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1. INTRODUCTION

Until recently the production and processing of cane for sugar accounted for very significant percentages of the employment, income, land use, and foreign exchange earnings in a large number of tropical developing countries. In the 1980's, however, sugar has become an industry in crisis.

The world market for cane sugar has declined due to the increased competition from beet sugar and corn sweeteners and to other economic factors. Due to the low world market prices for sugar, cane production and processing are not profitable in many areas. Many sugar estates and mills have been closed, with severe adverse effects on the employment and income of many thousands of people. In other areas sugar production is maintained only through substantial governmental subsidies. Most cane-producing countries have few opportunities to create profitable new uses for the land and labor that have been engaged in sugar production. Most export-oriented crop strategies require large investments and reduce labor requirements; competition can be stiff, and markets are often smaller than anticipated.

Traditionally, the entire cane industry has been organized to maximize the output of sugar. The tops and leaves of the cane plant have usually been left in the fields. The bagasse remaining after crushing the millable cane stalks has been treated primarily as a residue to be disposed of as cheaply as possible, rather than as a valuable co-product. Around the world much of the molasses generated in sugar production is used as animal feed, although other options such as ethanol production may produce higher economic returns.

In the typical sugar mill, the bagasse remaining after the juice is extracted from the cane stalks is burned as a boiler fuel in inefficient low-pressure boilers that were designed to dispose of all of the bagasse. The steam is normally used to generate mechanical power for cane milling and process heat for sugar refining. In most mills some of the steam is also used to generate electricity for use in the mill.

Due to the inefficient use of the available bagasse, sugar mills rarely contribute surplus electric power to the grid. Bagasse cannot be stored for very long without special precautions to avoid spontaneous combustion or fermentation. Its utilization as a boiler fuel for electric power generation is usually limited to the season in which cane is being harvested and milled.

As the crisis in the sugar industry has deepened, many observers have agreed that the only routes to profitability involve the more complete and diversified use of the products that can be derived from the cane plant. Although there are some other options, this Report is confined to the use of cane to produce energy. It focuses primarily on two recent proposals for the production of electric power for the grid using cane residues and supplementary fuels. It also reviews use of cane juice or molasses to produce ethanol for blending with gasoline. In both types of cane energy systems, the objective is the production of energy as well as sugar or sugar products.

The two current proposals for grid power from cane have several common elements: (a) the intensive cultivation of high-tonnage cane varieties using new cane management techniques, (b) the production of a storable biomass fuel or fuels for use in the season in which no bagasse is being produced, and (c) the efficient use of these biomass fuels in modern utility type power plants operating during the cane-milling season and most of the non-milling season.

Both proposals have evolved from experience with cogeneration projects in the sugar industry in Hawaii and from research on energy from cane and tropical grasses between 1977 and 1983 at the University of Puerto Rico, in Louisiana, and in Florida. These latter research programs, funded by the U.S. Department of Energy, demonstrated that the volume of biomass fuel produced per acre of cane field could be multiplied by the use of cane management techniques designed to

increase overall growth rather than the sugar content of the cane stalk.

The first proposal reviewed in this Report was made by an assessment team sent to Jamaica in the summer of 1984 by the U.S. Agency for International Development. Working closely with Jamaican agencies, the team proposed that a cane energy system be established at the government-owned Monymusk sugar estate and mill on the Clarendon plain on Jamaica's south coast. New cane management techniques would be used on about 12,000 acres of government-owned land and about 8,000 acres of privately owned sugar estates and small farms. A new power plant would be built alongside the sugar mill.

Most of the information on the Monymusk project used in this Report has been drawn from the report of the AID assessment team that was completed in October 1985. A more detailed examination of several aspects of the Monymusk proposals was commissioned by AID in 1985 and is being carried out by the Ronco Corporation of Washington and Kensington, California, in cooperation with the Bechtel Corporation of San Francisco.

The second proposal described in this Report has been developed by the Center for Energy and Environment Research (CEER) at the University of Puerto Rico for the Municipality of Arecibo and the Puerto Rican Office of Energy. The Phase 1 report was issued in August 1985. It outlines the creation of a cane energy system on 12,700 to 16,000 acres of land around the Cambalache sugar mill, which has been closed since 1981. The mill would be opened and modernized and a new power plant would be built alongside the mill.

Both the Monymusk and Arecibo projects would be established on Caribbean islands on which there is a strong demand for molasses for the production of rum. The Monymusk mill would continue full-scale sugar production to meet domestic needs for sugar and for the blackstrap molasses demanded by Jamaican rum distillers. The Arecibo project would produce only "first-strike" sugar, utilizing about 60% of the sugar in the cane juice, and enriched molasses for use in rum production.

In some other countries, either raw cane juice or molasses could be used to produce fuel-grade ethanol. Although the Monymusk and Arecibo proposals focus on electric power, cane energy systems in other locations may include ethanol fuel production.

This Report is divided into sections on growing and harvesting biomass fuels in cane fields (pp. 3 to 6), producing power for the grid with these fuels (pp. 6 to 9), the uses of the cane juice produced in cane energy systems (pp. 9 and 10), the costs and revenues associated with these systems (pp. 11 to 13), and the national benefits derived from these systems (pp. 14 and 15).

Data from Puerto Rico on the poroduction of cane, residues, and other fuels in the University of Puerto Rico research and the Arecibo project have been converted from short tons to long tons, the measurement used in the Monymusk proposals, to facilitate comparisons between the two projects. One long ton equals 1.120 short tons or 1.016 metric tons.

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2. GROWING FUELS IN CANE FIELDS

The most innovative features of both the Monymusk and Arecibo proposals relate to the production, harvesting, storage, and utilization of new types of biomass fuels. These include the harvesting of cane tops and leaves along with the stalks, the separate harvesting of the tops and leaves, the production and harvesting of "energy grass," and the use of these fuels in the proposed power plants.

A. Managing Cane to Maximize Fuel

The cane management system developed at the University of Puerto Rico includes important changes in the traditional techniques for soil preparation, planting, fertilization, irrigation, and harvesting.

Production Cycle: The UPR system involves a three-year cycle including a crop from the original planting and two ratoon crops harvested from regrowth from the original planting. A similar cycle is contemplated in the Arecibo project in Puerto Rico. The first ratoon crop was the most productive of the three crops in the UPR tests. A third ratoon crop has been considered for the Monymusk project in Jamaica.

