal commodity for international trade, its world market is in fact highly segmented, due to a combination of economic, political and social factors. More than two thirds of all sugar is consumed in the country of origin, with growers and processors protected by subsidies and non-tarrif barriers in the typical case. Only 30% of world production is traded on international markets, and only two-thirds of that (or 20% of the total) under anything approaching competitive conditions as described by textbook economics.

Within national markets, consumer demand for sugar tends to follow population growth and be relatively insensitive to changes in prices and incomes. In the jargon of economists, it is inelastic with respect to prices and incomes. However, industrial demand is sensitive to price and has been severely affected in some countries by competition from other sweeteners, especially fructose derived from corn.

On the supply side, cane growers face lead times of twelve to eighteen months. Like most farmers, both beet and cane growers are vulnerable to the vagueness of disease, government policy, insects and the weather. Across both countries and years, overproduction is more common than the opposite. At times, worldwide inventories may exceed twice the desired level. At the end of the harvests in 1986, the excess was equivalent to 50% of target stocks and 16% of annual world consumption (Economic Research Service 1987).

Because of these surpluses, the need to maintain employment and foreign exchange, lack of good alternative uses for beet or cane land and the inability to finance a switchover, almost all producers must stay in the business in the short run. Indeed, many countries are forced to aim for maximum exports over a wide range of sugar prices. Consequently, the world market for sugar is a residual market, in which most product moves with export subsidies, is sold at "dump" prices or both.

As a result, world market prices for sugar are frequently below not only the life-cycle costs of production in most countries but short-run incremental costs as well. And a small change in demand or supply (or in expectations about them) brings about a disproportionate change in price. Reflecting these conditions, a typical world price for raw sugar (Contract No. 11, f.o.b. Caribbean) fell to a 15 year low of less than three cents per pound in 1985. During 1977-86, the average of this price was only 10.4 cents and during January-February 1987, only 6.9 cents (Economic Research Service 1987). At press time, world sugar for delivery in New York was less than seven cents a pound for May 1987 and less than eight cents for July 1988.

According to RONCO (1986), no significant improvement in sugar prices may be expected during the next decade. As for 1986-88, the World Bank projects an average price below nine cents, in constant 1985 dollars. Such prices are, of course, well below the 11 to 15 cents believed to represent the range of average life-cycle production costs (1985) for the world's major exporters (Economic Research Service 1987).

The United States would seem to be an important exception to the above. After all, this country accounts for about 13% of world sweetener consumption. Almost half of its requirements are still supplied by beet and cane sugar. Its domestic price is maintained in the neighborhood of 21 cents per pound by an elaborate system of loans, subsidies and trade restrictions that fairly well limit sugar imports to the country's production deficiency. Finally, this artificial price is above the highest average, life-cycle production cost calculated, on a raw equivalent basis, for any crop year during the period 1979-80 to 1984-85 (Economic Research Service 1987).

However, U.S. demand for sugar is declining steadily, U.S. producers are relatively high-cost producers, and the extraordinary political power of the growers and processors is on the wane. Sugar deliveries for calendar 1986 (raw value) were down for the ninth consecutive year - 2.8% from 1985 and 7.6% from 1984, with industrial demand the hardest hit. Beverage demand was down 21.5% from 1985 and 70.6% from 1984, due to substitution by HFCS. A further decline in total deliveries of 1% is forecast for calendar 1987 (Economic Research Service 1987).

The U.S. Administration's budget proposal for fiscal year 1987-88 provides for a four-year, phased reduction of the average loan rate for raw sugar, from the present 18 cents per pound to 12 cents, effective with the 1987 crop. This latter price is below the average U.S. production cost for any of the crop years 1979-80 through 1984-85 (Economic Research Service 1987). Given the Federal deficit, the increasing cost of sugar subsidies and on-going changes of a political and structural nature in the U.S. Congress, a convergence of the U.S. and world prices over the next decade is a strong possibility.

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Although the Commonwealth of Puerto Rico is "outside" the U.S. for the purpose of sugar movements, it "inside" for most other economic purposes and its domestic sugar price reflects the U.S. situation. Moreover, production costs by mill, calculated on a comparable life-cycle basis, would lie between 50% to 100% above the current U.S. market price. Finally, there is no hope that Puerto Rico's traditional industry will ever again be competitive in the U.S. or world markets.

In brief, almost everywhere, the traditional sugar business is a bad business to be in, both in the short-run and in the long-run, whether one is producing for export or producing for local consumption.

The Case for Cane

In contrast to our pessimistic evaluation of the traditional sugar industry, we are optimistic about its raw material - cane. If only one can figure out a way to make it profitable, cane is a very desirable crop for subtropical climates, particularly in developing countries. Compared to other crops, it has several outstanding advantages which have encouraged us to design a new industry based on this ancient raw material, whose use goes back to prehistoric times. These advantages include:

- High yields of vegetation per acre, as high as 200 to 260 metric tons of total vegetation per hectare (90 to 120 short tons per acre), under the "multipurpose cane" management system (MPCMS). Among other things, this reflects cane's ability to absorb a wide range of the light spectrum through multiple photosynthetic paths, to store energy as sucrose and to grow 24 hours per day for 365 days per year, in a favorable climate. Indeed cane may be the best commercial plant for converting solar energy to dry matter;

- Under certain conditions, a long harvest season, which lasts most of the year, weather permitting. When outputs are multiple, tonnages high and rendiments relatively low, as with MPCMS, project economics are less sensitive to seasonal variations in rendiment than in the traditional sugar industry. High oil prices and low sugar prices reduce this sensitivity even more;

- A wide range of derivatives, including animal feeds, beverages, building materials, chemicals, foodstuffs, liquid fuel (fuel-grade ethanol) and solid fuels, with considerable flexibility in adjusting output mix to market conditions and technological change. In particular, cane bagasse at 48% moisture (mcwb) contains around 8.5 million BTU's per short ton; and cane trash, at 20% moisture (mcwb), around 13.3 million BTU's;

- Multiple sources of output flexibility including: the range of genetic material and variety of mechanized harvesting techniques available to growers; the ability to adapt mill tandems to the nature of the raw material, to vary the number of strikes in the boiling house (e.g. from zero to three) and to store all mill outputs indefinitely (if bagasse is densified);

- Cane bagasse and trash may be combined with a wide variety of other fuels in stoker-fed boilers, for year-round operation of a cane-based energy unit;

- Resistance to hurricanes and similar storms;
- Favorable environmental impacts, at least under MPCMS (low herbicides, high tonnage plowed under at replanting and, with some harvest systems, clean cane to the mill); and,
- High employment generation in low wage areas, through labor-intensive field operations.

In designing a new industry to process this versatile raw material, it is preferable to retain as much flexibility as possible. For example, to optimize energy output, it is essential to use high-pressure boilers. However, these pieces of equipment are expensive and may last for 30 years. Within that time frame, a lot of things can happen, such as the development of a market for high-volume sucrose chemicals or a market for high-ethanol turbo fuels. Also it takes time to replant large acreages in cane. To keep one's options open (as well as for other reasons), one should plant at least some cane varieties with a high ratio of stalk to total vegetation and, within that category, a high rendiment. An exclusive emphasis on fiber content alone will tend to make one heavily, if not exclusively, dependent on increasing petroleum prices and the demand for baseload generating capacity as the sources of one's profitability. This may be a good strategy for the medium run, but it may also be (depending on the values of oil and sugar) a money loser in the short run and may foreclose taking advantage of non-oil opportunities in the long run.

The New Cane Industry in Puerto Rico

Based on extensive field research (AES/CEER 1982), the experience of other parts of the world (e.g. Hawaii, Sudan) and a project analysis for the Cambalache Mill in Arecibo, Puerto Rico (CEER 1985), the Commonwealth of Puerto Rico has developed a concept of a new industry based on cane. If all goes according to plan, the analysis of the first multipurpose "Biomass Project" of this new industry will begin shortly, incorporating field work described elsewhere by Dr. William F. Allison (1987). As a nucleus, the Project will use an existing cane mill in Barrio Aguirre, Municipality of Salinas, Puerto Rico.

Because Puerto Rico's electric generating system has excess capacity and U.S. sugar prices are still high, the initial outputs of the Project will probably be high pressure steam for a nearby electric generating station to substitute for imported petroleum in existing equipment, three-strike raw sugar and blackstrap molasses. Medium term, the outputs may be electricity for grid supply, "A" sugar and "A" molasses. In this regard it is noteworthy that Puerto Rico is importing almost half its annual sugar requirements of 170,000 short tons and about 80% of its molasses requirements (Junta de Planificacion 1986).

The supplementary fuels remain to be determined, but the most likely candidates are cane trash, energy grasses and a refuse-derived solid fuel. Initial investment is estimated at $22 to $25 million, excluding investment in drip-irrigation facilities. A similar but larger project ($58 million) is being considered for the Monymusk Factory, Clarendon Parish, Jamaica (RONCO 1986).

Cane Industry Impacts and Needs

The salient characteristics of this new industry, which cuts across four economic sectors, are as follow:

- General Characteristics

  - A money maker, i.e. projects should earn an acceptable life-cycle return on investment, with tax exemption but without subsidies; tax exemption is considered by the project only a subsidy if it is unnecessary to produce the desired economic behavior for which it is granted or there are better, alternative instruments, in which case, it should not be given, if it can be avoided.

  - Multiple outputs, which vary from time to time and place to place, as market and technological conditions change; i.e., in the new industry, the cane mill acts like an oil refinery, not the traditional sugar mill. However, in nearly all cases, energy will be a principal product and revenues from its sale will cover 50% or more of life-cycle costs.

  - A new industry with fundamental changes in every sector, not the traditional industry with technological patches here and there.

- Agricultural Sector

  - The management system is MPCMS, whose principal objectives are expressed in terms of yields per acre, including total vegetation and individual outputs, not "sweetness" of the cane stalk. Great attention is given to seedbed preparation, seed selection, fast closure and continuous growth, through steady flow of water and nutrients (e.g., by drip irrigation). In this system, one more than makes up on a volume basis for what one loses on "quality".

  - Variety selection, and harvesting, loading, transport and milling systems are integrated for project, not system, optimality.

- Transportation Sector

  - As noted, the transportation system is integrated with the agricultural and milling operations.

  - Movements of harvesting, loading and transportation equipment are controlled by cellular radios and computer, to minimize time lost and the deterioration of cut cane.

- Manufacturing Sector

  - Milling is integrated with agricultural and transportation operations, as noted previously.

  - The mill does not produce its own energy but, instead, operates in a cogeneration relationship with a nearby energy unit, which supplies the mill with steam and power.

  - Energy consumption in the mill is optimized.

- Other Public Services

  - The energy unit is separate from the cane mill and may even be under different ownership. The primary purpose of this unit is to produce electricity and/or steam for the national electric system. The unit operates in a cogeneration relationship with the mill, in supplying the latter with power and steam (e.g., by pressure relief valves from the unit boiler or low-pressure extractions from the unit turbogenerator).

  - The energy-unit boiler operates at high pressure and temperature, with a stoker capable of handling a wide variety of sold fuels. Steam pressure and temperature will vary according to the customer's needs (e.g., supply for feedwater heaters in a nearby generating station, supply for a turbogenerator in the Project energy unit) but, in most cases, should probably not exceed 900 psig and 900°F. On paper at least, higher pressures (e.g., 1,250 psig) and temperatures may be economically attractive, in terms of the incremental return on the incremental investment, both of which can be significant. However, such pressures and temperatures impose stringent requirements on the maintenance of feed-water quality and (especially under conditions of cogeneration) on the recruitment, training, and retention of boiler-station personnel. In turn, meeting these requirements may have implications for personnel policies in the rest of the economy, especially in developing countries. Also, for some organizations, it is a severe "technological leap", to go directly to 1,250 psig from the pressures of 150-200 psig still used in the traditional sugar industry. Finally, if the requirements for water quality and personnel are <u>not</u> met, boiler availability and efficiency may fall to the point where the incremental return is negative, instead of positive. In brief, boiler pressure and temperature are not arcane subjects, of interest only to the mechanical engineers, but have important ramifications that cut across the engineering and social sciences to impact on society in many different ways.

  - Assuming 40 days for normal maintenance, the energy unit operates about 325 days a year using supplemental fuels such as biomass pellets, cane trash, coal, densified bagasse, energy grasses, refuse-derived solid fuels, wood chips and/or wood chunks. Economic analysis will usually indicate that, where a new boiler is an option, it is better to put one's money into

increasing pressure and temperature than into drying biomass fuels with flue gasses from a lower-rated steam generator. Also, where supplemental fuels, other than densified bagasse, are available, it will normally be found preferable to use them and burn all the bagasse fresh. Densifying bagasse not only costs money and energy, but may result in diseconomies of scale because less bagasse in the harvest season may mean smaller boilers and turbogenerators. The initial cost of a double-extraction, condensing turbogenerator is particularly sensitive to its rated capacity.

- Supplemental fuels are used during the milling season, as well as in the off season to assure steady operation of the energy unit as a base-load supply to the national electric system and also, to permit optimization of the energy unit's capacity, by removing the maximum expected daily cane supply as an accidental constraint on this capacity and on the capacity of the supplemental fuel system.

Conclusion

There is a clear need for a new industry to utilize the many advantages which cane offers subtropical, developing countries. By now, all of the components of this new industry have been thoroughly studied or commercially proven somewhere. What Puerto Rico proposes to do, for the first time in history, is put them together into a whole that works, is economically feasible, retains jobs and, eventually, creates new ones. This is primarily a management problem, not a technological problem; althougth we expect, in the process, to learn a good deal more about the technologies involved and maybe develop some additional technologies as well. Other parts of the world can and should set up similar projects. However, such projects are complex and sensitive to local conditions. Careful planning and design is essential. The rules of thumb given above are a guide to what to expect, but should not be used as a substitute for calculation. Your particular situation may be different.

Finally, as regards to this new industry, we are all students, as yet, with a lot to learn. We need to communicate with one another, fully and continuously, as we go along. Experience in the traditional sugar industry may prove useful, or it may prove a barrier to understanding, depending on the individual. However, in no case does being an expert in the old industry make one an expert in the new. After several multi-purpose biomass projects are up and running, there will be plenty of time to talk about expertise!

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CHAPTER II

COMPARATIVE YIELD TRIALS WITH TREE AND GRASS ENERGY CROPS IN HAWAII: A PRELIMINARY REPORT ON CURRENT RESEARCH

By

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Executive Summary

Short-rotation, intensively managed tree and grass crops are potential sources of supplemental biomass feedstock for sugar industry cogeneration power plants and may serve in the future as sources of liquid fuel. The development of an energy business based on the use of a biomass feedstock will depend in part on the dry-matter yield potential of the crops used. This paper reviews the present use of biomass energy in the Hawaiian sugar industry and progress being made toward the breeding and selection of a Hawaiian energy cane in addition to considering the use of alternative biomass feedstock.

To determine the relative dry-matter yield potential of grass and tree crops, we have established trials in five diverse Hawaiian locations on four islands. Each location includes a small-plot species evaluation trial and a large-plot yield trial. This report includes only preliminary comparative height data of the species included in the trials since all the plots were installed less that one year ago.

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COMPARATIVE YIELD TRIALS WITH TREE AND GRASS ENERGY CROPS

Tree Crops

Eucalyptus spp. were reported by Schubert and Whitesell (1985) to be the highest-yielding short-rotation tree crops in five upland sites in Hawaii at 2 to 5 years of growth. Nitrogen-fixing trees evaluated in the study were either poorly adapted or had a wood density too low to warrant consideration as biomass crops under the conditions of the experiments. Eucalyptus saligna was reported to produce dry matter at the rate of 22.5 tonnes/ha/year (10.1 tons/acre/year) in high-N (nitrogen) plots in a fertilizer trial at Akaka Falls (an upland site) on the island of Hawaii (BioEnergy Development Corporation Annual Report, unpublished). There was a strong yield response to fertilizer N in the trials. At another Hawaii site, Skolmen (1983) stated that Eucalyptus grandis produced 56 m^3/ha/year with a specific gravity of 0.5 to 0.6. The estimated dry-matter yield from the site was 28 tonnes/ha/year (12.5 tons/acre/year). On a lowland site, Brewbaker (1980) reported that Leucaena leucocephala cv. 'K8' produced an annual dry-matter increment of 28.8 tonnes/ha (12.9 tons/acre).

Campinhos et al. (1984) reported that vegetatively propagated eucalyptus at Aracruz Florestal S.A. in Espirito Santo, Brazil, produced dry matter at the average rate of 40.3 tonnes/ha/year (18.1 tons/acre/year) in a 7-year rotation. In comparison, the yield of unimproved eucalyptus planted as seedlings was 15.2 tonnes/ha/year (6.8 tons/acre/year). Thus, an almost three-fold increase in dry-matter yield was made at Aracruz resulting from a switch to vegetatively propagated eucalyptus. Aracruz has a eucalyptus breeding and selection program in place to produce higher-yielding trees with more uniform wood density (Zobel et. al. 1983).

Grass Crops

Grass species are also highly productive. Sugarcane (Saccharum spp. hybrids) and napiergrass (Pennisetum purpureum) have emerged as highly productive grass biomass crops for the tropics. Alexander (1985) reported that the average yield of first generation Puerto Rico energy canes in experimental plots was 64 tonnes/ha/year (28.7 tons/acre/year) between 1978 and 1980. Second and third generation varieties of Puerto Rican energy canes were selected for high fiber and fermentable solids, respectively, and were also high-yielding (Samuels and Chu 1982).

High yields of energy canes were also reported from Louisiana (Giamalva 1985). The highest-yielding cultivar, L791002, produced 151.4 tonnes/ha of cane (67.9 tons/acre) with a dry matter composition of 39%, giving a dry-matter yield of 59 tonnes/ha/year (26.4 tons/acre/year). The Louisiana yield is very high when one considers that one growth occurred in the winter months with the October planted cane.

Hawaiian cane is also high-yielding, and considerable potential exists for breeding and selecting a high-fiber energy cane with further introgression of Saccharum spontaneum germplasm. If all selection pressure for sucrose content were removed, considerable gains could be made in increasing total biomass (Tew 1982). In fact, a program of reciprocal recurrent selection in Saccharum spontaneum and S. officinarum was initiated for biomass improvement in 1984 (Schnell, personal communication, 1986). Crossing and early visual

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selections are complete, and yield testing will commence in 1987. The Saccharum hybrids produced from the breeding program are to be compared to the napiergrass cultivar, banana grass, in at least four locations.

Currently, the recovered dry-matter yield (calculated from the 1985 production figures, unpublished data, HSPA) from the Hawaiian sugarcane crop is 32.8 tonnes/ha/year (14.7 tons/acre/year) as shown in Table II.1. With current harvest, transport and cane cleaning methods, including burning the crop before harvest, we estimate that approximately 26% of the dry matter is lost from the field to the final production of sugar, molasses solids, and fiber (Kinoshita, unpublished data, HSPA, 1986). Thus, the field yield of dry matter of the Hawaiian crop is approximately 44.3 tonnes/ha/year (19.9 tons/acre/year). We estimate that an energy-only sugarcane agricultural operation in an unirrigated site would have to yield 57.9 tonnes/ha/year (26 tons/acre/year) of fiber to equal the cost of production at the current ($20/bbl) cost of oil (Kinoshita, personal communication, 1987). The development of a Hawaiian energy cane through breeding and selection will be necessary as a first step to produce the increased yields necessary for an energy alternative.

Both trees and grass crops under good management practices are capable of producing large quantities of biomass feedstocks; however, yield data are not usually available to make comparisons of relative yield potential under the same experimental conditions. To fill this data gap, comparative yield trials with trees and grasses were installed in five diverse Hawaiian locations.

Table II. 1
1985 Production of the Hawaiian Sugar Industry
(25.82-month crop of 83,029 acres)

Product	Wet Weight	Dry Matter	Dry Matter
	(tons)	(%)	(tons)
Sugar	1,012,249	99.76	1,009,819
Molasses	271,705	85.52	232,362
Bagasse	2,713,118	50.74[a]	1,376,780
Total Dry matter (1985 crop) (tons)			2,618,961
Yield Dry matter/acre/year (tons)			14.67

[a] Fiber and sucrose only, does not include other solids.

