PN-ABP-41

Bioenergy Systems Report

Power for the Grid from

Sugarcane Residues

August 1989

Office of Energy
U.S. Agency for International Development

The Bioenergy Systems Reports are published by the Bioenergy Systems and Technology Project (BST), the United States Agency for International Development, Bureau for Science and Technology, Office of Energy. The BST Project has been staffed by:

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POWER FOR THE GRID FROM SUGARCANE RESIDUES

INTRODUCTION

Since 1979 the Bioenergy Systems and Technology Project (BST) of the Office of Energy, U.S. Agency for International Development, has assisted developing countries with the analysis of options for the production of energy from biomass. The BST Project has concentrated primarily on new opportunities to produce energy from the residues generated by the processing of major agricultural crops, especially sugar cane and rice. These activities will be continued in a new Biomass Energy Systems and Technology Project (BEST) to be initiated on October 1, 1989.

Activities carried out under the BST project and objectives of the new BEST project were reviewed in April 1989 in the Bioenergy Systems Report on "Biomass Energy Systems and Technology Project - The A.I.D. Approach: Using Agricultural and Forestry Wastes for the Production of Energy in Support of Rural Development." The following three paragraphs from the April Report summarize the rationale for A.I.D.'s special interest in energy from sugarcane residues.

Many countries receiving U.S. foreign assistance rely greatly on the production of sugar to provide employment and earn foreign exchange. Among agricultural commodities in A.I.D. countries, sugar cane is by far the largest crop (660 million metric tons annually). Some seven million people are employed full-time in A.I.D. countries, with over 30 million directly dependent on sugar industry income.

During the 1980s the sugar cane industry worldwide suffered from over-supplied markets and low prices, with concomitant decreasing export earnings and trading power. Market instability has been exacerbated by shrinking U.S. and EEC sugar quota markets, negligible consumption growth, state take-overs of heavily indebted private sugar companies in order to preserve employment, poor management in many locations, and the lack of resources for maintenance and new investment. As a result, many sugar cane industries in A.I.D. countries have suffered consistent financial and employment losses which have led to declines in foreign exchange earnings and government revenues and reduced stability in agricultural regions.

Based on four years of effort in feasibility studies, research, and field project development, A.I.D. views energy and new product markets as significant opportunities for exploitation by producers of sugar cane. The BEST program concentrates on commercial energy production from the sugar industry because of the increasing need for electricity and liquid fuels in A.I.D.-assisted countries and the existence of proven commercial technology that could greatly increase the amount of electricity produced at sugar factories. Electricity sales to public utilities, as well as sales of other alternative products such as fuel alcohol, boiler fuel, animal feed, paper, particle board and fertilizer, appear to offer promise as new commercial avenues for the sugar cane industry.

Although other diversification options for the cane industry have been examined in several countries, the present Report is focussed exclusively on the use of sugarcane residues to generate electric power for sale to utility companies.

A previous Bioenergy Systems Report on "Cane Energy Systems" in March 1986 compared two proposals for the generation of power for island grids in the Caribbean area. The first proposal, developed by a BST assessment team in Jamaica in 1984, involved the construction of a new power plant at the government-owned Monymusk Sugar Estate and mill. The second proposal, developed by the Center for Energy and Environment Research (CEER) at the University of Puerto Rico, outlined a plan for reopening the Cambalache sugar mill in Puerto Rico and the construction of a new power plant at the mill.

The present Bioenergy Systems Report provides a digest of information drawn from reports on subsequent studies and assessments sponsored by the BST Project. The scope of these reports is summarized below:

Jamaica Cane/Energy Project Feasibility Study, 248 pages, September 1986.

This report contains a detailed evaluation of the feasibility of the steam-electric cogeneration facility at the Monymusk mill which had been proposed by the BST assessment team in 1984. The feasibility study was conducted by a team provided by RONCO Consulting Corporation and Bechtel National, Inc.

Electric Power from Cane Residues in Thailand: A Technical and Economic Analysis, 140 pages, September 1986.

A team of specialists visited Thailand early in 1986 to investigate ways in which the sugar industry might improve its economic prospects by selling new products. The team concluded that the most attractive option would be the generation of electricity during the non-milling season using cane field residues (tops and leaves) as fuel. The report reviews a range of alternatives for power generation, from minor alterations of existing systems at five mills to two types of new power plants at sugar mills. (This report and the following three reports were prepared under an A.I.D. contract with the RONCO Consulting Corporation of Washington, D.C., and Kensington, California.)

The Sugar Industry in the Philippines: An Analysis of Crop Substitution and Market Diversification Opportunities, 103 pages, December 1986.

A team of specialists visited the Philippines in the late spring of 1986 to review opportunities for crop substitution and product diversification in the sugar industry. One of the major options for product diversification identified by the team was the production of electricity for the grid at sugar mills located on Luzon, using bagasse and field residues burned in more efficient boiler/generator systems. The report provides an introduction and overview of the potential for cane power systems in the Philippines, but does not include technical or economic analyses of systems at specific mills.

Cane Energy Symposium, Vol. I (Summary), 58 pages, Vol. II (Presented Papers), 86 pages, April 1987.

These volumes include the proceedings of the Cane Energy Utilization Symposium which was sponsored by the BST Project and the Hawaii Natural Energy Institute in Hawaii in April 1987. Vol. I summarizes presentations and field trips; Vol. II contains the complete texts of nine papers presented at the Symposium. Four of the papers provided detailed information on the collection and use of cane trash in Puerto Rico, the Dominican Republic, and the Philippines.