Soil Preparation: Land leveling or smoothing is necessary to facilitate irrigation and to eliminate depressions that cause accumulation of water and salt in high-salinity areas. The soil is prepared by deep plowing with a moldboard plow to a depth of 18 to 24 inches (45 to 60 cm) to improve soil tilth and to allow the plants to seek water and nutrients without restriction. Liming may be necessary to correct soil acidity. A heavy-duty commercial rotavator was used for final seedbed preparation at UPR, although the unit used a lot of fuel and required a skilled operator to avoid damage to the rotavator or tractor. In the UPR tests, subsoiling was used to increase aeration and drainage; subsoil was fractured and roots were pruned with a heavy subsoiling attachment one month after planting.

Planting: In one of the UPR field tests, the highest tonnages were produced from cane planted in rows that were about 7 feet (213 cm) apart instead of the traditional 150 cm spacing in Puerto Rico. The wider spacing was justified primarily as a means of avoiding injury to the cane stubble and young shoots during mechanical harvesting and the resulting adverse effect on subsequent ratoon crops; this wider spacing might not be necessary in fields harvested by hand. Somewhat wider spacing may be desirable, however, for new cane varieties.

Irrigation: Ample water throughout the year is essential in order to achieve high cane tonnages. The UPR experience indicated that the continuous growth of the cane requires the equivalent of 5 to 7 acre inches of rainfall each month during the 12-month cycle. In most cane production, water is withheld during the last few months before harvest to increase the sugar content of the stalk and encourage the withering of the unwanted tops and leaves. Cane grown for maximum biomass, however, will be fully irrigated until harvest in order to encourage the maximum growth of the whole plant. Seven irrigation wettings are now applied to the soils at the Monymusk estate in Jamaica. To maximize biomass, the number of wettings would be increaed to between 11 and 13 at three-week intervals for heavy clay, and more frequent applications would be made to lighter soils.

Fertilization: In most areas, increased use of fertilizers is necessary to maximize biomass production. The UPR experiments used about twice as much fertilizer as is normally used in cane production in Puerto Rico. A doubling of the level of nitrogen added to the soils is also anticipated at Monymusk in Jamaica. The extent of the additional fertilization needed will depend, of course, on the fertility of the soil in each area. In both projects, fertilizer would be applied in two to three applications.

Harvesting: The cane management system developed in Puerto Rico is based on the mechanical harvesting of the cane, since manual harvesting would be prohibitively expensive in areas subject to U.S. minimum wage laws. The Monymusk proposals in

Jamaica assume that the cane will continue to be harvested by hand during at least the next decade. The principal differences in the harvesting of conventional cane and cane grown for maximum biomass relate to the handling of the cane tops and leaves, which will be discussed in the subsequent section.

Productivity: The six-year experiments and field trials at the University of Puerto Rico led to annual yields of over 98 long tons of biomass per acre. This yield was nearly four times as high as the average conventional sugarcane production in Puerto Rico, which is about 24 long tons per acre.

Both the Arecibo and Monymusk analyses used more conservative estimates of biomass production. The Arecibo report projected an average of 76 long tons per acre with the most productive U.S. cane variety (US 67-22-2) on a three-year cycle and an average of 58 long tons per acre from a promising local variety (PR 980). The Monymusk report in 1984 estimated that the production of millable cane at Monymusk would eventually reach 65 long tons per acre or almost three times the current average in Jamaica, which is also about 24 long tons per acre. (The Arecibo estimates included the harvesting of tops and leaves along with the stalks, while the Monymusk estimates referred only to stalks.)

The estimates of potential productivity at Monymusk will be refined using data from field trials to be initiated early in 1986. The trials will be conducted by the Sugar Industry Research Institute of Jamaica in cooperation with Ronoco Corporation. They will include several different varieties, ecologies, and season planting patterns.

B. Using Cane Tops and Leaves for Fuel

Most cane fields in developing countries are burned the day before the harvest to remove most of the leaves. This burning consumes potential boiler fuel that has been estimated to be the equivalent of 2.5 to 4.0 barrels of oil per acre. After burning, the stalk of millable cane is cut by hand with a machete. The tops of the plant and the remaining leaves are left in the field.

Since the tops and leaves have been considered valueless "field trash," the volume of this material has not been accurately measured. In conventional cane production in Puerto Rico, the quantity of the tops and leaves has been estimated at about 11 tons per acre per year. In the UPR tests of variety US 67-22-2, a prolific producer of stems and foliar canopy, the trash reached 23 tons per acre.

There are three options for the utilization of tops and leaves as fuel:

(1) Whole-Plant Harvesting, Separation of Tops and Leaves Before Milling

In Hawaii tops and leaves are often harvested with the stalks and the whole plant is transported to the mill. There the millable cane is mechanically separated from the trash; the tops and leaves are diverted directly to the boilers and do not go through the milling rollers with the stalks. The principal limitation on the application of this technique in cane energy systems in developing countries is the high capital cost of the "Olsen Rolls" used to separate stalks and trash. This option was not included in the Monymusk or Arecibo proposals.

(2) Whole-Plant Harvesting, Milling of Tops and Leaves with Stalks

This technique has been proposed at the University of Puerto Rico and would be used in the Arecibo project. Experience indicates that whole-plant harvesting would provide 25% more total biomass than the traditional harvesting of only millable cane stalks. In a cane energy project involving an existing sugar mill, however, the fiber-grinding capacity of the mill sets a limit to the amount of cane that can be processed. Since the mill must grind tops and leaves along with the stalks, whole-plant harvesting of this type decreases the amount of sugar produced per ton of fiber processed. Some increases in throughput may be feasible, but this would further reduce sucrose extraction. The attractiveness of this option would depend on the relative economic values associated with the production of sugar and of fuel.

Since the harvested tops and leaves are mixed with the bagasse remaining from the milling process, this combined fuel is subject to the same storage limitations as bagasse from conventional sugar mills. This approach does not provide a source of fuel that can be used to maintain electric power generation during the wet season in which no cane is being harvested and processed.

(3) Separate Collection of Tops & Leaves

This option involves the separate harvesting of the tops and leaves after the millable cane has been removed from the fields. The Monymusk proposals rely primarily on such separate harvesting of cane tops and leaves to provide most of the storable fuel needed in the power plant during a relatively short non-milling season.

The tops and leaves would be dried for a few days in the sun, turned with a mechanical disc rake, and dried for a few more days. At the end of a week the biomass should have a moisture content as low as 20%. It would then be raked, baled, stacked on trucks, and hauled to a storage area. It could be stored outside, since even a heavy rain would penetrate only an inch or two into the heavy thatch.