Review of Biomass Energy Produced by The Hawaiian Sugarcane Industry

Consideration of the current energy status of the Hawaiian sugar industry is a necessary part of this assessment. Although Hawaiian sugarcane varieties are not specifically selected for production of biomass energy, considerable use has been made of the by-product fiber (bagasse) for electrical power generation, a large portion of which is exported from sugar mills. The energy efficiency of the Hawaiian sugar industry was reviewed by Kinoshita (1984). He concluded that, compared to other crops, the Hawaii-produced sugarcane crop and its end-products (raw sugar, molasses, and fiber) are among the highest-yielding in the world with regard to gross heating and digestible energy values. The energy efficiency ratio (digestible energy yield divided by net fossil-fuel energy input) and the net energy yield (digestible energy yield minus fossil energy input) were reported to be 3.2 and 130 GJ/ha/year, respectively. Only corn silage production compared favorably with sugarcane at a net energy yield of 90 GJ/ha/year. Sugar beets were produced at the substantial net energy loss of 75 GJ/ha/year.

In 1985, 10.4% of Hawaii's electricity was generated by the sugar industry (unpublished data, HSPA). The importance of power generated by the sugar industry is evident when one considers the percentage of power supplied by it in the neighbor islands (Table II.2).

Table II.2
Electrical Energy Generation by Island
Attributed to the Hawaiian Sugar Industry in 1985*

Island	Biomass**	Total	% Biomass
	--- kWh x 10^6 ---		
Hawaii	193	643	30.0
Kauai	144	358	40.2
Maui	178	770	23.1
Oahu	102	5,736	1.8
1985 Total	618	7,507	8.2

*Unpublished data, HSPA.
**Sugarcane bagasse.

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Methodology Used for Present Yield Trials

To determine the relative quantity of dry matter produced by trees and grasses, we established yield trials in five diverse locations on four Hawaiian islands. Each site included a replicated large-plot trial with three tree species and one grass species and a replicated small-plot species trial (10 m x 10 m), usually with eight species. Sugarcane was included as the grass species in all the trials except at Ho'olehua, Molokai, where the napiergrass cv. 'banagrass' was used. The tree and grass species used are listed in Table II.3.

Table II.3
Tree and Grass Species Planted in HSPA Biomass Trials

Acacia mangium
Acacia mearnsii
Casuarina cunninghamiana
Casuarina equisetifolia
Eucalyptus alba
Eucalyptus camaldulensis
Eucalyptus citriodora
Eucalyptus grandis
Equcalyptus saligna
Eucalyptus urophylla
Leucaena diversifolia 'K156'
Leucaena leucocephala 'K636'
Leucaena hybrid 'K743'
Saccharum spp. hybrid H67-1158
Saccharum spp. hybrid H72-6110
Pennisetum purpureum 'Banagrass'

Seedling trees were grown in dibble tubes and were transplanted to the field by the dibbling method of planting. Sixty grams of 14:14:14 fertilizer was applied to each tree at the time of planting. Additional fertilizer was, and will continue to be, applied at approximately 3-month intervals with the amounts varying by the nutrient status at the individual sites. The large plots were planted with trees spaced at 2 m x 2 m (2,500 trees/ha); in the small plots, trees were spaced at 1 m x 1 m (10,000 trees/ha). Thinning is planned for the small plot plantings. The sugarcane and 'banagrass' were planted in rows 1.8 M wide by standard industry practices.

Data Collection

Tree plots will be harvested at 5 years from planting and grass plots will be harvested at intervals which will vary by site but will be between 6 to 10 months for the 5-year period of the test. Periodic growth data will be taken in both the small and large tree plots.

Results (Preliminary Height Data)

Height data are reported from the small-plot species trial in three sites: Ho'olehua, Molokai; Mountain View, Hawaii; and Kilohana, Kauai (Tables II.4, II.5, and II.6). Eucalyptus spp. were the fastest-growing trees in each of the sites for the initial measurement. The fastest-growing nitrogen-fixing tree in the upland sites was Acacia mearnsii.

Table II.4
Height Data for Trees at Ho'olehua,
Molokai (Site at 3.5 months)

Species	Height
	(cm)
Eucalyptus camaldulensis	100a*
Eucalyptus grandis	80b
Casuarina equisetifolia	64c
Eucalyptus saligna	59cd
Casuarina cunninghamiana	51de
Leucaena 'K636'	32f

* Means with the same letter are not significantly different at the 5% level (Duncan's multiple range test).

Table II.5
Height Data for Trees at Mountain View,
Hawaii (Site at 7.5 months)

Species	Height
	(cm)
Eucalyptus urophylla	240a*
Eucalyptus robusta	208ab
Eucalyptus grandis	198ab
Eucalyptus saligna	189ab
Acacia mearnsii	168bc
Leucaena leucocephala	134c
Casuarina equisetifolia	122c
Acacia mangium	71d

* Means with the same letter are not significantly different at the 5% level (Duncan's multiple range test).

Table II.6
Height Data for Trees at Kilohana, Kauai
(Site at 8.5 months)

Species	Height
	(cm)
Eucalyptus urophylla	299a*
Eucalyptus grandis	282ab
Acacia mearnsii	251b
Casuarina equisetifolia	169c
Leucaena 'K636'	133cd
Leucaena diversifolia	117d
Acacia mangium	112d
Leucaena 'K743'	104d

* Means with the same letter are not significantly different at the 5% level (Duncans' multiple range test).

Conclusions and Summary

Both C_4 grasses such as sugarcane and napiergrass and C_3 trees such as Eucalyptus and Leucaena are candidates for renewable energy crops. Although dry-matter yield data are available for the individual crops, there is a data gap with regard to the yield potential when grown under the same conditions. We have established both tree and grass crops on five diverse Hawaiian sites in order to obtain such information on relative yield potential.

The program at the Hawaiian Sugar Planters' Association Experiment Station to produce a Hawaiian energy cane, and the energy status of Hawaiian sugar industry are discussed in relation to the above.

Acknowledgement

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CHAPTER III

HARVEST AND PREPARATION TECHNOLOGY FOR BIOFUELS

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Introduction: Economically Viable Biofuels and the Five F's

In the search for plant species that may offer promise of becoming technically and economically viable sources of raw materials for biofuels, it is logical to consider first the cultivated crops for which the technology for propagation and harvesting has already been developed, such as sugarcane.

There is a rule of thumb for the five F's--Food, Feed, Fiber, Fuel, and Fertilizer--which describes a hierarchy of value for agricultural products. Like other rules of thumb, it doesn't seem to be based on any easily proven logic, it just happens to be generally true. It means that an agricultural product will have a higher value if it can be used for Food (for humans) rather than Feed (for animals) and so on down the line.

Our interest is now focused on Fuel. We would like to explore whether agriculture can produce biofuels that can be cost competitive with fossil fuels and, thus, provide a sustainable, renewable alternative energy resource. We know that biofuels have always provided a major contribution to our energy resources, remembering that petroleum has been used for little more than a century and nuclear energy for only a few decades. Our real concern is to have energy resources cheap and plentiful, enough so that we do not have to make drastic changes in our way of like as the fossil fuels are gradually depleted. At present, though, fossil fuels still provide the basis for comparison in evaluating the economic attractiveness of alternative energy resources, such as biofuels.

Because Fuel is ranked lower than Food, Feed, and Fiber in the five F's, it is generally not profitable to devote good crop land and production inputs to the exclusive production of biomass for fuel. Several programs to do this have been attempted, but their success rate is not good. However, when food, feed, or fiber crops produce large quantities of crop residues as a by-product, the economics of recovering and utilizing these residues as a biofuel source may become attractive. A specific example of immediate interest is sugarcane.

Sugar Cane As A Biofuel Crop

Sugarcane is a crop that produces extremely large quantities of biomass because it is so efficient in photosynthesis and plant growth. Since it is such an important traditional crop in the tropics, its potential for producing biofuel merits a careful look. The sugarcane industry has been in financial trouble recently in many places around the world because of low sugar prices, an over-supply of sugar stocks on the world market, market competition from other sweeteners, and high production costs. For some sugar producers as in Hawaii their ability to efficiently generate and sell electric power has provided an additional source of revenues that helps to keep them solvent.

The fiber content of millable cane, which emerges from the milling process as bagasse, is traditionally used to provide boiler fuel to generate steam for powering the mill and refinery, as well as for process steam. Through proper design and management, high levels of energy efficiency in using bagasse fuel can result in an excess of generated power that can be exported from the sugar factory to the public utility grid or to other applications.

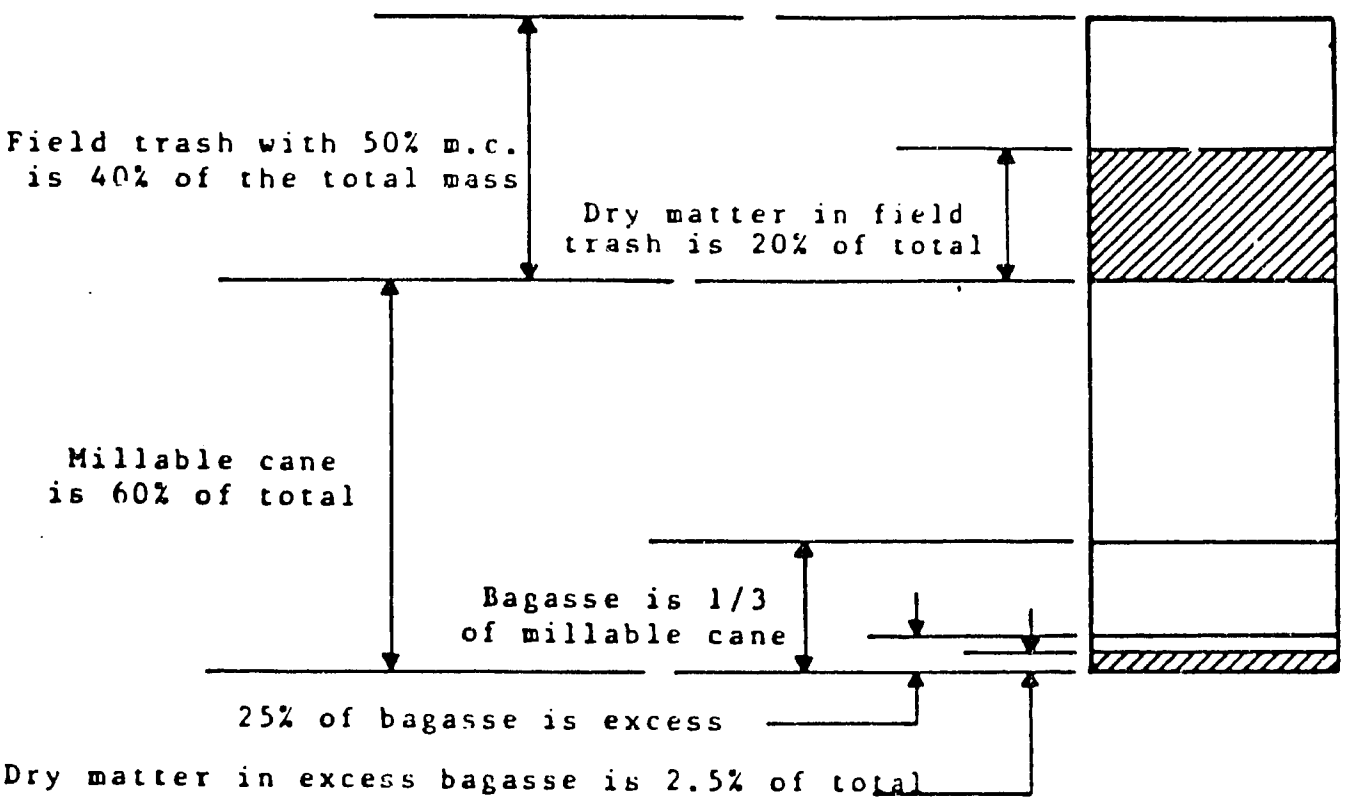
In addition to the cane fiber available in the form of bagasse, there is also a very large portion of the cane plant that consists of tops and leaves that could be used for energy. These components are usually separated from the millable cane in the field during the harvest operation and, up until now, have generally been an unexploited resource. These tops and leaves may in fact represent an energy source equal to or even greater than that provided by bagasse.

This energy potential is illustrated by Figure III.1, which is based on observed values that are typical of the various components of the cane plant with tops and leaves at the time of harvest. Sixty percent of the total biomass is millable cane. In the milling process, about one third of the millable cane is converted into bagasse at 50% moisture content wet basis after the juice is extracted. Most of the bagasse is immediately burned as boiler fuel to produce process steam most of which is used to generate the power required by the mill. At typical system efficiencies, about 25% of the total bagasse produced during milling is excess. This could be used to generate surplus electricity for sale during the milling season. For example, if we start out with one metric ton (1000 kg) of fresh cane plants in the field at the time of harvest, the dry matter content of this excess bagasse available as a biomass fuel is 2.5% of the original total fresh weight or 25 kg.

But let's look at the tops-and-leaves portion of the cane plant. This amounts to 40% of the original total weight at a 50% moisture content wet basis. The dry matter portion of this component is 20% of our original metric ton of fresh material, or 200 kg, and it has no prior commitments. It is simply called field trash crop residue, or "barbojo". Note that the barbojo outweighs the excess bagasse by eight to one.

It is proposed that barbojo is an attractive biofuels source, either for direct combustion for thermo-electric power generation or as a feedstock for gasification or other conversion processes. Any large-scale commerical program for biofuels derived from barbojo or from any other crop residues must give consideration to these three important factors:

Figure III.1
Typical Portions by Weight of the Sugarcane Plant



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1. Determination of the quantities of biomass available (metric tons per hectare) from the crop residues, and its physical and chemical properties particularly moisture content, ash content, and heat value;

2. Timewise matching of the availability of biofuels supplies with demand;

3. Selecting appropriate systems to harvest and transport the biofuels.

The importance of each factor is discussed at some length in the following sections. All three issues must be dealt with in any proposed cane energy project.

Determining Available Energy and Properties of Biofuel Crop Residues

An "ideal" biomass fuel would give the following attributes:

- Low moisture content and high calorific value;
- Year-round availability;
- Physical form and combustion characteristics suitable to the requirements of the power plant or conversion process; and
- Located at the power plant or processing plant.

In reality, most crop residues have a relatively high moisture content typical of growing plant material, they are available only for a few weeks or months of the year corresponding to the harvest season, are bulky with low density and irregular shape and size, and are distributed with different landowners over the large areas in which the crops are grown. To be economically viable, a biomass fuel system must be properly designed so that the crop residues can be gathered, dried, transported, and eventually stored, burned or converted at a cost that is lower than other energy alternatives. The development of biomass fuel systems must be based on proven performance and cost data for all the operations and these data must be obtained under actual large-scale field conditions.

The energy value of most lignocellulosic materials, such as crop residues, is close to 4500 kcal/kg (8100 BTU/lb). This is the high heat value of combustion when the completely dry material is burned. A metric ton (1000 kg) of dry biomass will produce about 4.5 million kcal (18 million BTU) of heat energy when burned. By comparison, a barrel of fuel oil will produce 1.5 million kcal (6 million BTU) so that a metric ton of completely dry biomass fuel is equivalent in high heat value to three barrels of petroleum. An increase in the moisture content and a higher ash content of a biomass fuel reduces its heat value. A precise determination of the quantities of crop residue available based on the combustion properties, especially moisture content and ash content, is a necessary step in the design of any biomass fuels system.

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As an example of the information on quantities of cane crop residues, we may refer to a study done in the Dominican Republic for the Dominican Electric Corporation (ABA International and SERCITEC 1983). Results of the measurements on the quantity of barbojo available show a rather consistent correlation between cane tonnage and barbojo tonnage per hectare. On the average, for each ton of cane there is 0.66 ton of barbojo at a field moisture content of 50% mcwb when harvested. This ratio permits an easy calculation to estimate the quantity of barbojo available based on cane production records or projections.

High tonnage cane of variety PR 980 when irrigated at Barahona produced 123 metric tons per hectare of millable cane and 90 MT/ha of barbojo at 50% moisture content, yielding 45 MT/ha of dry matter as biomass (Table III.1). At the low end of the spectrum in this study, a non-irrigated field of variety PR 1028 at Colonia Cairnito near Consuelo produced 39 MT/has of cane and 27 MT/ha of barbojo at 59% mcwb for a dry matter biomass yield of 11 MT/ha.

Table III.1
Yields of Cane and Barbojo

Location	Variety	Tonnage	Cane MT/ha	Barbojo MT/ha	Barbojo Moisture Content %	Barbojo Dry Matter MT/ha
Barahona	PR 980	High	123.1	89.7	50.0	44.8
Barahona	PR 980	Medium	71.3	46.3	54.8	25.4
Barahona	PR 980	Low	34.7	51.3	56.6	29.1
Consuelo	PR 980	Medium	52.6	29.9	45.1	13.5
Consuelo	PR 980	Low	46.9	33.4	49.4	16.5
Quisqueya	PR 1028	High	86.2	46.9	50.0	23.5
Quisqueya	PR 1028	Low	33.3	28.6	51.1	14.6
Consuelo	PR 1028	Low	39.2	26.9	41.0	11.0
Consuelo	CP 5243	High	69.7	47.4	44.9	21.3
Consuelo	CP 5243	High	60.7	49.0	46.6	22.8
Consuelo	CP 5243	Low	52.1	34.0	53.9	18.3

Source: ABA International and SERCITEC, 1983.

The moisture content of barbojo decreased from an average value of 50% at harvest time to values below 35% after four days of drying in the field. Based on the observed patterns of moisture content change, as for example those shown in Figure III.2, it can be concluded that drying in the field beyond six days is not important in achieving a lower moisture content. Obviously, after the first few days of field drying, the moisture content is influenced more by weather conditions than by field drying time.

The calorific value of barbojo samples was measured and compared to the established values for bagasse. The average value for ash-free barbojo was found to be 4527 kcal/kg (8149 BTU/lb), which is 98.2% of the accepted value for ash-free bagasse. The average ash content for barbojo gathered at Barahona ranged from 11.0 to 12.9 percent. For barbojo gathered in the Quisqueya and Consuelo areas, ash content ranged from 5.67 to 7.42 percent (Table III.2).

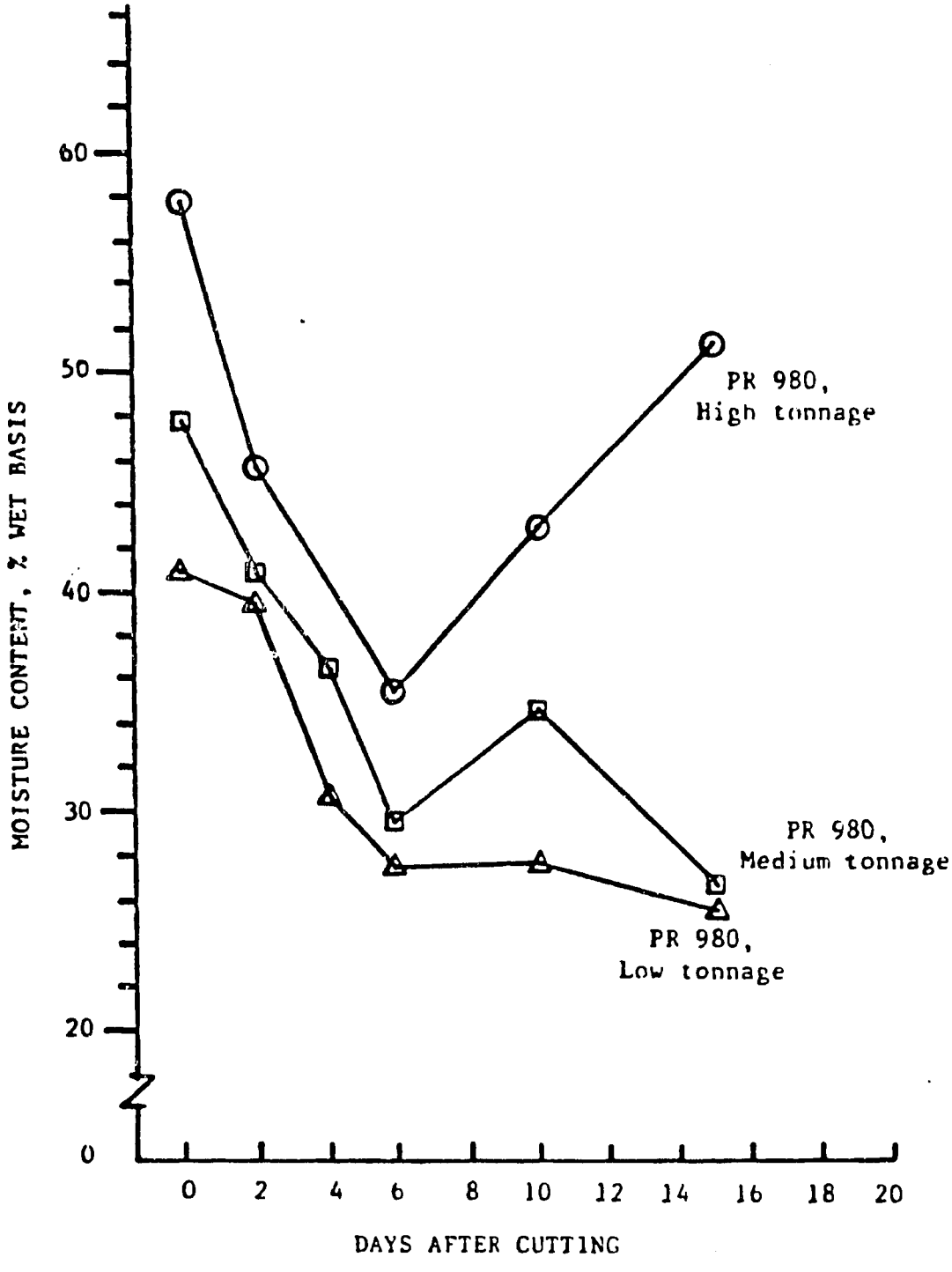
This Dominican Republic study provided useful quantitative results to indicate the amounts and energy related properties of biomass fuel that may be expected from cane crop residues, as well as establishing the methodology for such studies. The amount of barbojo available in other locations will be influenced by cane varieties, cultural practices and agro-climatological conditions. Detailed studies should be done for each location and for each particular approach to cane and trash harvest operations to obtain the specific information required for a biomass fuels system.

Table III.2
Ash Content of Oven-Dried Barbojo Sampled
at Cutting Time

Location	Variety	Mean Ash Content %	Standard Deviation
Barahona	PR 980	12.11	1.440
Barahona	PR 980	11.03	0.565
Barahona	PR 980	11.19	1.048
Consuelo	PR 980	6.28	1.016
Consuelo	PR 980	7.08	1.778
Quisqueya	PR 1028	5.99	0.830
Consuelo	PR 1028	7.31	0.475
Consuelo	CP 5243	7.12	1.070
Consuelo	CP 5243	7.18	1.231
Consuelo	CP 5243	5.03	0.268

Source: ABA International and SERITEC, 1983.

Figure III.2
Barbojo Moisture Content Changes During In-Field Drying
Barahona, PR 980



Source: ABA International and SERCITEC. 1983.

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Matching Time Availability of Biofuel Supplies with Demand

The seasonal nature of the biofuel supply poses serious problems for storage. Because of its relatively low density, the volume of biomass fuel required for even a modestly-sized power plant is so large that the cost of storing several months fuel supply under-roof is generally prohibitive without some resource processing. For purposes of illustration, we may consider the value used in the projected barbojo and bagasse fuel requirements for the 30 megawatt thermo-electric plant San Predro I (ABA International and SERCITEC 1984). The plant will operate 330 days of the year, whereas the cane harvest season lasts only 180 days. During harvest season, the power plant would use 128,174 short tons of bagasse and 52,000 short tons of barbojo. During the off-season, 342,697 big round bales of barbojo fuel would be required, with a net volume of 1,308,086 cubic meters. That is like a forty acre field, with barbojo stacked more than twenty feet deep!

To deal with this storage problem, outdoor storage is considered a possibility for sites with short annual cropping seasons. Big, round bales have the ability to shed rain and tend to lose moisture during outdoor storage, as long as the moisture content at the time of baling is 35% or less. Also, it may be possible to store rectangular bales outdoors if they are properly stacked and, perhaps, covered by loose barbojo or impervious sheets.

Low-cost storage, densification, or conversion processes to increase the energy content per unit of volume must all be evaluated and compared for each project. Of course, it would be very helpful to increase the length of the harvest season and shorten the off-season whenever this is feasible. For fuel systems that use a combination of biomass and fossil fuels, it is more logical to store fossil fuels to be used in the off-season, not biomass.

Selecting Machinery Systems to Harvest and Handle Biomass

Insights may be gained on the feasibility of particular systems by observing their experiences to date in places where trash collecting operations have been carried out. In Puerto Rico, experiments have been and are being conducted with wheel rakes and large round balers to gather cane field trash in conjunction with the project "SugarCane for Multiple Uses". An important aspect of this study will be field evaluations of harvesting methods for high tonnage cane with a view to recovering field trash as well as the millable cane. During December 1986, a Farmhand Model F-7 wheel rake was reconditioned and used to windrow field trash, and then a New Holland Model 851 baler was used to make several bales, demonstrating the technical feasibility of this proposed method of gathering field trash[1]. The typical bale weighed about 1650 lb/bale. These trials demonstrated the critical importance of a careful raking operation: windrows must be straight and not too large for the baler-pickup mechanism to work without clogging; and cane or weeds with roots still attached to the ground may cause problems for both raking and baling. Overall, the rake operated very effectively and the baler showed promise, with minor adjustments, of satisfactory operation for the purpose of recovering cane field trash. Extensive field trials are needed to obtain complete performance data for the baler and for the bale handling systems.

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[1] Equipment manufacturers' names are provided for technical reasons and do not imply product endorsement.

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At Central Romana, located on the southeast coast of the Dominican Republic, there are 3,300,000 short tons of cane milled annually from 64,000 hectares of plantations. Cane is harvested without burning with manual cutting and loading operations. The mill produces furfural and electric energy from its bagasse and barbojo. Barbojo is recovered, primarily from fields that are to be replanted as well as those fields which are relatively close of the mill for convenient transport. However, it is left on fields that are to be ratooned for ground cover to conserve moisture and suppress weed growth. The average production from fields that are to be replanted is 50 tons of cane and 20 tons of barbojo fresh weight per hectare, which yields about 14 tons of barbojo sun-dried to 30% moisture.

Since 1981, barbojo has been harvested with conventional forage handling machines. First, the barbojo is windrowed using conventional side delivery hay rakes, a John Deere Model 650 PTO rake pulled by a John Deere Model 2140 tractor of 70 PTO HP. After raking and sun-drying, the windrows are run over by pull-type forage harvesters equipped with windrow pickups. John Deere Model 3940 and 3970, and Hesston models 7160 and 7165 are in use, with John Deere Models 4040 (91 HP) or 4440 (140 HP) tractors. This equipment picks up the barbojo, chops it into small pieces, and blows it into a cart that is drawn behind the harvester. These modified cane carts are then pulled by tractors to transloading stations where the chopped barbojo is transloaded into railroad wagons for delivery to the mill. The performance of the harvesting system is shown in Table III.3.

Approximately one ton of barbojo is recovered for four tons of cane. The rakes are adjusted to a height which avoids picking up stones and dirt and, thus, leaves a small amount (about 20%) of the total barbojo on the fields. The use of the PTO-driven rakes makes it possible to do this. Formerly the raking operation at Central Romana used Vicon ground-driven wheel finger rakes, but they were too thorough in picking up not only barbojo, but stones as well. Since the ground clearance of these rakes cannot be increased, a different raking system was used.

One of the major concerns is the durability and ruggedness of equipment, both rakes and harvesters, for the rough conditions encountered in handling cane trash. Design modifications by machinery manufacturers could be done to improve the performance and extend the working life of this equipment. For instances, the teeth on the John Deere rakes are mounted with rubber pads that increase their useful life and they are also reinforced by U-shaped steel brackets made in the local shop.

Careful blade adjustment and maintenance are important to good machine performance. The forage harvester blades are sharpended daily and changed monthly. The blade sharpeners are incorporated in the forage harvesters. The John Deere Model 3970 field chopper has a metal detector, which automatically stops the pickup mechanisms if a piece of metal is encountered. This is an important, highly desirable feature, making this the favorite model.

The normal expected machine operation is 4 ha per day for each forage harvester and 8 ha per day for each rake. The machines work about 5 hours per day and have 5 hours per day down time. A total of five harvesters works as a team. For each forage harvester, one operator and one assistant is required. For each rake, only one operator is required. One driver and one assistant is required for each transport unit consisting of one tractor and seven carts. The 1985 costs for gathering barbojo up to its transfer to the railroad were RD$23.30 per ton or US$8.2 per ton (US$1.00 = RD $2.85, 1985).

Table III.3
Barbojo Harvesting System Performance 1984-85 Crop
at Central Romana, Dominican Republic

Tons Barbojo Collected (MT)	27,931
Acres Collected	5,716
Tons/Acre	4.9
Working Days	145
Tons/Working day	192
Average Moisture (Taken at the Factory)	28%
HARVESTER	
Field Efficiency (Effective Hours/Working Hours)	74%
Tons/Machine Day	42
Tons/Effective Hour	5.7
RAKES	
Field Efficiency	85%
Tons/Machine Day	62
Tons/Effective Hour	7.1

The harvesting of barbojo has been in operation at Central Romana for the past six years. From the operational and economic points of view, they are quite satisfied with the results.

Conclusions and Recommendations

The experience with barbojo harvesting at Central Romana has established the technical and economic feasibility of the harvest and preparation of biofuels. This success was achieved by using currently available forage harvesting machinery for the gathering and transport of cane field trash with a system based on field choppers. Similarly, the trial with conventional wheel rakes and big round balers in Puerto Rico have established the technical feasibility of the use of this machinery on cane trash from fields cut by machete

without burning. To date, trials have not been extensive enough to obtain complete performance and cost data, nor to establish the technical and economic feasibility of bale transport and storage systems. Still, these observations lead us to conclude that conventional forage harvesting machinery can be used successfully in many cane growing regions where mechanization is possible to harvest field trash for use as biomass fuel.

Looking farther into the future, there is a need for trash harvesting strategies that are consistent with the machine harvest of millable cane, especially the high tonnage cane. Field burning improves cane harvest efficiency but, of course, reduces the biomass. Full-plant harvesting and loading of millable cane along with tops and leaves simplifies these operations, but takes away the opportunity for sun drying in the field. Selecting cane varieties with a high stem of leaf ratio expedites machine harvest and can result in more bagasse, but reduces the amount of sun-dried barbojo. Most cane growing areas will eventually want to use some form of mechanical cane harvest, thus, compatible trash gathering systems need to be developed and evaluated. Machines need to be selected based on attributes and performance.

Whether the crop residues are used as boiler fuel, feedstocks for gasification, or other conversion processes, the gathering, transport, drying, and storage needs are similar. Systems to be evaluated should include conventional rectangular balers as well as round balers, forage choppers, and other possible machines. It would seem to be in the best interests of the U.S. domestic cane growing areas as well as USAID countries such as Jamaica, Thailand, the Dominican Republic, and the Philippines to support the designation of a central site or institution for a systematic field-based program of machine development and evaluation. Factors to be considered in the selection should include the following: a solid institutional base with an established reputation for cane/energy research and development; relatively long cane harvest season to allow ample time for field trials; a wide range of physical and agronomic conditions; sufficient arrangements for the procurement, or importation, of experimental machines; and support facilities for machinery modification and repair. With such an institution, the knowledge gained through individual endeavors in the Dominican Republic and Puerto Rico can be shared and greatly enhanced.

ACKNOWLEDGEMENTS

The use of brand names and models is for informational purposes only and does not imply an endorsement of these particular machines by the author.

The author wishes to acknowledge the support of the Dominican Electric Corporation for sponsoring the 1983-84 barbojo studies, the USAID for their support of studies in Jamaica and Thailand, Central Romana and the Puerto Rico Land Authority for their cooperation, and ABA International Inc. and RONCO Consulting Corporation for the opportunity to participate in cane/energy studies.

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CHAPTER IV

FIELD EXPERIENCE IN THE COLLECTION AND TRANSPORT OF CANE TRASH (BARBOJO) AT CENTRAL ROMANA

By

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Introduction and Setting

The Central Romana sugar mill is situated next to La Romana town (latitude 18° 25' N; longitude 68° 59'W) on the southern coast of the Dominican Republic. It draws its cane supply from approximately 64,000 hectares. Of these, some 39,000 hectares are owned by the mill (Administration) and 21,000 hectares are private growers' (Colonos). In addition, the Administration has approximately 50,000 hectares dedicated to pastures.

Central Romana has ground an average of 3,104,539 metric tonnes of cane with an average 96° sugar yield of 12.2% (8.2 TC/TS) during the past five crops. Crop length has averaged 205 days. Practically all the cane is cut and loaded by hand, without prior burning. About 77% of the cane is hauled from the field to the railway loading stations by ox-drawn carts, and the remainder by tractor-drawn trailers. The oxen feed entirely on cane tops during the cropping season. Most of the cane (91%) is transferred from the carts and trailers into 30- to 40-ton railroad wagons by fixed cranes; the remaining 9% is transferred by hand. All the cane is transported to the mill along standard gauge (1.2m) railroad.

Besides producing sugar and molasses, Central Romana also produces electrical energy and manufactures furfural from bagasse. During the cropping season, about 15,000 kW/hr of electricity are generated for its needs at the mill and other related companies, such as a hotel and tourist complex.

Cane Trash Energy Characteristics

When cane is cut without burning, a large quantity of residues, referred to as "barbojo" (cane trash), is left in the field. Normally this amounts to about 30% of the total cane tonnage. Its moisture content is around 50% mcwb. The amount of "barbojo" varies among varieties and depending on prevailing growing conditions. Extreme values as low as 15% can be found in certain of our commercial varieties. Within a week, on sunny days, the barbojo's moisture content decreases to about 30% mcwb. Values of less than 20% moisture are frequently obtained.

FIELD EXPERIENCE IN THE COLLECTION AND TRANSPORT OF CANE TRASH (BARBOJO) AT CENTRAL ROMANA

Under Central Romana's conditions, this trash mulch plays an important agronomic role. Almost all the cane is cultivated under rainfed conditions with a rather low and erratic rainfall pattern (1,000-1,400 mm/year). This climatic stress, coupled to the low water-holding-capacity in most of the soils (2.5-15 cms), subjects the cane to prolonged drought periods. The remaining trash blanket, therefore, helps to preserve the moisture in the upper part of the soils, besides providing weed and erosion control and enhancing soil fertility through the addition of organic matter.

During the cane renovation or replanting program, it is standard practice to burn the trash residues of the previous crops. This burning is done to speed up and facilitate soil preparation prior to planting. By so doing, large amounts of a potential source of biomass energy (barbojo) are literally wasted. The renovation cycles vary according to soil type, averaging a plant cane and seven ratoons. Cane is usually cut about 12 months of age. Fields are renovated in Central Romana when they average around 50 tonnes of cane per hectare, thereby leaving behind about 14 tonnes of sun-dried barbojo of which, generally, 12 tonnes are collected.

The calorific value of oven-dried barbojo has been calculated at about 4,180 Kcal/Kg (7,540 BTU/lb). At 30% mcwb, this amounts to about 2,850 Kcal/Kg. Therefore, a metric tonne of sun-dried barbojo is equivalent in calorific value to about 78 gallons of Bunker C fuel.

Due to the energy crisis, originated by the rise in the cost of oil and oil derivatives, it seemed logical to utilize this wasted biomass instead of destroying it by burning. A study at Central Romana was carried out to determine the economic advantage of using barbojo as a source of energy. This study comprised collecting barbojo in recently harvested cane fields and transporting it to the factory.

The low density of the barbojo has been its main limitation for use as fuel. Its density varies according to the collection method. Some average values by different collecting systems are shown in Table VI.1.

Table VI.1
Average Density of Barbojo by Collecting System

Collection System	Average Moisture (% mcwb)	Average Density (Kg/M^3)
Chopped	30	120
Round bales	30	170
Rectangular bales	30	225
Briquettes	10	630

FIELD EXPERIENCE IN THE COLLECTION AND TRANSPORT OF CANE TRASH (BARBOJO) AT CENTRAL ROMANA

Cane Trash Collection

Several systems of collecting and transporting barbojo were studied. The equipment used were conventional forage handling equipment. The advantages of baling versus chopping babojo were compared. Both systems proved to be economically feasible. Nevertheless, under Central Romana's conditions chopping was considered most appropriate. This allows one to make better use of the existing field and factory facilities.

In the field, it was possible to adapt the conventional cane carts and loading stations to handle barbojo. In the factory, the chopped barbojo is received in the existing side-tipping platform off the railroad system.

The collection system comprises of the following operations:

1. Windrowing the trash

First, the trash is windrowed using conventional hay rakes. This allows the harvesters to reduce the number of passes over the field. A 9-foot rake was selected. The model being used is a John Deere 650 P.T.O. rake[1] works with a 70 P.T.O. H.P. tractor. The performance of this equipment is shown later in Table VI.2.

2. Trash harvesting

The windrows are then collected by a pull-type forage harvester equipped with windrow pickups. This equipment picks up the trash, chops it into small pieces and blows the trash into a cart drawn behind the harvester.

The equipment models used by Central Romana in this collection system include:

MODELS	H.P. (P.T.O.)
John Deere 3940	91
John Deere 3970	140
Hesston 7160-7165	140

The trash is transported to the loading station by two types of modified cane carts pulled by tractors. One consists of specially-contructed portable boxes, which are placed on top of the cart floor. They are lifted using a standard cane loading station or a mobile crane. While the boxes are on top of the wagons, the bottom is opened and the barbojo falls into the wagon. Another type of collection uses side-tipping carts, with these carts going to a platform placed under the standard cane-fixed crane where, once on top of the platform, they then are tipped over into the railroad wagon. Both systems have been successfully in operation for five years.

[1] Equipment manufacturers mentioned in the study does not imply product endorsement.

The performance of this windrowing and harvesting are given in Table VI.2.

Table VI.2 shows that approximately one tonne of sun-dried barbojo is collected per four tonnes of cane harvested. The quantity collected is 11.8 tonnes per hectare or about 83% of the expected barbojo yield per hectare. The presence of stones and drainage ditches in the fields make it difficult to collect a higher percentage. Table VI.3 shows the operational efficiencies obtained with the equipment being used.

Table VI.2
Barbojo Harvesting Equipment Performance

Production (Tons barbojo/year)	25,700
Yield per Area Harvest (Tons barbojo/ha.)	11.8
Cane/Barbojo, Ratio (Tons cane harvested/Ton barbojo picked up)	4
Operating Days (Working days/year)	136
Daily Yield (Tons/day)	190
Labor (Harvesters/day)	5
Yield per Laborer (Tons/harvester/day)	38
Effective Yield (Tons/harvester/effective hour)	5.7
Equipment (Rakes/day)	3.4
Equipment Yield (Tons/rake/day)	55
Effective Equipment Yield (Tons/rake/effective hour)	7.0

Estimated Costs

The present cost per tonne of barbojo harvesting excluding railroad transport, is RD $23.30/gt (1 US$ = RD$3.30) or US $7.10/gt (Table VI.4). Railroad transport costs are excluded since this operation must be conducted within the normal cane transporting operation.