Only about 60% of the tops and leaves would be removed from the fields; the remainder would be left on the ground to provide mulch and impede erosion. The Monymusk team estimated in 1984 that the annual harvest of tops and leaves at Monymusk could reach 75,000 long tons.

Field trials of cane trash collection are being planned, possibly in Florida, using modified commercially available hay-making machinery. These trials will provide a basis for more reliable estimates of the supply of cane trash for use as fuel and of the costs of collecting this biomass.

In the Arecibo project, some remaining leaf trash would be raked, baled, and stored in order to add about 31,000 tons to the annual fuel supply for the power plant.

In many locations in the Dominican Republic, cane is not burned prior to harvest. An evaluation by ABA International of Hawaii indicated that cane tops and leaves could provide a viable alternative to imported oil for power generation. The Dominican Electric Corporation (CDE) is now planning to use baled tops and leaves as a supplementary fuel with coal in a 30 MW power plant to be built at San Pedro de Marcoris.

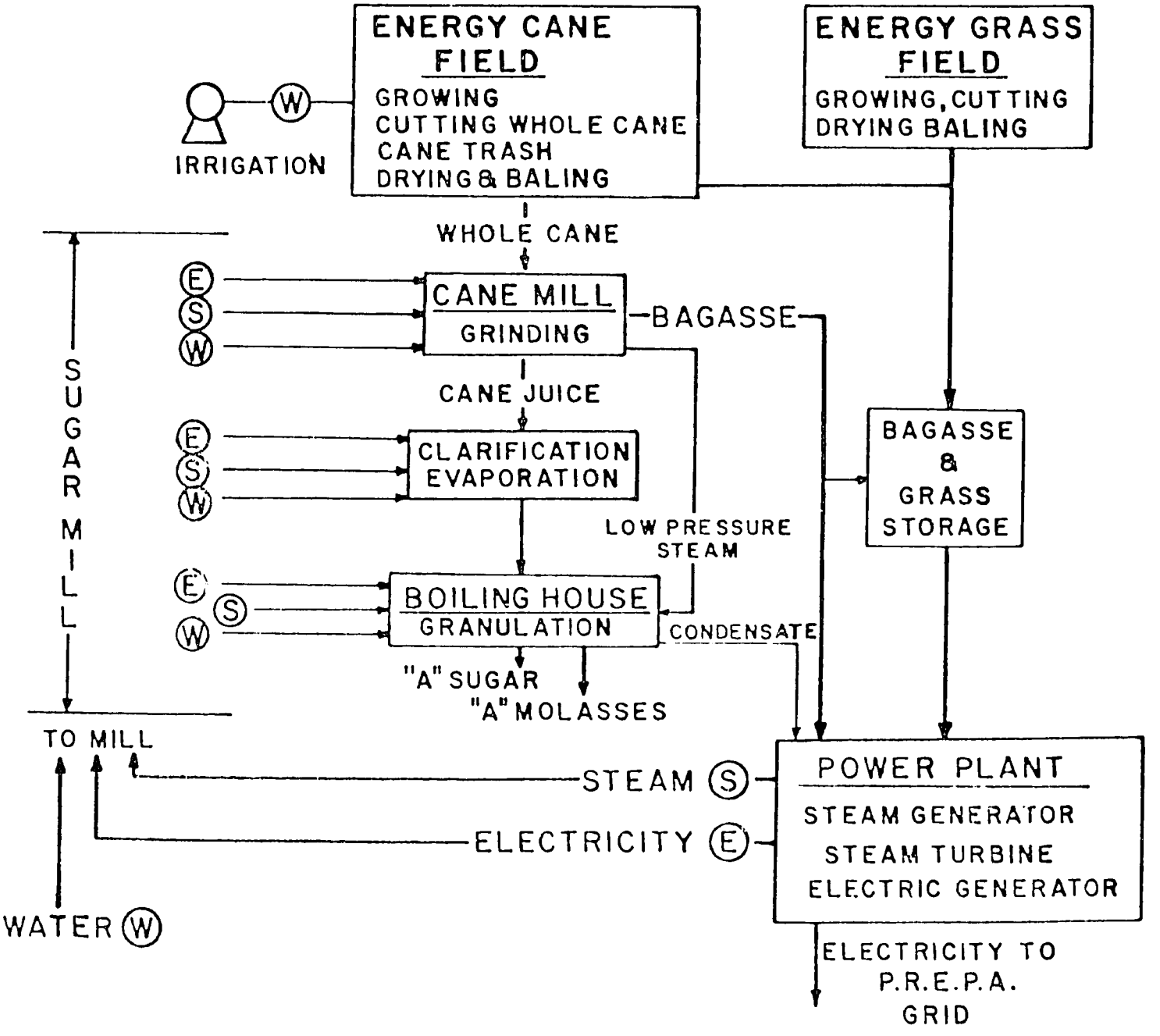
C. Growing Biomass for Fuel

The Arecibo proposals reflect the UPR approach to cane energy systems that relies heavily on the separate production of other biomass that can be stored and used as fuel during the season in which no bagasse is being produced. Field trials at UPR indicated that the most promising potential fuel is Pennisetum pupurem (Napier Grass), which resembles sugarcane. It produces two crops a year and can be ratooned five times in a three-year cycle before replanting. This "energy grass" would be harvested with a rotary scythe mower-conditioner drawn by a tractor, raked and turned twice for solar drying, and baled in .7 ton square bales.

The Arecibo power plant would operate primarily or exclusively on energy grass for 136 days in the non-milling season. Yields in Puerto Rico were expected to average about 59 long tons of green material per acre per year over the three-year production cycle for this fuel.

Neither the techniques nor the costs of producing and using energy grass as fuel have been demonstrated as yet in commercial-scale operations. In a limited combustion experiment in Puerto Rico, very dry (15% moisture) pulverized grass caught fire on the conveyors; this experience indicates the need to control drying to retain a moisture content of about 30% for optimum handling.

The proposed use of energy grass in the Arecibo project in Puerto Rico is indicated in the diagram on the following page.



D. Other Potential Biomass Fuels

Several other types of biomass fuels have been suggested as possible boiler fuel for the power plant of a cane energy system during the non-milling season. If sufficient land is available, it may be possible to use woody biomas from fast-growing species. Eucalyptus, Casurina, Cassia, Leucaena, and Albizia have been suggested. (See "Growing Trees for Fuel," December 1982 Bioenergy Systems Report.) In some areas, crop residues or agroindustrial wastes could be used as supplementary fuel.