Table VI.3
Harvesting Equipment Efficiencies

Operational Efficiencies	Efficiency
	(%)
Hours worked by harvester/hours programmed	77
Effective Harvester Hours	52
Operational Efficiency*	52
Field Efficiency**	68

* = (Effective hours/Hours programmed) x (100)
** = (Effective hours/hours worked) x (100)

Table VI.4
Estimated Costs Per Tonne of Barbojo Harvested

Cost Component	Unit Cost	Percentage of Total Cost
	(DR$/ton)	(%)
Equipment*		
Windrowing (Rake+Tractor)	4.17	18
Harvesting (Harvester+Tractor)	8.71	37
Field Transport (Tractor)	5.30	23
Field Transport (Carts)	2.58	11
Railwagon Loading (Crane)	1.71	7
Equipment Sub-Total	22.50	97
Labor	0.80	3
Total Costs	23.30	100

* = Includes operator.
1 US$ = RD$3.30 (1987).

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Conclusions and Future Prospects

From the economical and operational points of veiw, the results of the barbojo harvesting program that has been in operation at Central Romana since 1982, have been satisfactory. For the 1986-87 crop, the amount to be harvested is planned to be the same as the present crop, namely 25,000 tonnes. Future program expansion must consider that cane transport (e.g. by railroad to the mill), cannot be affected by additional trash collection.

The main problem encounted in the operation is equipment breakage due to the relatively weak construction of the forage harvesters in use. This is logical since they are designed for forage harvesting and not barbojo harvesting. We are aware that an equipment manufacturing firm has shown interest in developing a stronger harvester for this type of operation, thereby possibly accomplishing better performance. This is encouraging since other countries have shown an interest in barbojo harvesting.

Presently the Dominican Government is planning to develop a barbojo harvesting program in order to produce electricity. This program intends to harvest approximately 1,700 tons of barbojo per day to supply a 30 MW thermo-electric plant. The collection system selected for handling the barbojo producers rectangular bales.

In conclusion, the experience at Central Romana proves that it is economically and technically feasible to harvest barbojo for use as a source of biomass energy. The actual collection system selected always depends on many site-specific factors. In each instance, a study should be done so as to choose the system that best suits users needs.

CHAPTER V

TRASH FOR FUEL: A LUISITA PROJECT

By

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Introduction

In Crop Year (CY) 1983-84, Central Azucarera de Tarlac (CAT), in conjunction with her sister company Hacienda Luisita (HL), embarked on a field experiment to utilize cane trash for fuel. This was at a time when bunker fuel cost in the country was at its all time high. Since CAT had a refinery, distillery, CO_2 and yeast plant, her bagasse supply was always short of her fuel requirement. It was mandatory to seek cheaper, alternative sources of fuel. Thus was conceived the "Trash for Fuel Project".

Company Profile

CAT is located 2 hours north of Manila. It operates a 7,000 ton of cane per day (TCD) mill, and has a refinery with a daily refined output of 7,500 50kg, and a distillery that produces 12 million liters of alcohol annually while recovering 4,000 tons of CO_2 and 500 tons of yeast.

Hacienda Luisita (HL) runs a 6,500 hectare farm from which it generates some 350,000 tons of cane annually, supplying 40% of the cane requirement of the mill. Normally, only 5,000 ha. are planted to cane per season. The hacienda has a population of some 20,000 of which about 15% can be gainfully employed in the mill and farm. There is a constant pressure to provide employment opportunity for the other residents of the farm. The trash collection is viewed simultaneously as an income augmenting project that can provide a positive social impact on the community.

Crop Year 1983-84 Experiment

Before CY 1983-84, HL adapted the Australian method of farming sugarcane. With it came the use of mechanical planters and harvesters. Since the basic machines already were available, it was natural to also collect the trash mechanically.

The collection of trash was simple: as the mechanical harvesters chopped off the cane tops, a windrower followed to pile up the trash, then a mechanical baler was used, and finally the baled trash (dimension = 1 ft x 2 ft) was loaded into trucks for delivery to the mill. These were fed manually to the boilers (See Annex V.1 for cane trash project requirements).

No significant problems were encountered in the production of the baled trash except the lower output of the mechanical harvesters. Cutting fresh cane, the harvesters averaged about 20 tons of cane per hour (TCH), versus 30 TCH for burnt cane. It is a common practice on the sugar farms to burn the cane before harvesting to maximize cutting and loading.

Although trash collection proved technically feasible, the trash baling operation was discontinued because of problems faced in feeding the boilers. Because no equipment was available at the mill to chop and shred the cane trash to the large boilers, the baled trash was manually fed to the small boilers. Eventually, the small boilers were put out of commission and the experiment ended.

For CY 1983-84, 158,364 bales of trash were produced of which 120,571 bales (1,058 tons) were used for fuel. The remainder was used for compost and cattle feed. The bunker for oil (BFO) equivalent of the baled trash burnt by the boiler was 243,455 liters[1]. The 1987 cost equivalent per ton of baled trash is ₱645 (US $31.50). In terms of BFO at ₱2.80 per liter, this amounts to ₱756 (US $36.87) or a net savings of ₱111 (US $5.41) per ton baled trash.

Crop Year 1987-88 Project

A fuel oil price increase will definitely be implemented in the Philippines no later than the second half of 1987. Since the trash for fuel project is justified even without a fuel price hike, it is imperative to implement the trash for fuel project on a full scale basis.

CAT will consume some 12 million liters of bunker fuel or, alternatively, about 50,000 tons of trash. The 350,000 ton crop of HL can generate at least 60,000 tons of trash. In effect, CAT could eliminate completely the firing of bunker oil by using its waste products.

For CY 1987-88, we expect to recover 50,000 tons or 80% of the estimated trash available. One half will come from standing cane, the other half from harvested cane. The total fuel savings value ₱34.8 M per year while projected annual expenses are ₱22.5 M. Projected net annual savings that directly accure just from fuel substitution amount to ₱12.3 M or $600,000 (See Table V.1).

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[1] The assumed conversion rate is 270 liters bunker fuel oil (BFO) per ton of baled trash at 15% moisture content wet basis.

Table V.1
Estimated Annual Fuel Costs and Benefits
From the CAT-HL Trash Project
(1987)

Fuel Benefits and Costs	₱/Year	U.S.$/Year
A. Annual Fuel Savings: Displaced Bunker Fuel Oil Value of Trash[a] :		
- Standing Cane[b]	18,794,498	916,804.78
- Harvested Cane[c]	16,018,900	781,409.76
- Total Annual Fuel Savings	34,813,398	1,698,214.54
B. Projected Annual Expenses[a]		
- Standing Cane		
Collection	₱ 2,458,500	
Baling	6,730,390	
Transport	2,507,915	
Subtotal	11,696,805	570,575.85
- Harvested Cane		
Collection	₱ 1,273,300	
Baling	6,966,097	
Transport	2,595,746	
Subtotal	10,835,143	528,543.56
- Total Cane Expenses	22,531,948	1,099,119.41
C. Projected Net Fuel Benefits/Savings:	₱12,281,450	$ 599,095.12

Assumptions: 80% Recovery of Available Trash

Standing Cane Trash	24,585	tons
Harvested Cane Trash	25,446	tons
Total	50,031	tons

	₱ Value	US$ Value
[a] See Annex 2 for details.		
[b] Standing Cane Trash: One ton of trash = 273.025 liters of BFO @ ₱2.80/liter	764.47	37.29
[c] Harvested Cane Trash Value: One ton of trash = 224.83 liters of BFO @ ₱2.80/liter	629.52	30.71

In addition to the obvious significant advantage of a net annual fuel savings of at a minimum ₱12 M (over a half million U.S. dollars), the project will generate other equally important benefits. These include:

a. Social Impacts - Excess labor on the hacienda can be absorbed by this project to augment household incomes. The project's labor component is worth ₱6.5M (Table V.2). Some 300 additional families or 10% of the estimated number of hacienda families will be employed, giving each family an annual income of ₱21,500;

b. Additional Sugar Revenues - The milling of clean and unburnt cane will result in higher recovery of sugar per ton of cane (PSTC) while reducing steam consumption. Our experiment showed an improved PSTC of 10%, or a combined additional sugar revenue for CAT-HL of about U.S. $1 Million (Table V.2). The value of reduced steam consumption cannot be determined at this time.

Table V.2
Estimated Net Economic Benefits from
The CAT-HL Trash Project

Net Annual Benefits	Million ₱ Value/yr	Million US$ Value/yr
Net Fuel Savings	12.3	0.6
Additional Labor Income	6.5	0.3
Additional Sugar Revenue	20.5	1.0
Total Annual Net Benefits	39.3	1.9

See Annex V.2 for further detail.

Source: Company estimates.

Future Operational Setup Needs

Using cane trash for energy will require some specific changes in the operations at the mill. These changes can be easily described as field or mill site needs.

A. Field Operations - There are two sources of trash, standing and harvested cane, whose collection will require operational changes at the mill. These include:

- Standing Cane - Prior to the harvesting of cane, dry leaves of standing cane will be manually collected and brought to stationary balers. At least two balers, which can be transported from one farm lot to the other debate as the trash supply demands keep, will have to be acquired.

  At the start of the milling season in October/November when the fields are still comparatively wet, the detrashing of standing cane will open the field to more sunlight. This will hasten field drying and permit early entry of the mechanical harvesters. Moreover, it will help increase the PSTC. In contrast, sugar recovery at the start of milling without detrashing is lower normally because of the relative wetness of the cane.

- Harvested Cane - At present, the harvesting of HL cane is done mechanically as well as manually.

  During manual harvesting, cane laborers or "tabaseros" will detrash the cane after cutting it, and at the same time loping off the cane tops. The trash will be collected and baled by another gang who will perform the operation similar to the baling of standing cane.

  During mechanical harvesting, mechanical harvesters automatically chop off the cane tops as they harvest. The cane tops are piled up on the sides by tractor-pulled windrowers, after which the mechanical balers come in to bale the trash. The collection process can be augmented manually.

B. Mill Site - Because CAT has suspension boilers, baled trash must first be shredded prior to feeding. Consequently, a conveyor system must be installed plus a shredder or muncher so that the baled trash is loosened before mixing with the bagasse for direct feeding.

   Excess bagasse temporarily displaced by the trash will have to be stored outside. The storing process will increase the thermal value of the bagasse because of its eventual lower moisture content.

Normally, bagasse accumulated after milling adds up to 10,000 tons, which is equivalent to about one month's refining operation. In contrast, with the trash project about 60,000 tons is estimated to be accumulated. This will require a more sophisticated bagasse handling system. Consequently, a bagasse briquetting machine may be needed. Also, a warehousing system will be introduced and at least two payloaders must be bought. In the long run, these additional capital needs are minor, when compared to the significant net economic and social benefits we envision to reap from this project (Table V.2).

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Annex V.1

CAT - HL TRASH PROJECT REQUIREMENTS

HL

1) Acquisition of Baling Machines (suitable for detrashed cane leaves and harvested cane tops):

- Make and origin
- Capacity, number of units, costs and delivery time
- Operating requirements and costs
- Operator training
- Maintenance requirements

2) Establishment of a product handling and transport system:

- Appropriate collection and transport system
- Maximized utilization of facilities
- Maximized use of existing transport facilities

3) Creation of a management organization to handle the project:

- Personnel
- Program mechanics
- Operational monitoring and control
- Synchronization of program with other form activities
- Other field requirements

CAT

1) Acquisition or fabrication of a suitable disintegrator, conveying and feeding facilities (commensurate with the quantity of trash available periodically):

- Make and origin
- Capacity, number of units, costs and delivery time
- Operating requirements and costs
- Operator training
- maintenance requirements

2) Installation of a suitable handling and storage facilities for delivered trash considering mode of delivery:

- Facilities required, cost and installation time
- Personnel requirement

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3) Establishment of adequate handling and storage facilities for displaced bagasse:

- Facilities required, costs and installation time
- Personnel requirements

4) Formulation of an appropriate fuel management system considering magnitude of the project:

- Organization
- Personnel
- Program Mechanics
- Operational monitoring and control
- Synchronization of program with other boiler activities
- Other boiler requirements

Other Needs

1) Phases of implementation and timetables.

2) Field observations of baling machine performances for making equipment selection.

3) Program support and coordination.

4) Mechanics for supplied trash compensation.

Annex V.2
Detailed Costs & Benefits of
TDC-CAT TRASH PROJECT

Project Objectives

1) Use by Central Azucarera de Tarlac of Hacienda Luisita if its sugarcane trash, which is available from standing and harvested cane in lieu of bunker fuel oil, in its mills' boiler operations.

2) Creation of income generating projects to absorb excess TDC-HL labor presently forming part of overhead.

3) Increasing the net sugar revenues from the milling of clean and unburnt cane.

4) Making available cane points to support existing and expansion needs.

Average Breakdown of Cane Components

	GRAMS	% TOTAL
Cane Tops	183.6	10.8%
Dried Leaves	122.4	7.2%
Millable Portion:		
Cane Points	130.0	7.6%
Balance	1,264.0	74.4%
Total	1,700.0	100.0%

Projected Quantities

	Area	Trash Green	Trash Dried	Millable Cane
	(Ha.)	(T/yr)	(T/yr)	(TC/yr)
Standing Cane	5,000	-	30,731	-
Harvested Cane	5,000	46,097	-	350,000
Total	5,000	46,097	30,731	350,000
Per Hectare:				
Tons		9.2	6.1	70.0
Percent		10.8%	7.2%	82.0%

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Projected Value of Fuel Savings of Available Trash

A. Energy Content

	% Moisture (mcwb)	Heating Value (BTU/LB)	Steam/ Trash Ratio (lb/lb)
Standing Cane	15%	6,120	3,467
Harvested Cane trash*	30%	5,040	2,885

*Sun dried before baling from an initial moisture of 61% down to 30% moisture (mcwb).

B. Fuel Savings

Recovery	Trash	Equiv. Bunker Oil[a]	Value[b]
	(tons/yr)	(liters/yr)	(₱)
Standing Cane Trash:			
100%	30,731	8,390,357	23,492,999
95%	29,194	7,970,714	22,317,999
90%	27,657	7,551,071	21,142,998
85%	26,121	7,131,714	19,968,799
80%	24,585	6,712,321	18,794,498
75%	23,048	6,292,678	17,619,498
70%	21,512	5,873,321	16,445,298
65%	19,975	5,453,678	15,270.298
60%	18,438	5,034,036	14,095,300
Harvested Cane Trash:			
100%	31,807	7,151,178	20,023,298
95%	30,217	6,793,714	19,022,399
90%	28,626	6,436,000	18,020,800
85%	27,036	6,078,536	17,019,900
80%	25,446	5,721,036	16,018,900
75%	23,855	5,363,321	15,017,298
70%	22,265	5,005,857	14,016,399
65%	20,675	4,648,357	13,015,399
60%	19,084	4,290,678	12,013,898

a - at 28 lbs./liter
b - at ₱2.80/liter
Note: Tons trash for harvested cane adjusted to 30% moisture from 61% moisture representing a weight loss of 31%.

Projected Expenses

For purporses of this presentation the following conditions are assumed:

1) New baling machines will be acquired suitable for detrashed leaves and manually harvested canes.

2) Utilization of baling machines will be at 60% or 4.8 hours per 8 hour working day or 1,939.2 bales (17 tons) at 404 bales of 8.78 kgs per hour or equivalent.

3) Recovery of available trash will be 80%.

4) All cane manually harvested.

5) Compensation for trash collection delivered to baling machine site in field at ₱0.10 per kilo for detrashing of harvested cane and ₱0.05 per kilo for harvested dried cane trash.

6) All other costing based on prevailing rates.

Estimated Costs of Operations Per Ton Trash*

Cost Component	Cost Per Day	Cost Per Field Dried Ton
	(₱/day)	(₱/T)
A. Baling Costs:		
Labor	265.16	
Repair and Maintenance	159.30	
Depreciation	83.79	
Subtotal	508.25	29.90
Materials		84.40
Tractor Rentals		159.46
Total Baling Costs		273.76
B. Hauling Costs:		
Labor	524.90	43.31
Fuel		14.81
Depreciation		15.13
Repair and Maintenance		28.76
Total Hauling Costs		102.01
Total Cost Per Ton		375.77

Assumptions:
1) Average weight of bale is 8.78 kgs or 113.90 bales per ton.
2) Average operating hours is 4.8 per day.
3) Average production per hour is 404 bales.
4) Average production per day is 1,939.2 bales or 17 tons.
5) Average load per trip is 460 bales or 4.04 tons.
6) Projected baling rate of TASK (Tractor) is ₱1.40 per bale.
7) Cost of baling machine is DM 17,930 or ₱75,414.

*Assumes field-dried to 30% mcwb.

Other Economic Benefits

Assumptions: 350,000 Tons Cane
30% Burnt Cane
5% Trash in Delivered Cane

Tonnage Breakdown	Tons Gross Cane	Tons Trash
	(TC/yr)	(T/yr)
Burnt Cane	105,000	-
Unburnt Cane	245,000	12,250
Total	350,000	12,250

Sugar Loss Due Delayed Milling of Burnt Canes

= 105,000 x 0.10 PS/TC
= 10,500 Piculs
= 6,877.5 Piculs (TDC-HL Share)
= ₱2,063,250 at ₱300/Picul
= 3,517.5 Piculs (Mills Share)
= ₱1,055,250 at ₱300/Picul

Sugar Loss to Trash

Equivalent Bagasse

= 12,250 x 0.60/0.46
= 15,978.26 tons bagasse

Sugar Loss

= 15,978.26 x 0.03 x 0.86/0.982
= 419.795 tons sugar
= 6,637.08 Piculs sugar
= 4,347.29 Piculs (TDC-HL Share)
= ₱1,304,187 at ₱300/Picul
= 2,223.49 Piculs (Mills Share)
= ₱667,047 at ₱300/Picul

Sugar Loss Due Delayed Milling of Equivalent Tonnage

Assumptions: Combined weight and sugar loss equivalent to 10% of displaced tonnage (conversative).

= 12,250 x 0.10 x 1.6
= 1,960 Piculs sugar
= 1,283.8 Piculs (TDC-HL Share)
= ₱385,140 at ₱300/Picul
= 656.6 Piculs (Mills Share)
= ₱196,980 at ₱300/Picul

Harvesting Costs

= 12,250 x 0.98 x ₱25
= ₱300,125

Transport Cost

Basis: Cane Cars account of Mill at 5% haulage trucks at ₱15/ton

Cane Cars:
= None

Trucks:
= (12,250 x 0.95) - (350,000 x 0.95 x 0.02) x ₱15
= ₱74,813

Mill Fuel Loss Due Lost Tonnage

= (12,250 x 30% x 2,205 x 2.3) - (12,250/300 x 375,000 - 85,000)
= 6,796,096 lbs. steam/28
= 242,718 liters bunker oil
= ₱679,610 at ₱2.90/liter

Sugar Loss Due Lost Tonnage

= 12,250 x 1.6 x 33.5%
= 6,566 Piculs (Mills Share)
= ₱1,969,800 at ₱300/Picul

Molasses Loss Due Lost Tonnage

= 12,250 x 6.7 x 33.5%
= 27,495 gallons (Mills Share)
= ₱164,970 at ₱6/gal.

Railways Transport Cost

= 12,250 x 0.05 x ₱50
= ₱30,625

Summary of Costs and Benefits

Particulars	TDC-HL	CAT
	(₱/yr)	₱/yr
Harvesting Cost	300,120	
Transport Cost	74,813	30,625
Trucking Aid	(74,813)	74,813
Sugar Loss to Trash	1,304,187	667,047
Delayed Milling Loss	385,140	196,980
Lost Tonnage:		
Sugar	-	1,969,800
Molasses	-	164,970
Fuel	-	679,610
Electricity (22.6 kW/TC at ₱1)	-	276,850
Delayed Milling of Burnt Cane	2,063,250	1,055,250
TOTAL LOSSES	₱4,052,702.00	₱5,115,945

CHAPTER VI

ALTERNATIVE USES OF SUGARCANE FOR PUERTO RICO

By

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Abstract

Puerto Rico is one of the small tropical islands of the West Indies with a population of 3.5 million people having no known deposits of nuclear or fossil fuel. This industrialized island of 900,000 hectares (ha), whose economy was once highly dependent on revenues from sugarcane, is now looking at cane crop residues as a source of biofuel. Field trials totaling 100 hectares are underway to determine the amount, quality and cost of producing mechanized, irrigated sugarcane for food, alcohol and biofuel.

Introduction

Sugarcane has been commercially grown in Puerto Rico for almost 5 centuries. Only thirty years ago, approximately 100,000 hectares, representing over 90% of the total cultivated land, was planted to sugarcane. Over 90,000 workers were used to grow and harvest a million tons of sugar per year. However, during this period, the Puerto Rican government also began an aggressive program of industrial development. As industries were established, sugarcane planting began to steadly decrease. Currently, only 26,000 hectares are devoted to sugarcane, which produces only 87,000 tons of sugar and 22 million liters of molasses.

Puerto Rico needs to continue to produce sugarcane for several reasons. First, Puerto Rican rum made from blackstrap molasses is an important foreign exchange earner that is widely distributed and well accepted throughout the world. Second, insular sugar requirements can be produced and processed locally. Third, since no local deposits of fossil or nuclear fuels have been discovered, Puerto Rico is now totally dependent on imported oil to meet the energy needs of its people and industries. Finally, the land needs to be used productively. The alternative crops such as rice, vegetables and fruits that have been tried, cannot adequately nor fully substitute for cane due to their limited markets and high production costs, which adversely affect such attempted land use changes.

Puerto Rican Approach

Realizing these problems, our leaders decided to investigate how to rebuild the sugarcane industry and at the same time make sugarcane better serve the needs of Puerto Rico. The legislature appropriated $600,000.00 to establish 100 hectares of intensively cultivated sugarcane. The project objects are:

- Demonstrate to current cane growers that high tonnage commercial cane of 180 tons per ha year can be successfully grown in the irrigated south coastal plains of Puerto Rico;
- Mechanically harvest these crops to obtain soil free material for processing. The total plant is to be harvested and its components evaluated for alternative uses;
- Process the crop through one factory to determine the problems and potential for producing sugar, molasses, high test molasses and fiber for biofuel or other alternative uses; and,
- Determine the costs of:
    - a. Producing irrigated cane by gravity and drip irrigation systems of irrigation;
    - b. Harvesting by various harvesting systems;
    - c. Transporting cane to mills; and
    - d. Processing and associated problems.

Harvesting methods to be tried include harvesting both green and burned cane. Harvesting systems to be tested are the modified Claas and Cameco chopper-loader harvesters, V-cutter with grab loading and manual harvesting to evaluate mechanical harvesting efficiency. Mechanical harvesting tests will include the delivery of the whole plant to the factory along with conventional field separation of tops and leaves. Tops and leaves will be recovered following drying and windrowing. Windrowed tops and leaves will be baled for transporting, storing and evaluation.

Field Trials

Planting began in April, 1986 with the first harvest scheduled for the later part of April 1987. Two cropping cycles are to be tested using 3 commercial cane varieties to observe the effect of cropping cycles and varieties on the production, harvesting and alternative uses. One crop cycle is a 12-month crop followed by 12-month ratoons. The other crop cycle is an 18-month plant crop followed by 13 to 14-month ratoons. Some 40 hectares are planted in the 12-month cropping cycle and 60 hectares in the longer cycle. Precision land grading was completed on 24 hectares to evaluate gravity irrigation vs. drip irrigation on an adjacent 24 hectares field.

Preliminary Field Data

A 10 hectares field was planted during November and December 1985 to the same varieties as used in the demonstration planting. Harvest trials were completed in this field during February, 1987. Composition of the material by variety in the cane is show in Table VI.1. Table VI.2 shows the composition of materials in the same cane following harvest with the Claas chopper-loader system.

Table VI.1
Composition of The Cane

Variety	Tons of Material per ha			
	Mature Stalks (T/ha)	Tops and Attached Leaves (T/ha)	Detached Leaves (T/ha)	Total Material (T/ha)
PR 66-2281	208	26	10	244
PR 67-1355	175	48	15	238
PR 67-1070	126	43	15	184

Table VI.2
Composition of the Harvested Cane

Variety	Tons Material per ha			
	Chopped Cane Loaded in Carts (T/ha)	Tops and Leaves Left in Field (T/ha)	Cane left in Field (T/ha)	Total Material (T/ha)
PR 66-2281	188	33	5	226
PR 67-1355	172	52	6	230
PR 67-1070	126	56	4	186

Discussion

Preliminary harvesting experience has demonstrated the necessity of having adequate check plot data on current production and composition of the cane in field. From this data comparisons can be made between harvesting methods, efficiencies, etc. and at the same time, have a record of actual production. Without this basic data on production composition, actual material recovery data may not be fully explained. For example, a fire burned approximately 6 hectares of the 10 hectares plot intended for preliminary harvesting trials. Test plot data showed the field production was 244 tons of growing biomass per hectares. After burning, at least 208 tons were available for recovery; yet only 146 tons were recovered by the harvesting system used.

The data indicates large varietal differences in composition of materials. What is of particular importance is the stem to leaf ratio. As a biofuel, a high leaf to stem ratio may appear to be desirable as the production of total fiber per ha may be maximized. However, when considering the harvesting, materials handling and processing, a high stem to leaf ratio is definitely preferable as the total product may be handled by conventional harvesting and processing systems. Variety PR-67-1355 is an example of a sugarcane variety having a moderately high leaf to stem ratio which PR-66-2281 has a high stem to leaf ratio. The PR-67-1355 produced more dry matter per ha but the PR-66-2281 produced more fermentable solids and bagasse per hectares.

With continued support from the government, the ensuring date from future trials will be extremely useful in demonstrating the technical and economic possibilities for utilizing cane trash. If as successful, as it currently appears, cane trash utilization can be important to revitalizing the sugarcane industry and providing new products to the Puerto Rican economy.

CHAPTER VII

ELECTRICITY - END USE FOR BIOFUEL ON KAUAI

By

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Converting Biofuel to Electricity: Plant Design Improvements

The topic of dicussion for this session is end uses for biofuel. Of the three end uses being discussed this morning, it is felt that electricity is probably the most beneficial to Kauai. This statement may sound prejudicial, but economic indicators, which will be discussed later, will substantiate this claim.

The production of electricity using biofuel has been in existence since the invention of electric generation in the 1800s. When the sugar plantations first started operations in Hawaii, and to this date, the bagasse (biofuel) was burned in steam boilers to generate steam for sugar processing, and also to generate electricity. In the early days of the sugar industry, the steam boilers were designed to be incinerators, the main purpose of which was to get rid of the bagasse (biofuel) rather than to burn it efficiently. In those days, when more bagasse was produced than was needed, boiler efficiency was not of importance. Since then, sugar production has increased, outside markets for the bagasse energy have opened up, and the value of bagasse has increased as an energy source. With such new market opportunities, boiler efficiency has become critical, and steam boilers are not longer classified as incinerators.

The process of converting biofuel into electricity is well proven and has been improved again and again. In its simplest form, the process consists of using a steam generator or boiler, a steam turbine, and an electrical generator. The bagasse or other biofuel is burned in a boiler where its energy is converted into steam. The steam then is used to drive a steam turbine, the rotational energy of which is converted to electricity in the directly connected generator.

Now, let's take a closer look at the boiler: what it's made of and how modern technology has altered it in an effort to improve the efficiency of converting energy from one form to another.

Boiler Design Issues

The boiler converts the bagasse's chemical energy to thermal energy. The efficiency of this conversion process is based on the ratio of the input vs. output energy. The efficiency of the earlier boilers installed at the sugar plantations was less that 50 percent. In other words, for every 100 units of input energy (biofuel), there were 50 units of output energy (steam). As mentioned earlier, these boilers were not designed for efficiency, but to get rid of the excess bagasse. The boiler consists of a furnace where the bagasse is burned. The heat that is generated by the burnt fuel heats the water in generating turbines until steam is formed. The steam is used in turn to drive a steam turbine.

Since those early units, the boiler design has changed substantially. The energy that would normally be lost to the atmosphere is now being utilized with the addition of these various components:

- a Water-Cooled Furnace - Water cooling of the furnace walls by using water wall tubes minimizes the transfer of heat to the structural members and, consequently, they operate at temperatures within the limits of their strength. It also reduces external heat loss with a consequent improvement in thermal efficiency;

- a Superheater - A tubular heat exchanger that is exposed to the high temperature products of combustion whose function is to add additional heat to saturated steam after it leaves the boiler drum. The addition of heat to the saturated steam is accompanied by an increase in the temperature and enthalpy of the steam. Besides the energy increase in the steam, the superheater reduces stack loss with a consequent improvement in thermal efficiency;

- an Economizer - Economizers remove heat from the low temperature flue gas after the gases leave the steam-generating and superheating section of the unit. The heat is transferred to the boiler feed water before entering the boiler. Besides preheating the feed water, the economizer, like the superheater, reduces stack loss with a consequent improvement in thermal efficiency; and,

- an Airheater - Airheaters, like economizers, remove heat from the low-temperture flue gases and further reduce the temperature of the flue gas before it is discharged to the stack with a consequent improvement in thermal efficiency. The heat recovered from the gas is recycled to the furnace by the combustion air and added to the thermal energy released from the fuel for additional overall thermal efficiency.

A typical modern boiler will have an overall thermal efficiency of 85%-90%, depending on the type. In contrast, the efficiency of the earlier boilers installed at sugar factories was less that 50 percent.

Turbine Design Issues

The other major component of the conversion process is the steam turbine. The steam turbine converts the thermal energy of steam into electricity in the directly connected generator. Like the boiler, modern technology has changed the steam turbine, again in an effort to improve the efficiency of the conversion process.

The original steam turbine installed in sugar plantations was a noncondensing back pressure machine with very poor thermal efficiency. Since those early designs, the steam turbine has gone through several design changes all geared to improve the overall thermal efficiency of the unit. Among those design changes was the addition of several components including these:

- Turbine Extraction Valves - The function of extraction valves is to extract partly expanded steam from one or more points of the turbine to be used as: (a) process steam in a procesing plant such as a sugar factory and/or (b) regenerative feedwater heating. This extraction process results in highly efficient electrical power production, i.e., the only heat required in such a plant over and above that needed to provide the required process steam is the heat equivalent of the power generated by the steam before extraction. This process is legally referred to as cogeneration;

- an Electro Hydraulic Control System - This system is necessary to control the flow of steam to subsequent stages of the turbine and maintain the pressure in the extracting stages;

- Improved Blades and Sealing System - This system allows the steam turbine to operate at higher temperatures and pressures. Operating conditions of a modern steam turbine include pressures as high as 5000 PSI and 1200°F, with reheats to 1050°F and 1000°F; and

- a Condenser - The functions of a condenser are:

  - to produce an economical back pressure or vacuum at the turbine exhaust for the improvement of heat rates,

  - to deaerate the condensation, and

  - to conserve the condensation for reuse as boiler feed.

A modern straight condensing turbine with a capacity of 12,500 KW and inlet steam condition at 800 PSI at 825°F will have a basic efficiency of approximately 78%, far exceeding the efficiency of the earlier noncondensing turbine which was less that 50 percent.

Power Plant Heat Rate

The boiler efficiency and the turbine efficiency, although relatively good, are not the only items that operators at large industrial or utility power plants are concerned about. The overall utilization of the energy used in the production of electricity is the ultimate concern and is measured in terms of "plant heat rate".

By definition, one kWh of electrical power is equal to 3412 BTUs. Unfortunately, the process of converting biofuels to electrical power is relatively inefficient. The best possible "plant heat rate" obtainable is 4,900 BTU per kWh. To attain this theoretical maximum efficiency, it is necessary to recover all heat that is normally lost to the cooling water of turbine condenser. Hawaii's average "plant heat rate" is about 12,000 BTU/kWh. The best "plant heat rate" in the nation for utility plants belongs to the supercritical pressure stations, ranging from 8000 to 9000 BTU/kWh. The heat rate of a cogeneration plant is about 7,000-8,000 BTU/kWh.

The percentage of rejected heat, either up the boiler stack or the turbine main condenser, may be kept as small as possible within economic limits by the following methods:

- increasing the pressure and temperature - As a rule of thumb, every 100° of superheat will increase the overall efficiency by one percent;
- incorporating reheat - In general, efficiency is increased 4% to 6% using reheat method;
- regenerative feed water heating - For each 10°F feedwater temperatures rise, there is a 1% reduction in the heat quantity required to make steam;
- using topping cycle:
  - Steam topping
  - Gas topping (supercharged pressure boiler)
  - Binary vapor
  - Combined cycle operation - Kauai Electric's combined cycle plant presently operates with a plant heat rate of 10,500 - 11,000 BTU/kWh.

Benefits of Electricity as a Biofuel End Use

Earlier it was stated that electricity would be the most beneficial end use for Kauai's biofuel. At this time, that statement should be clarified by adding "for the near future". Liquid and gaseous fuel definitely will have a role in Kauai's goal of becoming energy self-sufficient. However, the first step to obtaining energy self-sufficiency is to fulfill the electrical requirements, for the following reasons:

1) The technological realty for converting biofuel to electricity has already been proven in Hawaii. Therefore, no R&D cost will be needed to put this into use;

2) One of Kauai's readily available natural resources is bagasse, which presently contributes to the production of electricity. Improvements in existing bagasse facilities could increase the electrical output of the existing facilities using existing bagasse;

3) It would be less costly, and quicker, to achieve energy self-sufficiency in the electrical sector using biofuel, than it would be to replace the direct use of oil with biofuel in other energy sectors, such as transportation, in the near term;

4) The effects of an oil dislocation on Kauai's economy would be less disastrous if Kauai was already more self-sufficient in the electrical sector; and

5) The development of new biofuel sources to be used in new and/or improved facilities will have beneficial effects on Kauai's economy, while at the same time lessening Kauai's dependency on oil.

In order to understand the above observations, a brief review of Kauai's economy and its energy use patterns is in order.

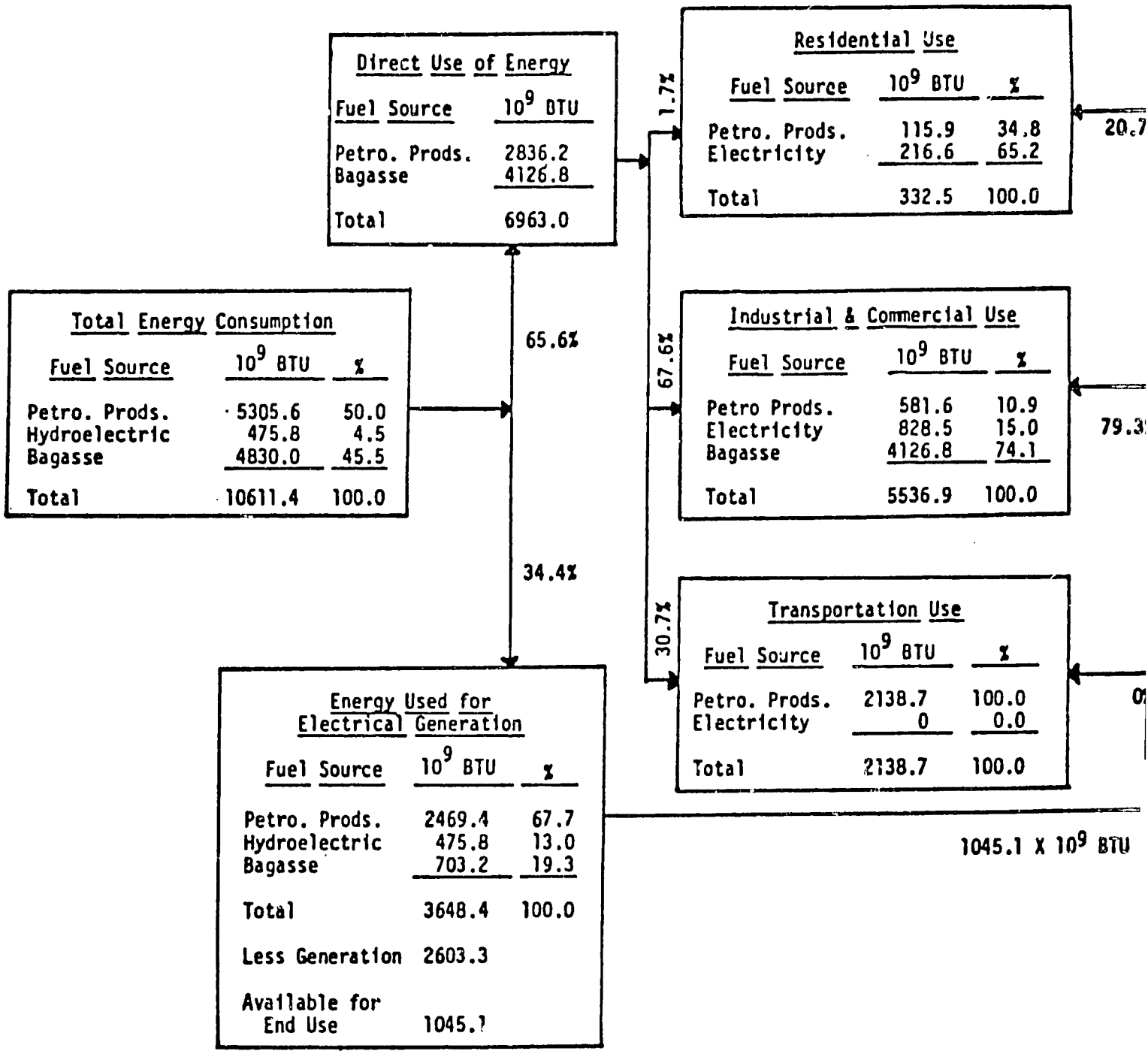
Kauai's Economy and Energy Production

Kauai's economy has long been dominated by agriculture and tourism. These two industries are important as the major sources of income and jobs for Kauai's residents. In 1960, 66% of the employment and 75% of the income on Kauai were generated by agriculture and its related sector. Tourism and its related activities represented 27% of employment and 23% of the income. So far, it has been these two major industries around which other economic sectors such as construction, wholesale, financial services, retail, and government services have been built. Without these sectors, it is doubtful that Kauai county could sustain its $485 million economy today.

In 1978, Kauai Electric's electrical sales were 201,000 kWh, 89% this was generated by Kauai Electric, which used only fossil fuel. The remaining 11% was generated by the plantations, which used indigenous resources (Figure VII.1). In 1982, Kauai Electric's total sales were 217,000 kWh, 45% of which was produced by Kauai Electric, using fossil fuel and 55% of which was produced by the plantations using indigenous resources. This 55% of electrical energy production from indigenous resources was the largest percent obtained by Kauai Electric and, perhaps, the highest ever achieved in the state.

The climatic conditions in 1982 greatly favored alternate energy producers. The winter months provided ample rain for hydroelectric plants, and weather conditions benefited agriculture. Together, these two factors helped produce the highest tons cane per acre in Kauai's sugar history. These factors, coupled with the damaging effects of Hurricane Iwa, which caused zero electrical growth rate for Kauai Electric, played a role in allowing Kauai Electric to obtain 55% self-sufficiency in the electrical sector.

Figure VII.1
Kauai Flow Diagram of Energy Consumption, 1978



Since then, the percentage of nonfossil fuel production of electrical energy has been slowly decreasing, due to the lack of nonfossil fuel projects necessary to keep up with electrical growth on Kauai. In 1983, the nonfossil fuel production dropped to 47%, or a decrease of 8 percent. Meanwhile during the same period, the electrical demand increased by 9 percent. In 1986, the contribution dropped even further to 39 percent. It is interesting to note that the non-fossil fuel contribution dropped from 47% in 1983 to 33% in 1984, and up to 39% in 1985. The huge drop in 1984 was due to a rotor failure at the 20 MW generating facility at a sugarcane plant, Lihue Mill. The rotor failure caused Lihue Mill Plant to be off-line for several weeks, showing the importance of the non-fossil fuel generating facilities at the Lihue Mill to the state.