3. GRID POWER FROM CANE RESIDUES

A. System Characteristics

In both the Monymusk and Arecibo projects, a large new power plant would be built alongside the existing sugar mill to generate electric power primarily for export to the grid. Both mills are located near high voltage transmission lines.

The initial Monymusk proposals assumed a boiler producing up to 450,000 pounds of steam per hour at a pressure of 1250 pounds per square inch (psig) above

atmospheric pressure and a temperature of 850°F (454°C). The power plant was assumed to have a double extraction turbine and a 46 MW generator. Although these assumptions influenced some of the other assumptions and conclusions described in this Report, no actual decision has been made on the size of the power plant pending a fuller assessment of the potential fuel supply during both milling and non-milling seasons. The team also assumed that about 7% of the gross power would be used in the power plant, about 3 MW would be needed for the operation of the sugar mill, and an additional 3 MW would be used for irrigation.

The proposed boiler in the Arecibo project would have a capacity of 315,000 lbs/hr at 850 psig and 900°F (482°C). The Arecibo report assumed that the new power plant would have a maximum output of 29.2 MW. While operating on bagasse in the milling season, the gross output would be 22.6 MW. Only 4% would be used in the power plant and 1.9 MW would be needed in the sugar mill. In the milling season the plant would export 19.8 MW to the grid. During the non-milling season, in which the plant would burn energy grass, gross power output was estimated at 26.5 MW and net power exports were expected to be 25.2 MW.

The steam pressures and temperatures proposed in both projects, although in common use in the sugar industry in Hawaii, are much higher than those normally used in the Caribbean. The Arecibo report noted that the proposed system wouuld require a much greater degree of care, efficiency, and maintenance than has been customary in the sugar industry. There has been some apprehension about the operation of a high performance boiler in a cane industry setting in Jamaica, and careful attention to these concerns has been promised.

In both systems the back-pressure steam from the power plant turbo-generators would be used to provide most or all of the mechanical power and process heat needed in the sugar mills. Most or all of the present boilers at both mills would be deactivated. The original Monymusk proposals indicated that about 130,000 lbs/hr of exhaust steam from the power plant at 200 psig would be used in the existing back-pressure turbines that drive the milling equipment in the sugar mill. Further analysis has suggested the possibilitiy of retaining the mill's newest present boiler to provide about 110,000 lbs/hour at 300 psi; this output would meet most of the mill's steam requirements.

In the Arecibo project about 80,850 lbs/hr of exhaust steam from the turbo-generator at 150 psig would be used in the turbines in the. At both mills exhaust steam from the milling department turbines would be used in the boiling house for sugar evaporation. Since the Monymusk mill would continue three-strike sugar production, the assessment team assumed that 56,000 lbs/hr of additional steam at 25 psig would be extracted from the power plant turbine to meet additional steam needs in the boiling house.

B. Power Plant Operations During the Cane Milling Season

Despite many similarities in the proposed pants, there would be significant differences in the operational patterns of the Monymusk and Arecibo power plants. These are due mainly to differences in the length of the cane-harvesting season and in the proposed systems for providing fuel to the power plants when no bagasse is being produced.

The length of the cane harvesting season depends on both the total volume of available cane and the extent of the period(s) of heavy rain when cane harvesting is not feasible. At Monymusk the cane-grinding season has averaged 216 days during the past decade; it lasted for 259 days in 1976 and 242 days in 1978 because of the higher output of the Monymusk estate during the mid-1970's. Due to the higher cane production expected in the energy cane system, the Monymusk proposals have assumed that the cane-grinding season can be extended again to an average of 240 days. During that period the power plant will operate on bagasse. Due to the longer rainy season, the Arecibo power plant will use cane residues for only 164 days per year.

The Monymusk sugar mill was originally designed to process 5400 long tons of cane per day. Due to declining cane production and poor maintenance of the mill equipment, the mill ground an average of only 2100 tons per day in 1983. The Monymusk proposals in 1984 assumed that, as a result of increased cane production and substantial upgrading of the mill equipment, the renovated mill would be able to grind 4500 tons per day. A major renovation program is now being carried out at the mill with World Bank financing; the upgrading program is designed to permit the mill to process about 4300 tons a day during a 172-day milling season.

The Cambalache mill operated in the 1970s at the rate of about 4100 long tons per day. The Arecibo project proposals assume that the reopened mill could grind 3750 long tons of traditional cane or about 3200 long tons of "energy cane" which would have an equivalent total fiber content. Due to whole-plant harvesting, the cane tops and leaves would be ground with the stalks. The Arecibo proposals assumed that the average fiber content on the whole cane would be 18.6%, in contrast to the 15% to 16% average in traditional milled cane. For these reasons, the estimated output of biomass fuel at the Cambalache mill (1324 long tons) was about the same as the 1984 projection of bagasse output from the Monymusk mill (1350 long tons).

The Monymusk power plant would use bagasse with about 50% moisture and a heating value of 4100 BTU/lb. A proposal to reduce the moisture content using heat from the power plant's stack gas was rejected due to the uncertain reliability of this fuel drying technique. In the Arecibo project the moisture content of the fuel would be reduced only slightly to 48% in order to meet the combusion requirements of the high-pressure boiler in the power plant; the heating value of this biomass is estimated at 4,099 BTU/lb.

The total heating value of the bagasse at each site would be nearly identical (around 12,500 million BTU/day). At Arecibo the bagasse, already augmented by cane tops and leaves, would be burned along with 190 tons per day of separatly harvested fallen leaf trash. The heating value of the combined whole cane bagasse and trash would be about 4,266 BTU/lb or about 15,500 million BTU/day.

Although the Arecibo proposals assumed a high fiber content of the harvested cane due to the inclusion of the tops and leaves, neither the Arecibo nor Monymusk estimates included projections of the impact of the possible use of varieties with a higher percentage of fiber in the stalks. Some varieties tested in Puerto Rico have a total fiber content of 21%, and cane breeders in Louisana have developed varieties with up to 30% fiber. The field trials to be carried out in early 1985 will provide data on the fiber content of whole cane grown at Monymusk with the new management techniques.