Future Considerations

What's in store for Kauai's future? Kauai Electric predicts that by 1996 its electrical requirements will reach 367,000 MWH. This will be an increase of 35% over today's 271,000 KWH. Assuming that no new alternate energy project is placed on-line by then, the contribution of nonfossil fuel production of electricity will drop to 28%. It also means that Kauai Electric will have to purchase 5,118,000 BBL of oil over that 10 year period at a current cost of $160 million to produce the necessary electrical needs for Kauai. Furthermore, the $160 million is at today's oil price, and does not take inflation into account. One could be led to think that the economic stimulation for producing biofuel is there.

All is not bleak for the future. It is hoped that some of the hydroelectric projects which are presently in the planning stages, will become realities. It is hoped that in 1989 the Wailua Hydro will be on-line producing an additional 16,000 MWH, which will increase the nonfossil fuel contribution to 39% of Kauai Electric's needs. Hopefully, the years following will see the realization of Hanalei Hydro, Lumahai Hydro, Wainiha Hydro, Kitano Hydro, and a wind farm, so that by the year 1993 the nonfossil fuel contribution will be 60% of Kauai Electric's needs (Figure VII.2).

Where does all of this leave us - with 40% of the electrical energy being produced by oil.

Conclusions

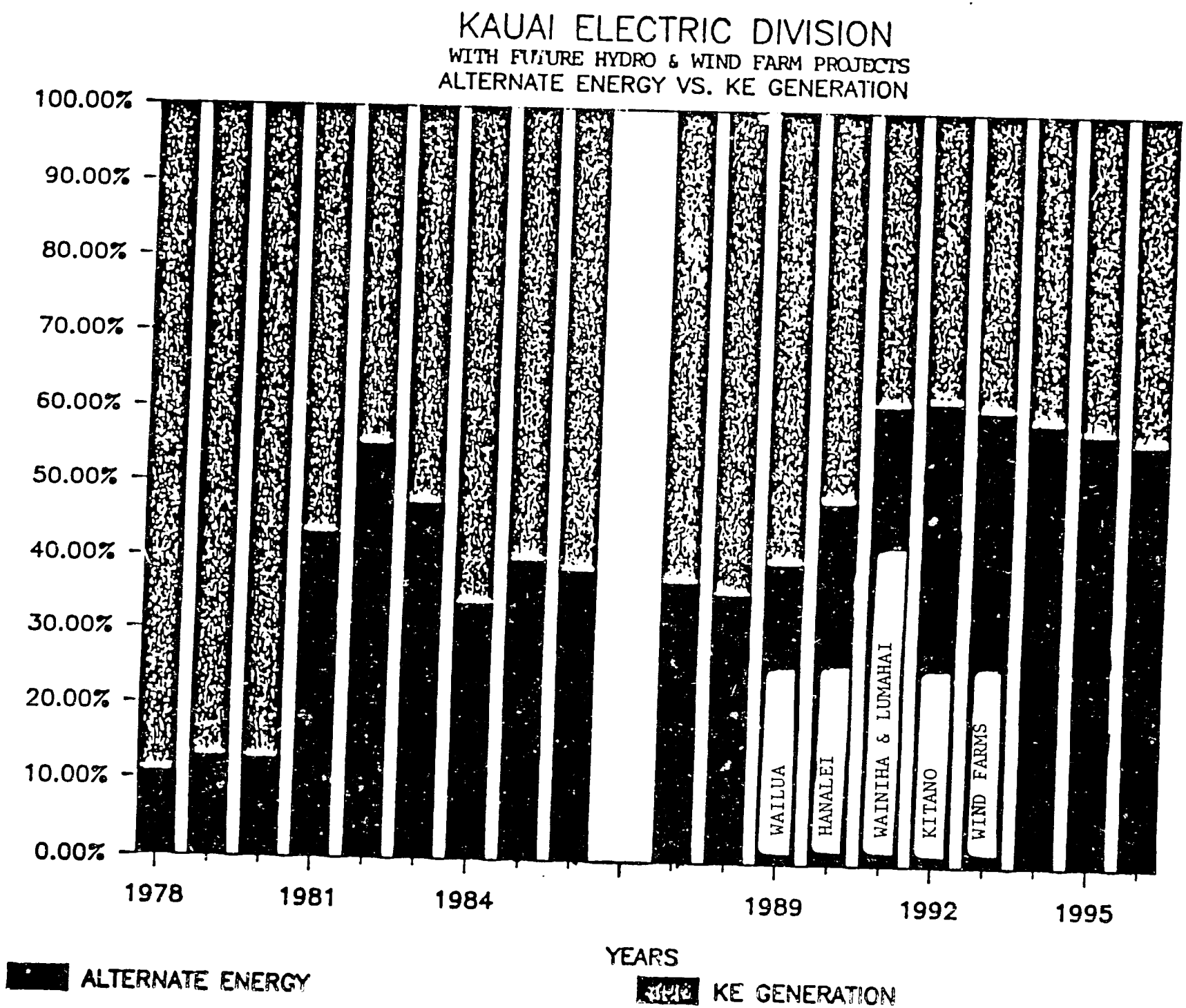
The following conclusions sum up the possibilities of biofuel use in Kauai:

1. As far as Kauai is concerned, the most beneficial use for biofuel would be the production of electricity;

2. The process of converting biofuel to electricity has already been proven to be economically feasible and continues to be improved upon;

3. Kauai has the capacity of becoming self-sufficient in its electrical sector if the existing potential of biofuel is used efficiently and additional agricultural products are made available; and

4. Biofuel could be the stimulant to restore Kauai's agricultural industry to its rightful place in Kauai's economy.


KAUAI ELECTRIC DIVISION
WITH FUTURE HYDRO & WIND FARM PROJECTS
ALTERNATE ENERGY VS. KE GENERATION
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
PERCENTAGE (%)
1978
1981
1984
1989
1992
1995
YEARS
WAILUA
HANALEI
WAININHA & LUMAHAI
KITANO
WIND FARMS
ALTERNATE ENERGY
KE GENERATION

CHAPTER VIII

NEW PROSPECTS FOR COGENERATION IN THE CANE SUGAR INDUSTRY*

By

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Introduction

Using advanced cogeneration technologies fired with cane residues, the cane-sugar industry could produce about as much electricity as is now provided by oil or about 1/5 of the total electricity generated by utilities in cane-producing developing countries (Table VIII.1).

Such a major role for cane-sugar producers in power generation is technically feasible, despite the face that, at present, all the bagasse, the fibrous residue of cane milling, is typically burned as fuel for the mill. The bagasse currently is used in small steam-turbine cogeneration systems to meet the modest steam, mechanical power, and electricity demands of sugar factories. A typical factory today might produce some 30-40 kWh of mechanical work and electricity per tonne of cane crushed. However, the present balance between cane residue supply and on-site demand reflects traditional sugar-factory designs intended to insure that the factory is energy self-sufficient and disposes fully of its bagasse "waste". If more energy-efficient power generating equipment were used as proposed by USAID's Cane Energy Assessment teams, considerable amounts of power could be produced for export to the utility grid.

Even more power could be produced if steam-conserving process technologies, now widely used in the oil-dependent beet-sugar industry (e.g. condensate juice heaters and falling film evaporators), were adapted to cane-sugar factories (Larson et al. 1987). Moreover, if the recovery and storage of barbojo, the sundried tops and leaves of the cane plant that are customarily burned off the cane just before harvest, prove to be commercially successful, its use as fuel would lead to additional electric power production during the months of the year when cane is not milled (Phillips 1986).

*The research reported here is being supported by the Office of Energy of the United States Agency for International Development, Washington, DC.

Table VIII.1 Electricity potential from sugarcane based on the 1985 production of cane, (A),[a] and actual total electric utility generation in 1982, (B),[b] in developing countries (10^9 kWh).

	A	B		A	B	A	B
ASIA						85	599
India	30.2	129.5	Iran	0.86	17.5		
China	18.3	327.7	Vietnam	0.78	1.69		
Thailand	10.3	16.2	Burma	0.43	1.52		
Indonesia	7.3	11.9	Bangladesh	0.40	2.98		
Philippines	7.1	17.4	Malaysia	0.30	11.1		
Pakistan	6.1	14.9	Nepal	0.12	0.284		
Taiwan	3.0	45.0	Sri Lanka	0.073	2.07		
CENTRAL AMERICA						63	100
Cuba	33.9	10.8	Jamaica	0.90	1.30		
Mexico	15.0	73.2	Panama	0.69	2.71		
Dominican Rep	4.0	2.38	Belize	0.47	0.065		
Guatemala	2.2	1.42	Barbados	0.43	0.339		
El Salvador	1.2	1.45	Trinidad & Tob.	0.34	2.30		
Nicaragua	1.1	0.945	Haiti	0.22	0.352		
Honduras	1.0	1.04	St. Chris. - Nevis	0.12	na		
Costa Rica	0.99	2.42					
SOUTH AMERICA						56	257
Brazil	36.3[c]	143.6	Guyana	1.1	0.255		
Colombia	5.9	21.3	Bolivia	0.75	1.40		
Argentina	5.2	36.2	Paraguay	0.34	0.569		
Peru	3.1	7.25	Uruguay	0.22	3.47		
Venezuela	2.0	39.0	Suriname	0.043	0.175		
Ecuafor	1.3	3.09					
AFRICA						30	167
South Africa	10.9	109.0	Mozambique	0.26	3.25		
Egypt	3.5	17.2	Somila	0.23	0.075		
Mauritius	2.9	0,320	Nigeria	0.22	7.45		
Zimbabwe	2.0	4.16	Angola	0.22	1.46		
Sudan	1.9	0.910	Uganda	0.15	0.569		
Swaziland	1.7	0.075	Congo	0.11	0.195		
Kenya	1.6	1.73	Mali	0.090	0.080		
Ethiopia	0.82	0.618	Gabon	0.052	0.530		
Malawai	0.66	0.410	Burkina Faso	0.043	0.123		
Zambia	0.61	10.3	Chad	0.034	0.065		
Ivory Coast	0.54	1.94	Guinea	0.021	0.143		
Tanzania	0.45	0.720	Sierra Leone	0.021	0.136		
Madagascar	0.43	0.342	Benin	0.021	0.016		
Cameroon	0.30	2.15	Liberia	0.013	0.389		
Zaire	0.28	1.48	Rwanda	0.009	0.066		
Senegal	0.28	0.631					
OCEANIA						2	1
Fiji	1.6	0.241	Paua N. Guenia	0.13	0.44		
ALL SUGAR-PRODUCING DEVELOPING COUNTRIES						236	1,124

[a] For the 1985 levels of sugar production (ISO 1986), assuming 100 kg of sugar is produced, on average, from each tonne of cane. For cogeneration based on the General Electric LM-500 steam-injected gas turbine. (See Figure VIII.1).

[b] From (World Bank 1985), except Taiwan, Iran, South Africa, Cuba, Trinidad & Tobago, and Venezuela, which are from (Bureau of the Census 1984).

[c] Based on cane used for sugar production only, which accounted for about 40% of all cane harvested in 1985 (M. Biagi 1986). Including the cane used for ethanol production (see Footnote 2), the total electricity potential from cane in Brazil is about 94 TWh.

New Cogeneration Prospects

Larger, more energy-efficient steam-turbine cogeneration systems have been installed in a few sugar factories. In Hawaii, some systems produce about 50 kWh/per ton of cane (tc) more electricity than is needed for on-site uses, thereby allowing such systems to export firm power to the electric utility grid (Gilmore Sugar Manual 1984). An even more efficient steam-turbine system is being considered for installation in one large sugar factory in Jamaica (RONCO 1986). The proposed unit would produce about 75 kWh/tc of exportable electricity. Plans for a Jamaican plant (Monymusk) include the use of barbojo to permit the plant to produce power during the off-season. This would boost total exportable electricity to about 180 kWh/tc. In a "steam-conserving" factory, a steam-turbine plant of the type proposed for Jamaica would be able to export 110-112 kWh/tc net of internal use, depending on the amount of barbojo used, in the off-season. Investments in steam-conserving retrofits would be quickly paid back from the revenues resulting from the extra electricity sales to the utility (Larson et al. 1987).

Advanced gas turbines offer the advantages of even higher thermodynamic efficiency and lower unit capital costs compared to the more familiar steam-turbine technologies (Larson et al. 1987)[1]. Moreover, in contrast to steam-turbines, small to medium scale economies are exhibited by such gas turbines. Thus, the economics of power generation are typically favorable at scales of just a few megawatts.

To date, gas turbines have required high quality oil or natural gas for fuel. However, operation of gas turbines on gas derived from coal has been successfully demonstrated in California (EPRI 1986). Lower-cost, more energy-efficient aircraft derived gas turbines fired with gasified coal are now being developed in the U.S. (Corman 1986), with a 5 MW pilot plant and a 50 MW commercial demonstration plant being planned for start-up in the early 1990's. The technology for firing gas turbines with coal gas would be largely transferable to firing with gasified bagasse or other biomass. In fact, operating gas turbines on biomass fuels should be easier because unlike coal there are no significant amounts of troublesome sulfur emissions with which to contend. One major U.S. private manufacturer has already begun development of gas-turbine systems fired with gasified biomass.

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[1] Recently there have been major improvements in the performance of gas turbines, stimulated largely by the surge in gas-turbine sales for cogeneration applications in the U.S. The cogeneration market began growing rapidly after passage of the 1978 Public Utility Regulatory Policies Act (PURPA), which facilitates the sale of excess electricity from cogenerators to electric utilities. Many of the improvements being made in stationary gas turbines have resulted from advances in jet engine technology, which were stimulated by the market pressures of high fuel costs for commercial airlines and more than $400 million of annual expenditures by the U.S. government and R&D for jet engines for military aircraft over the last decade (Larson and Williams 1986).

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Economics

An investment in a gasifer/gas-turbine system would be financially attractive, typically generating a higher internal rate of return and lower unit costs than an investment in a steam-turbine system (Figure VIII.1) (Larson et al. 1987). Moreover, because of its greater efficiency, the gasifier/gas-turbine system could produce more power (Figure VIII.2). For a steam-conserving sugar factory the amount of excess electricity available for export would be some 240 to 430 kWh/tc, depending on the amount of barbojo utilized, which is roughly double that for a steam turbine (Figure VIII.3). At a sale price of 6¢ per kWh, up to $25 of revenue would be generated per tonne of cane; this cane-derived revenue would be comparable to a sugar price of $0.25 per kg ($0.11/lb), which is about twice the 1986 world price.[2]

The economics of bagasse gasifier/gas-turbine cogeneration should also be attractive for many utilities. The busbar costs for power generation with a 52 MW biomass-gasifier/gas-turbine power system, calculated for an illustrative case in Jamaica, are shown in Figure VIII.4. Five levels of fuel processing (none, drying, baling and drying, briquetting, or pelletizing), with and without barbojo recovery are used. These costs are compared to the busbar cost for a central-station coal plant. The calculations are presented for these varying cases because it is unknown what level of fuel processing will be needed for gasification and, also, the commercial success of barbojo recovery has not yet been proven in Jamaica. In all cases, except those where no barbojo is recovered and extensive fuel processing is required, cane-power would be cheaper than power from what has previously been identified as one of the least-cost generating operations for Jamaica, a 61 MW steam-electric plant fired with imported coal (Montreal Engineering 1985)[3]. If stack-gas scrubbers were required on the coal plant to reduce sulfur oxide emissions, as they are in the U.S., cane power would probably be cheaper in all cases.[4]

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[2] Gas-turbine systems could also be installed at ethanol-from-sugar-cane distilleries. As in-house steam and electricity demands per tonne of cane would be comparable at modern distilleries to those at steam-conserving sugar factories (Electrobras 1981), such distilleries could also produce up to some 430 kWh/tc of exportable electricity. The producer price of alcohol would have to be $0.35 per liter (75% higher than in Brazil today) for alcohol revenues to equal those from electricity in this cane, assuming 70 liters of alcohol per tonne of cane.

[3] The power cost shown for the case of no barbojo recovery could be reduced by using an alternative fuel in the off-season. One possibility would be to burn distillate oil. Another would be to use another biomass feedstock (e.g. wood grown on plantations). Or a lower capacity cogeneration facility could be installed and some bagasse could be processed and stored for use in the off-season.

[4] The unit capital cost ($ per kW) for a new 200 MW coal steam-electric plant with scrubbers in the U.S. (EPRI Planning and Engineering Division 1986) would be about 40% higher than that estimated in (Montreal Engineering 1985) for a 61 MW plant (Figure VIII.2). At a size of 61 MW the cost would be higher still because of the scale economies of steam-turbine power generation.

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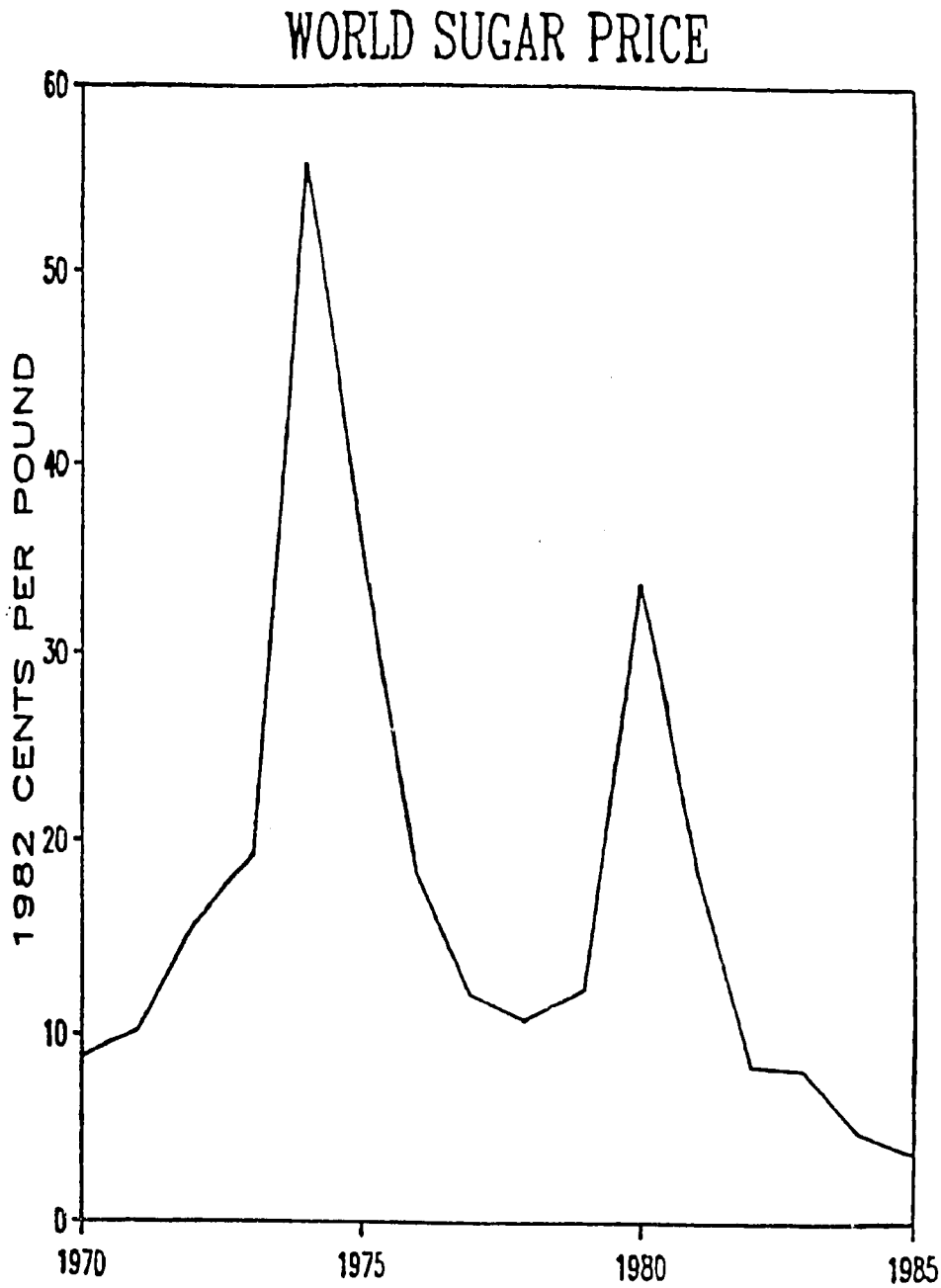
Figure VIII.1



The World-Market price of sugar, 1970-1985. Current-dollar prices from (International Sugar Organization, Sugar Yearbook, London, annual) have been expressed in constant 1982 dollars using the GNP deflator.