C. Power Plant Operations in the Non-Milling Season

The most important innovations in both the Monymusk and Arecibo proposals are in the proposed arrangements to supply the power plants with fuel for a major part of the period in which no cane is being milled and no bagasse is being produced. Quite different approaches to this important problem are taken in the two reports.

The Monymusk proposals assumed that the cane milling season can be lengthened to an average of 240 days as in some earlier years. Other biomass fuels would be used to operate the power plant for 50 to 70 additional days, bringing the total annual oprating period to 290 to 310 days. Both the Monymusk and Arecibo proposals provide for a period of more than a month during the non-milling season for maintenance activities.

In 1984 the Monymusk assessment team emphasized the use in the non-milling season of baled cane tops and leaves harvested by the process described on pp. 5-6 of this Report. The team estimated that 75,000 long tons of this fuel could be recovered annually. After solar drying in the fields, this "trash" would have a moisture content of about 20% and a

heating value of 6,600 BTU/lb, which is 60% higher than that of the bagasse as it comes from the mill. Each ton of the baled trash would provide about 14.8 million BTU. The bales retrieved from storage would be broken up and the fuel would be reduced to a size comparable to bagasse using a shredder and hammer mill. The team estimted that the baled trash could provide approximately 28% of the total BTUs used in the power plant annually.

There is little experience anywhere with the separate collection of cane trash and with the use of this biomass as a boiler fuel. Field trials on cane trash recovery scheduled early in 1986 will provide a basis for an evaluation of the feasibility and cost effectiveness of this approach to power plant operations in the non-milling season. Other biomass fuel options including "energy grass" are also being evaluated.

In the Arecibo proposals, all of the cane residues would be used as fuel during the milling season. Most of the tops and leaes would be mechanically harvested with the stalks; fallen dried leaves would be harvested separately, but would be burned during the milling season with the whole cane bagasse. During a 145-day period in the longer non-milling season, the Arecibo power plant would operate primarily on baled "energy grass" produced and harvested by the process described on p. 5. It would use about 40 long tons of energy grass per hour to produce about 525 million BTU/hr, which is about four-fifths of the heat produced during the milling season with whole cane bagasse and fallen leaf trash. In this mode the power plant would export 25.2 MW.

The agricultural operation required to supply the 910 long tons of dried energy grass needed by the power plant daily during most of the non-milling season would be almost as large as the cane-growing operation. The power plant would use 132,055 long tons of dried grass if fueled only with grass during the 145-day period. The production of this amount of energy grass would require between 5,700 and 7,100 acres (2300 to 2900 ha) or about 45% of the total land to be used for the project.

4. OPTIONS FOR THE USE OF CANE JUICE

In cane energy systems, which emphasize biomass for electricity generation, both the percentage of sugar in the cane and the potential sugar in a ton of harvested cane would be lower than in conventionally grown cane. A Jamaican variety that may be used at Monymusk is expected to have about 8% sugar, compared with 12% to 13% for conventional varieties that have been bred for high sugar content.

The potential sugar in a ton of harvested cane would be even lower if whole-plant harvesting is used, since about 20% of the harvested cane would consist of tops and leaves. Due to the increased cane production per acre, the potential sugar output per acre would be higher than in conventional cane production.

Variables in the milling department influence sugar recovery. Water and dilute cane juice are sprayed on the cane as it is crushed in several milling units, each of which consists of three grooved steel rollers. The liquids wash out soluble solids from the crushed stalks, but the resulting cane juice is very dilute and must be evaporated before it can be used for sugar production. Less liquid would be used in a "dry milling" process; the rate of sugar recovery would be lower, but less energy would be required for evaporation of the more concentrated juice.

If the rollers are worn, less juice and less sugar are recovered. Since Jamaica needs more sugar for domestic use, the Monymusk proposals in 1984 included the replacement of existing rollers with three new and eighteen reshelled rollers. Somewhat lower efficiency of sugar recovery would be acceptable in situations in which maximizing sugar recovery is not the primary objective; however, excessive roller wear results in an increased moisture content in the bagasse, which in turn reduces the heating value of the fuel.

There are several options for the use of cane juice produced in a cane energy

system. These are indicated in the following paragraphs and in the diagram at the bottom of this page.

A. "Three-Strike" Sugar, Blackstrap Molasses for Rum

In this option, the existing sugar mill is maintained in full operation. In conventional sugar production, the sugar is crystallized in a three-phase or "three-strike" process; the residue of this total process is blackstrap or final molasses. This option is attractive at present in Jamaica, which is currently importing up to 60,000 tons of sugar annually to meet domestic needs. Jamaica distillers insist that the use of blackstrap molasses is essential to maintain the unique flavor of Jamaican rum.

B. "One-Strike" Sugar, "A" Molasses for Rum

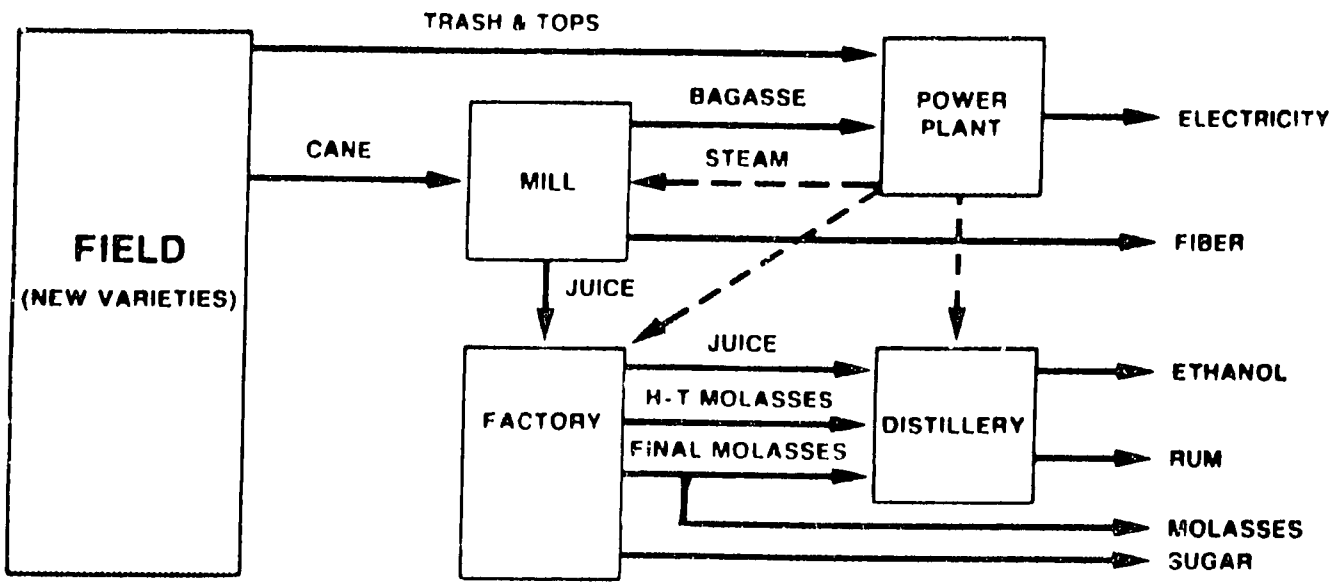
Under this option, suggested by the UPR studies in Puerto Rico, only one crystallization process or strike would be used. This would recover 60% of the sugar in the juice in crystallized form; the rest of the sugar would remain in "A" molasses. This option would be profitable in Puerto Rico; if used at Arecibo, it would replace 28% of Puerto Rico's current molasses imports, which amount to about 37 million gallons annually.

C. One to Three Strike Sugar, Molasses for Fuel Ethanol

Most of the fuel ethanol produced in cane-growing countries other than Brazil has been made from molasses. There are several advantages associated with the use of molasses as a distillation feedstock, compared with the use of raw cane juice. The molasses can be stored for use in the non-milling season. It can be transported to a distillery at another site. Since the molasses is already concentrated, less energy is needed for processing. A distillery next to a sugar mill can use exhaust steam from sugar processing.

D. Raw Cane Juice for Fuel Ethanol

Many of the ethanol distilleries built recently in Brazil were designed to use raw cane juice directly without the prior removal of any of the sugar. Such a distillery would be appropriate in a cane energy system in a country with a limited demand for sugar and molasses but a good market for fuel ethanol. This option might also be appropriate in a situation in which it was too expensive to build a new distillery and also to rehabilitate fully a badly deteriorated sugar mill; the mill's role would be limited to separation of juice and bagasse.



5. ESTIMATING COSTS AND REVENUES

The development of an cane energy project involves complex projections of capital and operating costs and of revenues.

A. Capital Costs

The largest capital cost is that of the modern utility-type power plant. Preliminary estimates indicated that a 46 MW power plant at Monymusk would cost the equivalent of about $40 million. The smaller plant in the Arecibo project would cost about $28 million.

Each of the power plants would substitute for additional oil-fired generating capacity which would have to be built on each island in the absence of the proposed energy cane system. The need for additional generating capacity in Jamaica is already clear. The Arecibo report stressed that the energy cane system should be initiated in Puerto Rico only if a determination had been made that the growth of the Puerto Rican economy will require new baseload generating capacity within the next ten years.

Both the Monymusk and Arecibo projects have been presented as total investment packages that include the capital and operating costs of the power plant. Half or more of the payback on each of the projects would come from the sale of electric power to the island utility company. Since both projects are based on the assumption that additional power generating capacity will be needed even without the cane energy system, the inclusion of the capital costs of the power plants tends to exaggerate the extent of the additional investment a country must make to establish a cane energy system.

Both the Monymusk and Arecibo proposals included substantial investments to rehabilitate the existing sugar mills to enable them to resume levels of operation approaching those for which they were designed. The cost of upgrading the cane yard, milling plant, and boiling house in the Monymusk mill was estimated to be the equivalent of $6.9 million. Most of these investments are now being carried out with World Bank financing. Only about $2 million may be needed for improvements and repairs to the Cambalache mill in Puerto Rico; one reason for the lower rehabilitation cost is that the mill would be used only for one-strike sugar production.

Upgrading of the irrigation systems and the agricultural machinery were considered necessary in both projects to achieve the planned level of output of cane and supplementary fuel. The current rehabilitation program at Monymusk funded by the World Bank includes $5 million for upgrading the irrigation system. The Arecibo proposals included $860,000 for drainage improvements over the first three years.

The Monymusk team proposed that $1.6 to $2.0 million be spent annually on agricultural machinery and equipment at Monymusk over the 15-year period analyzed; these expenditures are listed as capital costs. In the Arecibo proposals, the cost of agricultural machinery has been considered an operating cost. This is one reason why the production costs per acre or ton are higher than those projected at Monymusk, as indicated on p. 12.

B. Operating Costs

The production and harvesting of cane and supplementary fuels represent more than two-thirds of the operating costs in the Monymusk and Arecibo estimates. The production and transportation of cane and energy grass would account for 69% of the operating costs in the Arecibo project; agricultural costs were 71% of the estimated total operating costs in the Monymusk proposals.

In both projects higher cane tonnages per acre would be achieved through a significant increase in tillage, irrigation, and fertilization, which would involve higher labor, machinery, fuel, and fertilizer costs. The production costs per acre would be much higher than in conventional cane production. Due to the much higher productivity per acre, however, the

production cost of cane per ton would be lower.

In 1982-83, conventional cane production on the Monymusk estate cost the equivalent of about $290 per acre or about $13 per long ton for an average output of only 23 long tons per acre. The Monymusk team estimated in 1984 that the average cost of cane production with the new cane varieties and management techniques would be the equivalent of about $580 per acre per year over a three-year cycle. Productivity was estimated at 65 long tons per acre; the estimated production cost was about $9 per long ton.

If the Monymusk report had used the even more optimistic assumption that was used in the Arecibo report (i.e., 75 long tons of whole cane per acre per year), the estimated cost of cane at Monymusk would have been the equivalent of $7.75 per ton. The productivity data derived from the spring 1986 field trials will be used to develop more refined estimates of the cost per ton of cane production at Monymusk.

In Puerto Rico, which is subject to U.S. minimum wage laws, cane is mechanically harvested. The production cost estimates in the Arecibo report reflect the higher labor costs and the more extensive use of machinery; all machinery costs were considered operating costs, as indicated above. The report estimated that the production of 75 long tons of whole cane per acre per year would cost about $1,150 per acre or about $15 per long ton at the farm gate. The average cost of transportation to the mill was estimated at about $3 a ton, and the delivered cost of cane to the mill would be about $18 per long ton.

These estimates were considerably higher than the total costs (which included land rental and delivery costs) incurred by the University of Puerto Rico in producing high-tonnage cane on 200 acres in 1980-82. The total UPR costs were $1,027 per acre or only $9.33 per ton for a total yield of 98 long tons per acre per year.