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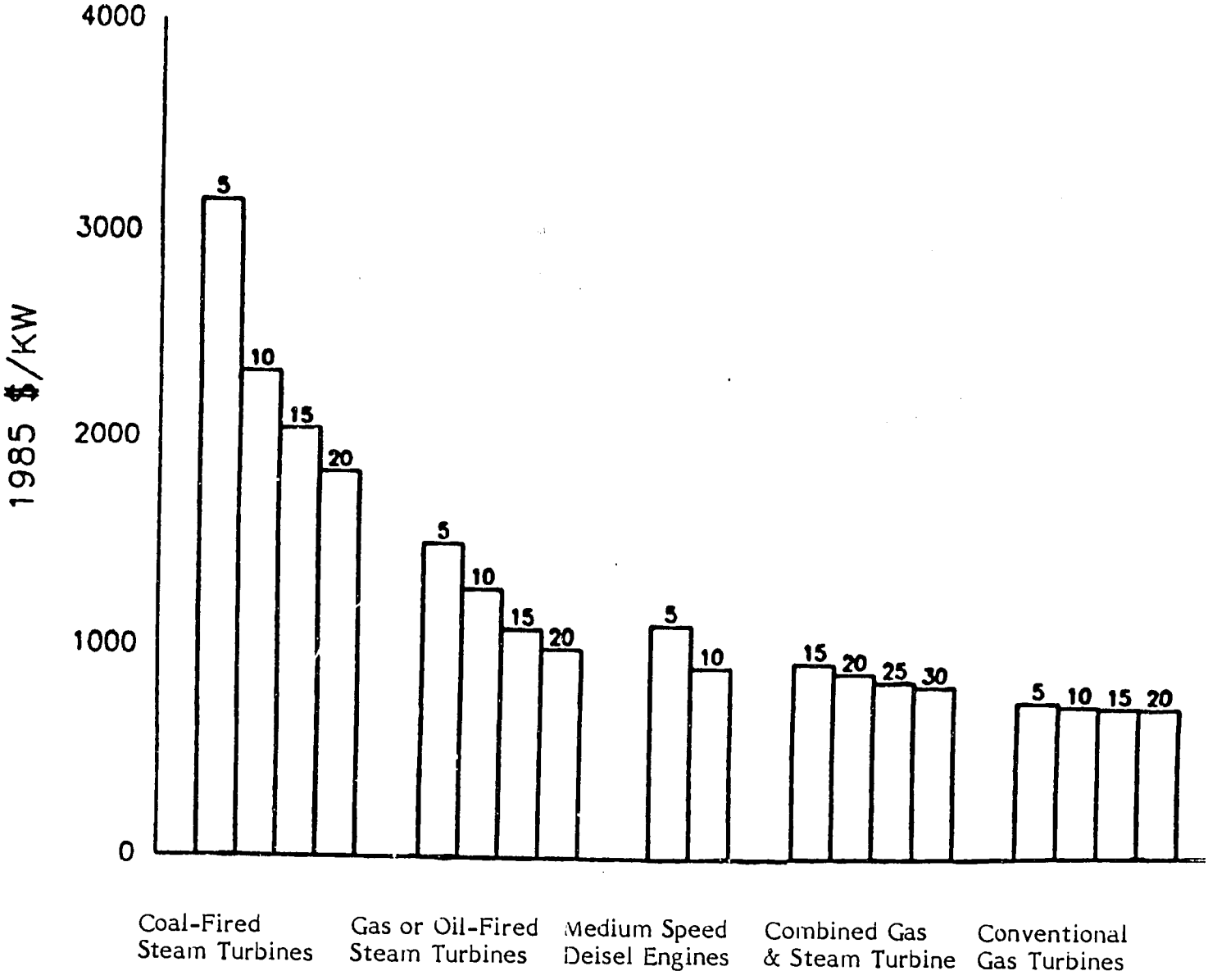
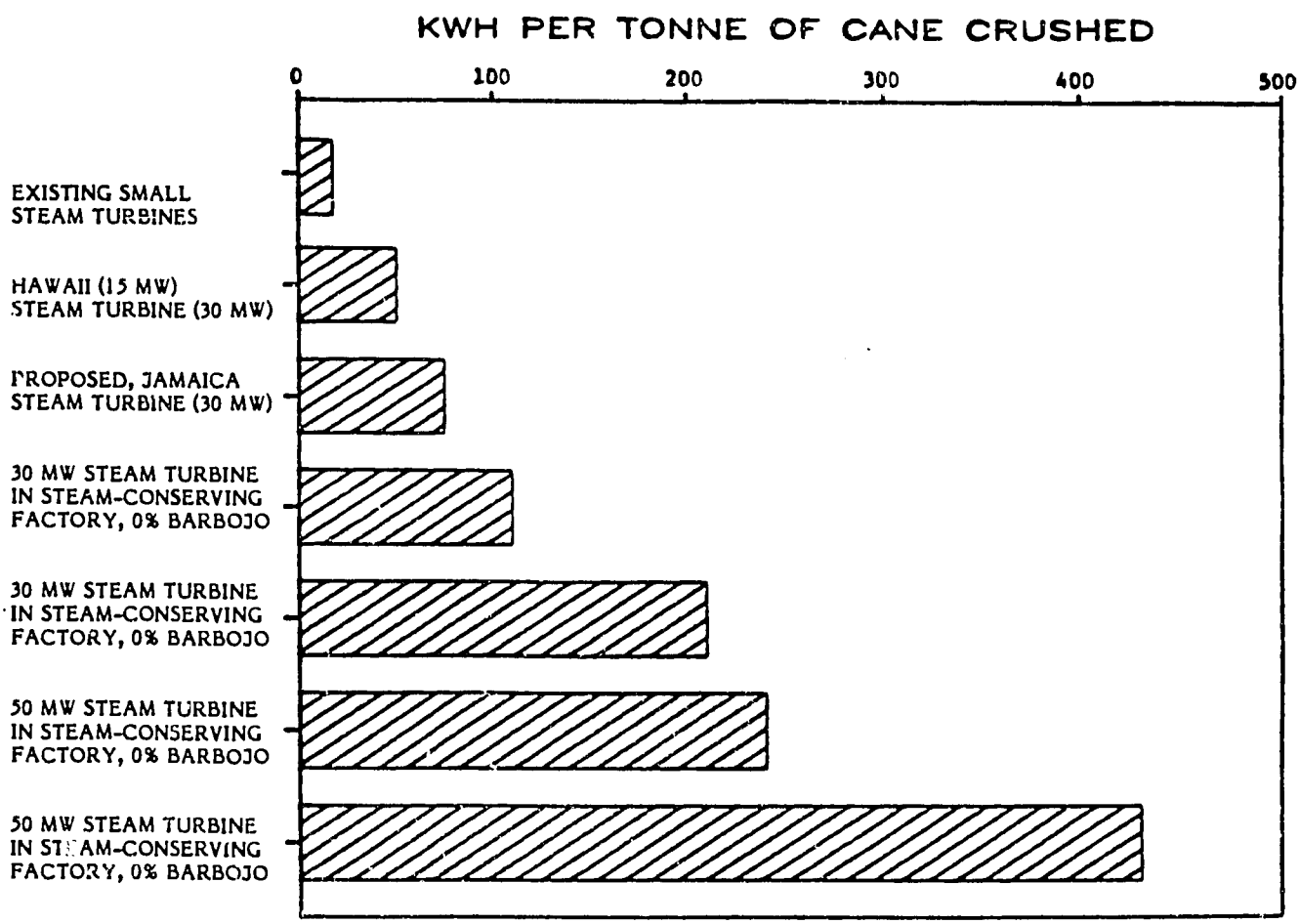
Figure VIII.2
Costs of Various Cogeneration Systems



Unit installed capital costs for small cogeneration systems. The numbers at the tops of the bars are the installed electrical generating capacity in MW. From (Office of Industrial Programs, "Industrial Cogeneration Potential, 1980-2000, for Application of Four Commercially Available Prime Movers at the Plant Site," U.S. Department of Energy, Washington, DC, 1984).

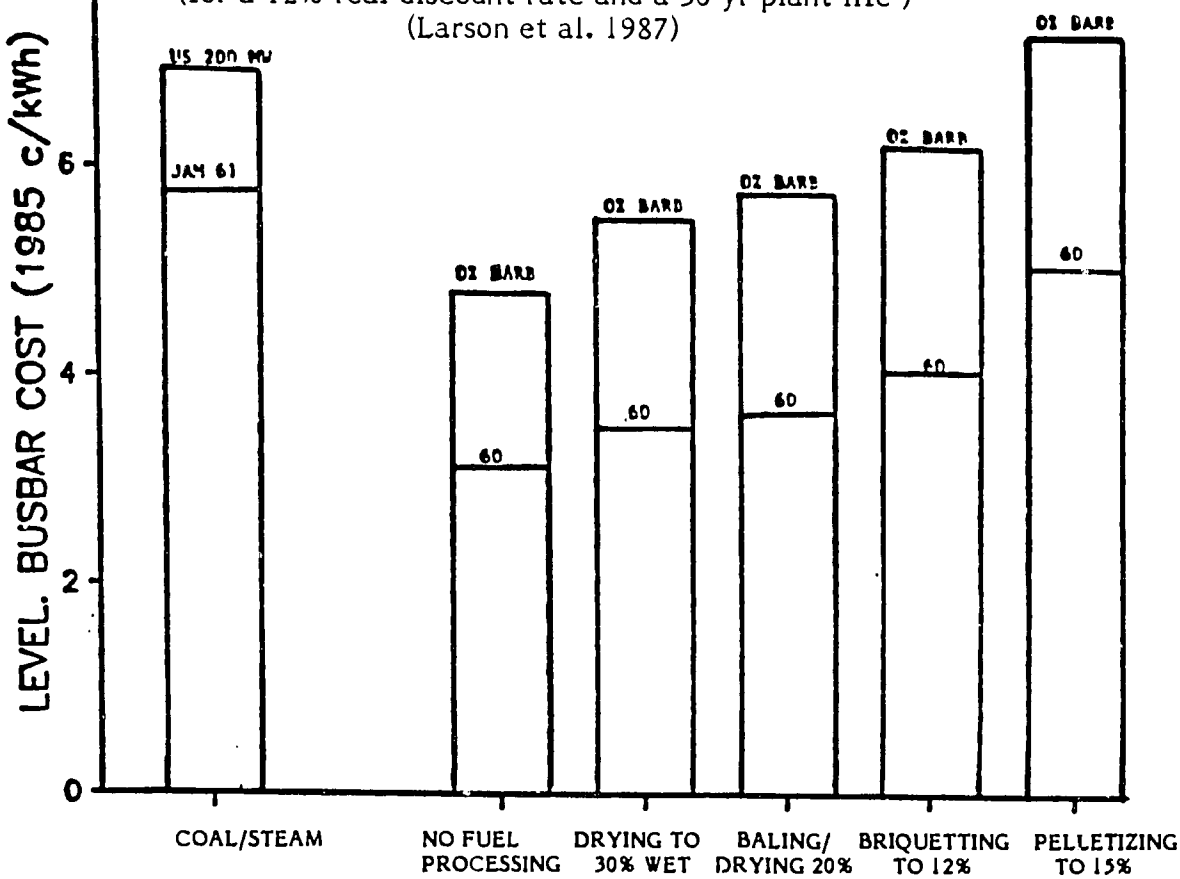
67

Figure VIII.3
Potential Generation of Exportable Electricity From Sugar Factories With Alternative Cogeneration Technologies
(Larson et al. 1987)



The 30 MW steam turbine is a condensing unit with a single controlled extraction, as proposed for a sugar factory in Jamaica (RONCO 1986). The gas turbine is a General Electric LM-5000 gas turbine modified for steam injection and coupled to a Lurgi dry-ash gasifier. Retrofits to convert an existing sugar factory into a "steam-conserving" factory include the use of condensate juice heaters and falling film evaporators. The two levels of barbojo recovery indicated are for 0% and 60% of the estimated total recoverable barbojo.

Figure VIII.4
Estimated Levelized Busbar Costs For Generating Electricity in New Powerplants
(for a 12% real discount rate and a 30 yr plant life)
(Larson et al. 1987)



The bar labeled COAL/STEAM is for central-station, coal fired, steam electric plants. The lower cost shown is for a 61 MW plant plus coal-handling infrastructure located in Jamaica, for which the total installed capital cost is estimated to be about $1300 per kW (Montreal Engineering 1985). The plant is assumed to operate with an annual average capacity factor of 66%, and the cost of coal imported into Jamaica is assumed to be $2.10 per GJ. The upper cost shown is for a 200 MW plant with flue gas desulfurization, located in the Midwestern United States, for which the installed cost is about $1800/kW (EPRI, Planning and Evaluation 1986). The plant is assumed to operate with an annual average capacity factor of 66%, and the cost of coal is assumed to be $1.60 per GJ, appropriate for the U.S. Midwest.

The bars at the right are for 52 MW steam-injected gas turbine (based on the General Electric LM-5000) operating on gasified biomass produced in a Lurgi dry-ash gasifier. The installed capital cost for the system (including the gasifier) plus steam-conservation retrofits to the sugar factory is estimated to be $1060 per kW (Larson et al. 1987). If no processing is required, the bagasse is "free", but barbojo would cost about $1.00 per GJ for harvesting, drying, and storing. The following total fuel costs (in $/GJ) are estimated with additional fuel treatment;

	Bagasse ($/GJ)	Barbojo ($/GJ)
Drying to 30% moisture:	0.60	1.00
Baling and drying to 20% moisture	0.90	1.00
Briquetting (12% moisture)	1.15	1.35
Pelletizing (15% moisture)	2.00	2.20

The annual average capacity factors for the gasifier/gas turbine would be 40% with no barbojo recovery and 72% with the 60% recovery.

Conclusions

Some engineering development work and a pilot demonstration remain to be carried out to bring biomass-gasifier/gas-turbine cogeneration systems to commercial readiness. How rapidly this technology is commercialized in the cane-sugar industry will probably depend more on how quickly institutional thinking patterns change than on technological and economic constraints. The introduction of gas turbines would be facilitated by a willingness of the sugar industry to view itself as a producer of two primary products, sugar and electricity, as well as by the willingness of electric utilities to consider gas turbines burning cane residues as a candidate least-cost power-generating option.

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CHAPTER IX

JAMAICA CANE/ENERGY PROJECT: PRODUCTION OF ELECTRICITY FROM SUGARCANE WASTES

By

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Background

Sugarcane production and processing is the most important agro-industry in Jamaica with annual production of over 2.2 million tons[1] of millable sugarcane from over 90,000 acres of land. The sugar industry is a major long-term employer of rural Jamaican labor and an important earner of foreign exchange. Most foreign exchange earnings result from sugar sales to the European Economic Community (EEC) under a guaranteed quota.

Worldwide, sugar operations are being carefully reviewed because of an extended period of over-production, slowed growth in sugar consumption, and low sugar prices. In Jamaica, the government has been forced to make changes in the Jamaican sugar industry in recent years including closing some factories. Production has been consolidated to eight sugar factories (see Figure IX.1), with a ninth, Bernard Lodge, continuing to operate past its scheduled closing date. The sugar operations at two of these eight factories, Monymusk and Frome, are currently being rehabilitated under a World Bank loan to the Government of Jamaica (GOJ).

This paper present results of a study prepared for the Monymusk Estate[2] and factory located in the Clarendon Parish agricultural region of south-central Jamaica (Figure IX.1). Sugarcane in this region grows on irrigated land. Because of productive soils and high levels of insolation, Monymusk Estate has traditionally produced profitable sugar crops. During the past decade, however, there has been a significant decline in cane and sugar production due to poor management and inadequate maintenance. Because of the sharp decreases in sugarcane available for processing at the Monymusk factory, unit costs have risen and the estate has become unprofitable, even at the favorable prices received under the EEC quota. New capital infusion and improved management are necessary to revitalize sugarcane production and the processing facilities at Monymusk Estate.

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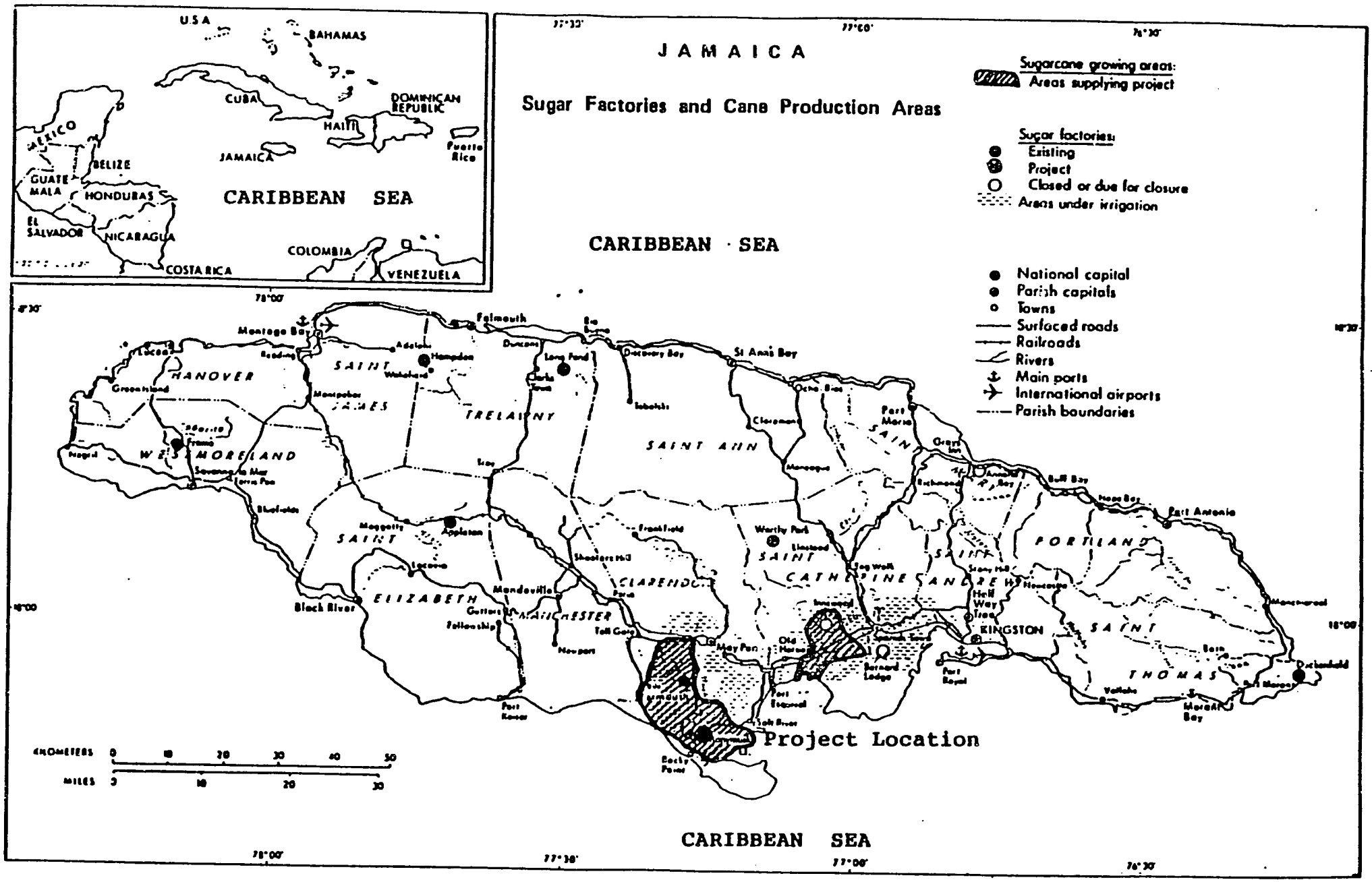
[1] References to tons in this paper are long tons of 2240 pounds unless specifically called tonnes (or metric tons) at 2205 pounds or short tons 2000 pounds.
[2] Formerly privately owned, Monymusk is now owned and operated by the government.