In both the Monymusk and Arecibo reports, the costs of harvesting cane tops and leaves are included in the overall estimates of the cost of cane production and harvesting but are not specifically identified.

Although different labor costs and productivity estimates were used, the estimated costs per ton of producing energy grass were rather similar in the two reports. These costs suggest that the production of energy grass for use as fuel may not be economically viable at present. Preliminary estimates indicated that energy grass could be produced in Jamaica for about $850 per acre; with a conservatively estimated output of only an average of 33 tons per acre over a three-year cycle, the cost of the fuel per ton would be about $26.

The Arecibo report estimated production costs for energy grass in Puerto Rico at $1,300 per acre but assumed a higher average output of 52 tons per acre over the three-year cycle. The estimated cost per ton was about $25; adding transport costs brought the delivered cost of the fuel to $28 per ton.

The operating cost of the power plant at Monymusk was estimated at the equivalent of about $2.2 million annually. Operation of the smaller plant in the Arecibo project was estimated at only about $1.0 million per year.

Mill operations would cost about $2.4 million per year in the project in Puerto Rico. The Monymusk report estimated only the additional costs of the cane energy system and assumed that there would be no substantial increase in mill costs.

C. Revenue From Power Sales

Both the Monymusk and Arecibo reports assumed that the energy cane project would be carried out by a single entity that would sell electric power to the island utility company. The total annual income from power sales would depend on the price per kWhr negotiated with the utility company.

At Monymusk, the revenue from power sales by year 10 was estimated at the equivalent of $18.5 million. The total revenue also included about $1.3 million in

savings in present electricity purchases from the utility for mill operations and irrigation pumping.

The Arecibo reported indicated that the project would not be feasible if power was to be sold at less than about 7.5¢ per kilowatthour. The maximum that could be expected would be about 10¢/kWh, which was about the estimated life-cycle cost of power from a new oil-fired power plant in Puerto Rico. The report indicated that the levelized annual capital and operating costs could be met if power was sold to the utility at about 10¢/kWh and about half of the total project revenue came from the sale of sugar and molasses. At 10¢/kWh the project would derive about $10 million annually from power sales.

D. Revenue From Sugar and Molasses

Substantial income from the sale of sugar, molasses, or raw cane juice is essential to the economic viability of a cane energy project. Projections of such revenue are very difficult because of the extreme fluctuations of sugar prices in recent years. Both the Monymusk and the Arecibo reports used 11¢ per pound as the assumed average price of sugar over a 15-year period.

The Arecibo report assumed that the price of sugar in the U.S. would gradually drop from the present subsidized level of about 21¢, while the Monymusk report followed the World Bank estimates that the world market price for sugar would increase from the present low level of about 5¢ a pound to around 14¢. The 11¢ price for sugar is lower than the landed price being paid at present for Jamaican sugar imports.

The Cambalache mill in Puerto Rico, which would make only first-strike sugar, would produce an income of about $6 million per year from sugar sales. The Monymusk mill, which would continue three-strike sugar production, would yield about $15 million in sugar revenue.

The Cambalache mill would produce more valuable "A" molasses, while the Monymusk mill would produce a larger volume of less valuable blackstrap molasses. Both proposals estimate income from molasses sales of about $3.6 million.

E. Other Possible Revenue

There are at least two other possible sources of revenue for a cane energy system designed for electricity generation. One would be the sale of raw cane juice to an adjacent but independent distillery. Another would be the sale of beverage or fuel alcohol produced within the cane energy system. Neither of these options has been included in the Monymusk or Arecibo proposals. The ethanol option may be re-examined, however, as a part of the Monymusk feasibility study now in progress.

F. Overall Financial & Economic Evaluations

The variations in the characteristics of the two projects and in the methodology of financial and economic analysis preclude a complete comparison of the bottom-line evaluations of the projects.

As proposed in 1984, the Monymusk power plant represented a total investment equal to about $40 million. A discounted cash flow analysis indicated that the power plant would have a present value of $45.6 million, employing a 10% discount rate, and an internal rate of return of 23.5%. When benefits and expenditures for the power plant were restated at a shadow exchange rate of five Jamaican dollars to one US dollar (instead of the 4:1 rate used elsewhere in the report), the present value of the power plant was $60 million and the internal rate of return was 25.9%. Since the 1984 study, the actual exchange rate has moved to 6:1, further improving the economics of the project.

The Arecibo project would involve a total investment of about $34.7 million and $1.7 million in initial operating losses during the first five years. The financial analysis indicated that during the subsequent twenty years the cash flows would be positive and total $84.5 million before inflation. The report estimated that the project would recover the initial investment and earn a return equivalent to 12.2% in mid-1985 financial markets.

6. MACRO-ECONOMIC BENEFITS OF CANE ENERGY SYSTEMS

The preceding section examined the costs and revenues associated with a cane energy system within the framework of conventional investment analysis. This section of the report will review the various macroeconomic and social benefits that would be derived by the region or country in which a cane energy system is located.

A. Increased Employment and Personal Income

The decline of the sugar industry has already had a very adverse effect on employment and personal income in most cane-producing areas. For example, the crisis in the industry was a significant factor in the increase in unemployment in Puerto Rico from 12% of the labor force in 1973-74 to 22% in 1983-84.

Many mills and estates are being kept in operation through governmental subsidies that impose severe burdens on overtaxed budgets. More mill closings are in prospect. There are few viable options in most countries for the use of the land, equipment, and labor which is or has been engaged in sugar production. Under these circumstances, the governments of many cane-producing countries have a strong motivation to find some means of rebuilding profitability and employment in the production and processing of cane.

The Monymusk assessment team concluded that the cane energy project would maintain present employment at Monymusk and create about 1,000 additional jobs in cane growing and harvesting. Similarly, the Arecibo report indicated that the project could contribute substantially to reducing employment in the Arecibo area. The project would generate the equivalent of 563 direct full-time jobs and 634 indirect jobs with a total new employment of about 1,200 jobs.

B. Reduction of Government Subsidies

Many governments are presently subsidizing unprofitable sugar production as a means of avoiding further unemployment and economic dislocation. The Monymusk mill has been losing about $7 million per year; Jamaica's total annual losses in sugar production exceed $20 million, not including the cost of importing sugar to meet domestic needs. Puerto Rico's sugar industry is also losing about $20 million a year. By restoring profitability in cane production and processing, cane energy systems can eliminate substantial government subsidies or losses in government-owned estates.

C. Reduced Electric Power Costs

A cane energy system could significantly reduce the capital and/or operating costs associated with the generation of electric power in the country or region. The system could eliminate or reduce the need for additional generating capacity using oil or coal. By expanding the island's generating capacity, the Arecibo project would reduce the need for a very expensive proposed coal-fired power plant. The Monymusk power plant would replace generating capacity in Jamaica that is already scheduled for replacement in the next few years.

The electric power distributed by utility companies in most cane-producing countries is produced primarily or exclusively in oil-fired steam plants or diesel-powered generators. Jamaica spent $93 million in 1983 on fuel for electric power generation. The use of bagasse and other biomass as fuel for power generation would result in major savings in fuel costs. The University of Puerto Rico estimated in 1982 that the cost of boiler fuel from a cane energy system would be about $1.90 per million BTU, compared to about $6.00 per million BTU if No. 6 fuel oil is used. The extent of the savings in fuel costs depends on the ultimate cost of the biomass fuels produced in the cane energy system and on the price of imported oil.

D. Reduced Foreign Exchange Expenditures

Cane energy systems can contribute significantly to the reduction of imports and help the country's balance of international payments. The largest foreign currency savings would result from the reduction in the future use of imported oil for electric power generation. The Monymusk assessment team estimated in 1984 that if the Monymusk power plant exported 39 MW of power to the grid for about 330 days per year, the foreign exchange savings would exceed $18 million annually. The actual extent of these savings would be influenced by the actual capacity and output of the power plant and the price of imported fuel oil.

Both the Monymusk and Arecibo projects would also provide substantial savings in reduced imports of sugar products. Jamaica imports about 60,000 long tons of sugar annually; Puerto Rico produces only about two-thirds of the sugar it needs. The reopened Cambalache mill would produce about 28,000 long tons of sugar and about 8.6 million gallons of A molasses. The molasses could replace up to 28% of Puerto Rico's present molasses imports.

A third category of possible foreign exchange savings could be generated by using raw cane juice or molasses to make ethanol to replace some of the nation's imports of crude oil or gasoline. The attractiveness of this option depends on the export price for sugar or molasses and the import price of crude oil or gasoline. A study by Ohio State University indicated that producing ethanol for domestic use from molasses would have achieved only modest net foreign exchange savings in Jamaica and the Dominican Republic and that making ethanol from raw cane juice would have resulted in a significant net loss in foreign exchange for both countries.

The production of ethanol for domestic use is most attractive in countries that are distant from molasses markets. In Zimbabwe a sugar company produces 40 million liters (10.5 million gallons) of ethanol annually, which are used in a 12.5% blend with gasoline. A second plant of this size is being considered to permit further savings in oil imports through the use of a 20% ethanol/gasoline blend.

E. Increased Exports

The recent environmental decision in the United States to phase out the use of lead as an octane enhancer in gasoline, in order to improve air quality, has opened the prospect of a greatly expanded market for ethanol in the U.S. About 520 million gallons were produced in the U.S. from grains in 1985, but the U.S. demand for ethanol could increase to more than twice that amount by 1990. Brazilian ethanol imports into the U.S. are subject to an import tax of 60¢ a gallon. Ethanol produced in the Caribbean region could enter the U.S. without tax due to trade concessions extended under the Caribbean Basin Initiative of 1982.

Ethanol is being produced at present in Costa Rica, El Salvador, and Guatemala and negotiations are under way for Brazilian-built ethanol plants in the Dominican Republic and Panama. Although neither of the cane energy systems described in detail in this report includes the production of ethanol fuel, the production and export of ethanol may be a major component of cane energy systems developed in the next few years.

F. Other Economic and Social Benefits

In addition to the measurable benefits listed above, a cane energy system would provide other important if less measurable benefits. The most important of these is the revitalization of the critically important cane industry, which would have a major positive impact on the economy in most cane-producing countries. The system would also reduce the vulnerability of the country's economy to fluctuations in the international prices of exported sugar and imported oil. By reducing employment and economic insecurity in cane-growing areas, the cane energy system would contribute to political and social stability.

CANE/ENERGY SYSTEMS ASSESSMENT PROGRAM

A program to assist with the assessment of the potential for cane energy systems is being funded by the AID Office of Energy in cooperation with USAID Missions. The Cane/Energy Systems Assessment Program is being managed by the Ronco Consulting Corporation of Washington and Kensington, California.

The primary goal of the Program is to assist USAID Missions and governments in cane-producing countries in analyzing the technical and economic feasibility of converting cane lands and facilities to a different mix of products, with emphasis on the production of electricity and fuel alcohol.

The announcement of the Program in September 1985 indicated that it may be appropriate to consider the technical feasibility and economic attractiveness of some form of cane energy system in a country if affirmative answers can be given to five questions: (1) Is the country's sugar industry important, but in trouble? (2) Do the problems of the sugar industry contribute to rural and urban unemployment, poor earnings on the part of small and large farmers, and foreign exchange shortages? (3) Are cane growers (private or public) interested in exploring diversification opportunities? (4) Does the country plan to expand the production of electricity or replace old generating facilities in the next decade? (5) If new or replacement power is needed, will this require the use of petroleum fuels or imported coal?

Initial priority is being given to (a) identifying countries in which cane energy systems appear to make sense in terms of the overall economic situation, the status of the sugar industry, and the country's energy needs, and (b) reviewing concepts and possibilities for cane energy systems with officers of USAID Missions and government agencies. At the time of the completion of this Report, consultative visits had been made or planned to Jamaica, Haiti, Honduras, Paraguay, and Thailand.

Where appropriate, the Program will provide teams of technical specialists equipped to make pre-feasibility studies to determine economically attractive alternatives. Such assessments will draw on the lessons learned in the first such assessment in Jamaica in 1984. Available consultants include cane agronomists, mill and factory specialists, powerplant engineers, ethanol distillery specialists, and development economists with experience in this area. The program will use specialists from four U.S. cane growing areas (Hawaii, Puerto Rico, Louisiana, and Florida).

The program has also prepared computer-based analytical models that can be used to determine optimal production systems under different conditions and to evaluate the economic attractiveness of these alternatives. These models have been tested in the cane energy program in Jamaica.

The Assessment Program is being carried out under the supervision of Mr. Alan Jacobs, Director, Office of Energy, Bureau for Science and Technology, Agency for International Development, Room 508, SA-18, Washington, D.C. 20523, Telephone: (703) 235-8902.

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