Figure XI.1


JAMAICA
Sugar Factories and Cane Production Areas
Sugarcane growing areas:
Areas supplying project
Sugar factories:
Existing
Project
Closed or due for closure
Areas under irrigation
National capital
Parish capitals
Towns
Surfaced roads
Railroads
Rivers
Main ports
International airports
Parish boundaries
CARIBBEAN SEA
U.S.A.
BAHAMAS
CUBA
DOMINICAN REPUBLIC
HAITI
JAMAICA
Puerto Rico
MEXICO
BELIZE
GUATEMALA
HONDURAS
EL SALVADOR
NICARAGUA
COSTA RICA
COLOMBIA
VENEZUELA
HANOVER
SAINT JAMES
TRELAWNY
SAINT ANN
SAINT MARY
WESTMORELAND
SAINT ELIZABETH
MANCHESTER
CLARENDON
SAINT CATHERINE
SAINT ANDREW
KINGSTON
PORTLAND
SAINT THOMAS
Montego Bay
Falmouth
Duncans
Long Pond
Ocho Rios
St Anns Bay
Port Maria
Hampden
Lucea
Greenhland
Savanna-la-Mar
Black River
Appleton
Mandeville
Frankfield
Shooters Hill
Worthy Park
Linstead
Spanish Town
Old Harbour
May Pen
Bernard Lodge
Port Royal
Port Antonio
Buff Bay
Hope Bay
Morant Bay
Port Morant
Kilometers 0 10 20 30 40 50
Miles 0 10 20 30
Project Location
CARIBBEAN SEA

The intent of the World Bank financed rehabilitation program at Monymusk is to return the operations to profitability by increasing cane production over a five-year period (1988-1992) to levels regularly produced before the Estate's decline. Funds provided under the rehabilitation program will be used to upgrade the millyard, crushing, juice processing, and sugar refinery facilities in the factory and to replace certain field machinery and irrigation pumps.

Objectives of Study

Beginning in 1984, the United States Agency for International Development (A.I.D.) in cooperation with the GOJ funded a study to determine the feasibility of producing surplus electricity from sugarcane residues at the Monymusk Estate factory for sale to Jamaica Public Service (JPS). The Trade and Development Program (TDP) and Bechtel Corporation worked closely with A.I.D. and the GOJ throughout the study and jointly funded preparation of a business plan that set forth economic and financial guidelines for commercial success.

A.I.D. supported the study for two primary reasons. Production of surplus electricity by the sugar industry would increase Jamaica's energy self-sufficiency and decrease the need to spend foreign exchange for imported fuel oil in the future. It could also provide a new source of revenue to the ailing sugar industry and generate additional employment opportunities in rural areas of Jamaica.

The GOJ nominated the Monymusk Estate as the site for the A.I.D.-led study. If the production and sale of surplus electricity to JPS was found financially and economically attractive at Monymusk, additional investment needed in the factory could be coordinated with planned rehabilitation and maintenance work in the bagasse house and power plant under the World Bank loan and with planned additions to electric capacity by JPS. Currently, JPS projects that growing electricity demand in Jamaica will require new baseload capacity by the early 1990's. At the time of the study, the factory and estate consumed more electricity than they produced on an annual basis.

The concurrence of the Monymusk rehabilitation program and JPS plans to expand national electric capacity presents an historic opportunity for Jamaica to integrate a new power station with a major sugarcane processing facility using indigenous fuels. Introduction of upgraded boiler and power plant technology coincident with the rehabilitation at Monymusk could enhance profitability in the sugar industry and present a model for rehabilitation at other Jamaican sugar factories.

Study Findings

The study identified equipment needs for surplus power generation given projected cane production levels and prepared estimates of the investment requirements. The study also identified and analyzed the technical, institutional and commercial issues and risks.

Historically, equipment used at sugar mills for producing steam and electricity from bagasse has been designed to provide sufficient power to meet internal needs while consuming all mill wastes to avoid disposal problems. The equipment currently used at Monymusk has been in service for about four decades and produces approximately 10 kWh/ton cane. In contrast to such traditional mill energy systems, the new, high performance boiler/turbogenerator equipment proposed in the study operates at higher temperatures and pressures and will produce almost ten times as much electricity per ton of cane crushed.

The goal of the World Bank rehabilitation project is to achieve production levels of about 740,000 tons of sugarcane from the 22,500 acres under government cultivation and the 4,000 acres planted by independent cane farmers by the early 1990's. The land also will produce approximately 500,000 tons of sugarcane tops and leaves for which there is no current planned use. From the millable stalks, the factory will produce about 70,000 tons of sugar and 21,000 tons of molasses.

Assuming cane production will reach the 740,000 ton level, the study recommends a plant design that uses two high performance boilers[3] to produce 300,000 pounds of steam per hour at 900°F and 900 psig coupled with double extraction condensing steam turbines. Figure IX.2 shows the flow of materials and energy through the factory. The estimated annual energy production is 785 million pounds of steam during the 46 week operating schedule and 171 million kWh of electricity. About 85% of the electricity or about 145 million kWh would be available for sale to JPS. The mill would be able to provide JPS about 21 MW of electric capacity during the eight month processing season and 35 MW during the four month "off-crop" period.

For the purpose of the financial analysis, the study assumed the boilers would be fueled with wet (50% moisture) bagasse[4], barbojo[5], and oil, providing 51, 24, and 25% respectively, of total fuel on an annual heat input basis. The annual estimated fuel cost for No. 6 fuel oil is approximately $2 million (6 million gallons or 134,000 barrels per year). Estimates of the amount of energy that could be produced from bagasse and barbojo are conservative. Estimates of energy produced from barbojo are based on expected productivity of a prototype barbojo collection and handling system now in testing. Fuel oil requirements could be reduced by drying and storing bagasse thereby increasing its useful fuel value or by expanding the supply of barbojo through a more agressive collection program.

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[3] Lower performance boiler/turbogenerators usually operate in the 600°F and 600 psig range or less.

[4] Bagasse is the fibrous residue left after the cane stalks are crushed at the factory. Bagasse is traditionally used as boiler fuel by sugar factories although some factories produce other products such as paper, particle board, or animal feed.

[5] The term barbojo comes from the Dominican Republic and means solar dried, sugarcane tops and leaves. Sugarcane tops and leaves are normally burned in the field before and/or after harvest.

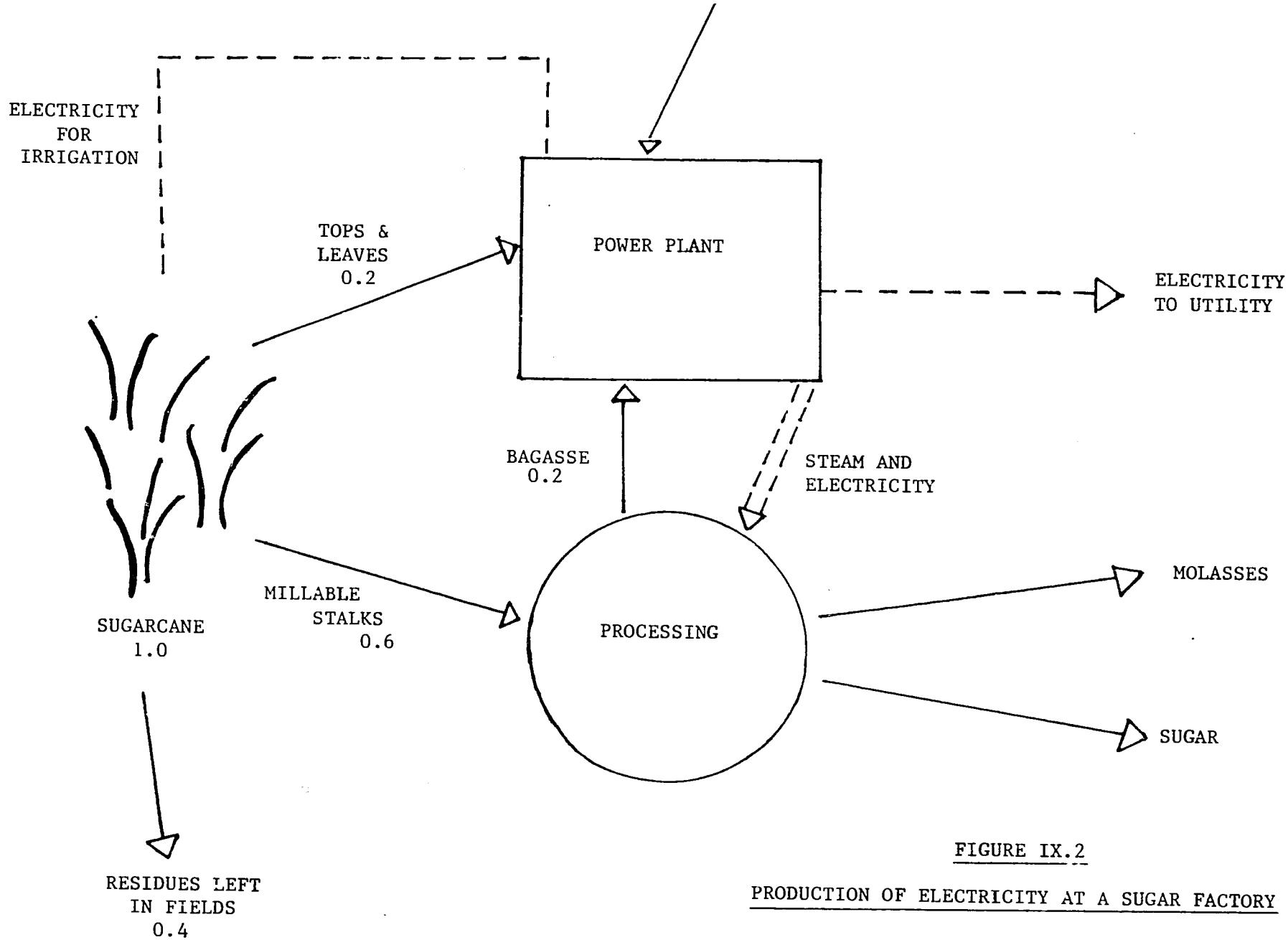

FIGURE IX.2

PRODUCTION OF ELECTRICITY AT A SUGAR FACTORY

The investment needed for the new power station is estimated to be $47.7 million. If private investment capital is used, the study estimated the breakeven cost of electricity production to be between 7¢ and 8¢ per kWh. This compares to over 7¢/kWh to overhaul and retrofit existing JPS oil-steam electric plants, and over 8¢/kWh for either a new coal steam electric or a new oil-gas turbine plant (Keppeler et. al., 1986).

With a levelized purchase price for power sold to JPS of 7.5¢ per kWh, the study estimated the internal rate of return (IRR) to be 16 percent. The study (Keppeler et.al., 1986) pointed out that an added agricultural investment of $9 million to modernize a part of the irrigation system not scheduled for improvement by the World Bank would increase sugarcane supplies and increase the overall IRR to 20 percent.

The value of power to JPS depends on the predictability and reliability of the power production and the period when it is available during the year. To receive a "capacity" payment for power generated, the Monymusk factory must provide firm power to JPS throughout the year. Since the Monymusk factory only operates approximately eight months per year, providing firm power will require significant changes in existing Jamaican sugarcane operations. The options are: 1) to extend the availability of bagasse and cane trash by extending the crushing campaign; 2) to enhance the fuel value of the bagasse through moisture reduction and store the resulting surplus bagasse for use during the off-season; 3) to harvest and store cane field residues to use during the off-season; 4) to supplement cane residues with fossil fuels during the off-season; and/or 5) various combinations of 1-4.

The least risky option is to burn fossil fuels, either oil or coal, during the off-season. Analyses carried out during the Jamaica study estimated the costs at which collection and storage of field residues and/or drying and storage of bagasse would be competitive with fuel oil or coal. As outlined in other papers at this workshop, several efforts in several countries currently are being undertaken to determine the technical feasibility and costs of various strategies.

The ability to store bagasse or barbojo is limited by the bulkiness of the material and the danger of spontaneous combustion during storage if moisture content is not kept below certain levels. Analysis done for the Monymusk factory showed the importance of the cost of the off-season fuel to overall project economics. Based on the results of the Jamaica study, the A.I.D. Office of Energy is funding research to examine; (1) rapid and controlled bagasse drying and densification for deferred combustion, and (2) recovery of solar dried, sugarcane tops and leaf trash by baling for deferred combustion. A.I.D. will sponsor tests of one barbojo recovery system in Jamaica in 1988. Further study will be required of rapid bagasse drying and storage techniques and their application to the Jamaican situation.

Key Considerations

The technical, institutional, and commercial risks of an investment at the Monymusk factory to produce surplus electricity for sale to JPS are significant. What follows are brief discussions of some of the key issues and risks. One of A.I.D.'s roles has been to identify and where possible minimize the risks to investors, the utility, and government in implementing a cane energy project in Jamaica.

Product Markets

Favorable market demand and prices for the products of the integrated facility (i.e., refined and raw sugar, molasses, and electricity) must be assured throughout the investment period. Without predictable prices for each product, neither foreign nor local private investors will participate in the project.

Most sugar in Jamaica is either sold on the domestic market (45%) or exported under the EEC quota (50%) although Jamaica still exports a small amount of sugar under a U.S. quota (5%). Domestic demand is expected to increase in the coming years and will more than offset any further decreases in the U.S. quota. The EEC quota is expected to remain constant.

The price for sugar is supported in each of Jamaica's markets and thereby protected from swings in world market prices. However, future prospects for cost-effective and adequate supplies of sugarcane are not assured without new investment in the land and facilities associated with sugar production. The World Bank rehabilitation loan provides evidence of the commitment of the Government of Jamaica and the international financial community to continued production of sugar in Jamaica.

JPS produces and distributes most power in Jamaica although the sugar and bauxite industries generate significant quantities of electricity for their own use. Satisfying investor concerns about the demand and price for surplus electricity produced by the Monymusk factory will depend on the willingness of JPS to sign a power purchase agreement. Jamaican electricity demand is growing more rapidly than was anticipated when their current expansion plan was prepared in 1984.

Facility Design

The unit cost to process sugarcane into sugar, molasses and bagasse depends heavily on capital utilization because costs to pay off capital usually represent by far the largest percentage of total annual costs at sugar factories. Returns on investment depend heavily on proper sizing of processing facilities and on achieving cane production targets.

Capital costs are equally important components of electricity production at sugar factories. The addition of a new capital-intensive cane energy facility to an upgraded processing complex will further increase the requirement that Monymusk Estate achieve planned sugarcane production targets. The level of production will also directly affect supplies of barbojo.

Obviously, the size and design of generation equipment depends on the planned fuel supply and the demand for steam and electricity in the sugar factory. Both the quantity of cane residues (bagasse and barbojo) available for fuel and the demand for steam and electricity in the factory are directly tied to the rate and duration of sugarcane processing at Monymusk. Risks associated with shortages of bagasse and barbojo caused by poor sugarcane harvests are reduced by designing the power system to use multiple fuels. Ideally, increased quantities of barbojo will be collected over time in order to reduce oil use below the projected 25 percent.

Design of the facility must also fit operating conditions at the site where it is installed. For example, water quality will be a critical design issue at the Monymusk site as will be the availability of personnel trained to operate high pressure boilers.

Management and Operational Changes

Several options were considered for developing power generation capabilities at the Monymusk Estate. The study team eventually recommended that power generation be integrated into overall plant operations. To attract investors, the study team felt the Monymusk Estate must commit to hire proven managers to oversee operation of the power plant. Technology and equipment cannot compensate for distracted or incompetent management. When the investments in sugarcane production and processing are held by different interests than the investments in power generation, carefully negotiated contracts between the parties and reliable accounting systems are essential.

The installation of a new cogeneration station requiring substantial capital investment (1300-$1400 per kW of capacity) will affect both technical and commercial aspects of conducting business at Monymusk. Management will need to optimize net revenues and profits from production of sugar, molasses, and electricity. Operating procedures and production goals will change. Reductions that can be made in field and process energy requirements will allow more electricity to be produced for sale in addition to reducing energy costs per unit output of sugar and molasses. This potential for double benefit could lead to installation of more efficient equipment and implementation of conservation measures that until now have not taken place. For example, considerable electricity savings could be attained at Monymusk by increasing the effectiveness of application of irrigation water. Currently, poor application methods lead to deep percolation of water beyond the effective rooting zone of cane plants. Electricity is wasted pumping water that does not increase productivity.

Traditionally, sugarcane harvest and processing have been scheduled during a six to seven month period in the Caribbean because of climate and juice quality considerations. Typical campaigns run 150 to 180 days. To maximize returns on the power generation investment, the goal for the Monymusk factory should be to provide baseload electricity for 46 weeks allowing approximately six weeks for annual maintenance.

Utility and Electric Power Agreements

To attract outside investment, both the Monymusk Estate and JPS must make long-term commitments to private electricity generation by the sugar industry at power purchase rates that provide investors an adequate return on their investment. If Monymusk can provide firm, baseload power (as opposed to providing surplus power sporadically), JPS can defer investments in new capacity, save on fuel costs, and justify paying "full avoided costs"[6].

The scheduling of the generation period and the power dispatch must be by mutual agreement of JPS and Monymusk. In the case of Monymusk, the purchase power agreement must also provide for distribution of the Estate's power to its pump stations over existing JPS lines.

Government Involvement and Benefits

The GOJ has strong socio-economic incentives to participate closely in negotiations that affect the sugar industry in Jamaica and has been a critical actor throughout the design of the World Bank rehabilitation program and the proposed cane energy project. If the project is successful and the mill becomes more profitable, part of the government funds now going for price supports to sugar commodity programs and electricity production may be available for alternative programs. A well designed, integrated energy/sugar facility should: 1) reduce the country's annual foreign exchange expenditures on oil (although under conservative assumptions some oil will still be needed for the new facility); 2) draw upon private resources rather than government borrowing capacity to finance part of Jamaica's future electricity generation; 3) help stabilize future electricity costs for JPS; 4) sustain or increase rural employment and income; and 5) possibly raise skill levels in the sugar growing region.

Summary

The key factors identified in this paper regarding how a new cogeneration facility at the Monymusk Estate can be designed, constructed, capitalized, operated and managed include provision for a reliable year-round cane residue supply, installation of energy efficient equipment to maximize excess power sales, integrated management of sugar and power operations, fair and well written utility contracts based on firm power sales by the Estate to the utility, and a thorough assessment of traditional product markets (sugar and molasses). The most important requirement is a commitment by all the investors, including the Government, to a competent and well-focused management. At present, the GOJ and private investors are actively negotiating for a cane energy system to be installed at the Monymusk Estate.

Financial benefits to the sugar industry from a cogeneration system are: 1) a reduction in the amount of electricity purchased from an external source (in this case JPS); 2) higher revenues through power sales; and 3) increased sugar revenues from a more efficient processing facility.

Benefits can be further enhanced through improvements in the energy efficiency of certain operations; i.e., irrigation and drainage pumping, sugarcane crushing and juice processing. If sugarcane residues currently left in the fields can be collected in sufficient quantity to displace projected oil consumption at the power plant, additional project benefits will be realized.

The national utility will benefit by; (1) deferring investment in new capacity, and (2) decreasing dependence on imported fuel supply.

The critical business contributions of the project include: 1) diversification of the sugar industry into new markets; 2) private sector investment in electricity generation; and 3) reducing foreign exchange requirements of the electricity sector.

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6 Full avoided costs include a capacity payment (capital deferment) as well as a fuel savings payment.

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