Trial Year Program Proposal, Nong Yai Sugar Mill, Thailand, 52 pages, August 1987.

This report contains a proposal developed by a team of specialists in the summer of 1987 in cooperation with the U.S.A.I.D. Mission in Bangkok, the Ministry of Industry, the Electric Generating Authority of Thailand (EGAT), and the management of the Nong Yai mill. The report recommended a trial-year program under which 3,750 kW of power would be generated using 100,800 tons of excess bagasse and 20,000 to 24,000 tons of cane trash. (BST sent equipment for cane trash harvesting to Thailand, and limited but successful tests were conducted at Nong Yai at the end of the 1988/89 milling season. Negotiations are under way for the two-phase implementation of the trial year proposal beginning in the 1989/90 season.)

Electricity and Ethanol Options in Southern Africa, 79 pages, September 1988.

A team sponsored by the BST project and the U.S. Trade and Development Program visited Malawi, Mauritius, Swaziland, Zimbabwe, and Zambia early in 1988 to make an initial assessment of opportunities for electricity and ethanol projects in the sugarcane industries of these countries. The report found attractive opportunities for one or two new power projects in Mauritius, for expanded ethanol production in Malawi, and for new ethanol production in Swaziland.

Electric Power from Sugarcane in Costa Rica: A Technical and Economic Analysis, 115 pages, July 1988.

This report presents the findings of a team of specialists that visited Costa Rica in May 1988. Using a computer model developed for sugar mill power investments, the team examined scenarios for several mills using varying assumptions as to the level of capital investment and power output. Net present value analysis showed that cane energy production could be attractive at several levels of investment. (This report was prepared under an A.I.D. contract with TEM Associates, Inc. of Emeryville, CA.)

Quarterly Reports On A.I.D. Cane/Energy Systems Assessment Program, Hawaiian Sugar Planters' Association, January, April, July, and October, 1988, January and April, 1989.

These reports and annexes review activities by the staff of the Experiment Station of the Hawaiian Sugar Planters' Association under an A.I.D. contract covering HSPA support of the BST cane energy assessment program. These activities include evaluation of cane residue recovery methods, review of cogeneration in the Hawaiian sugar industry, evaluation of bagasse drying and storing methods, and related consulting services and international institutional contacts.

NATIONAL ECONOMIC AND SOCIAL BENEFITS OF CANE POWER SYSTEMS

This section summarizes the economic and social benefits which a nation can derive from cane power systems.

1. Reduced Power Generation Costs

Each of the BST assessments has indicated that cane power systems could provide electric power at lower unit costs than most or all of the other power generation options available to the country.

The Monymusk feasibility study in Jamaica showed that the proposed cogeneration plant would produce electricity at lower cost than some of the units included in the Jamaican utility's least-cost capacity expansion plan. The cost of power per kWh for future capacity expansion was estimated at $0.066 for oil-fired steam plants, $0.083 for coal-fired steam plants, and $0.087 for oil-fired gas turbines used for peaking capacity. The Monymusk study indicated that the average cost of power from the cane energy plant would be about $0.063 per kWh.

BST's review of diversification options for the Philippine sugar industry indicated that sugar mills could provide power for the grid on the large island of Luzon at costs likely to be lower than the other options available to the National Power Corporation.

The BST team in Thailand found that the cost of power from new cane power plants ($0.028 to $0.032/kWh) would be well below the lowest likely total of avoided energy and capacity costs in oil-fired plants (about $0.050/kWh) and also lower than the cost of power generated in Thailand with imported coal ($0.044/kWh) or with domestic natural gas ($0.040/kWh).

Costa Rica's electric power agency (ICE) is under pressure to invest immediately in additional baseload capacity. The most attractive least-cost options, i.e., geothermal and hydroelectric projects, have long lead times. Current reliance on power generation with diesel engines and gas turbines is very expensive. A study for A.I.D. by RCG/Hagler, Bailly, Inc. indicated that up to 90 MW of power could be produced at financially attractive cane power plants in Costa Rica with power costs ranging from $0.020 to $0.045 per kWh. The BST team concluded that, in the short term, cane power investments are one of the least-cost options for the country and appear to be the only realistic indigenous fuel alternative in Costa Rica other than hydroelectric plants.

In a well-planned cane energy project, the savings in power generation costs would be shared between the sugar company, possibly a separate company building and operating the cane power plant, the electric utility, and the consumers of electric power.

2. Increased Profitability in the Sugarcane Industry

Sugarcane is grown in fifty-three A.I.D.-assisted developing countries. A healthy sugarcane industry is vital to the economies of many of these countries in terms of employment, income, infrastructure, and foreign exchange earnings. A cane power project can contribute on several levels to the increased viability and profitability of a major segment of the nation's sugar industry.

A profitable cane power project owned by a sugar company would contribute to the overall profitability of the company by providing an important new product (electricity) and source of revenue.

A cane power system can also increase profitability by reducing the company's expenditures for electricity and/or fuel oil. The Monymusk mill in Jamaica currently purchases power from the grid for irrigation pumping at $0.103/kWh, with a total annual cost of $1.26 million. The proposed cane power plant would produce this power at about $0.063/kWh, with an annual saving of nearly half a million dollars.

As a result of the proposed trial year program at Nong Yai in Thailand, the mill would avoid the purchase of 1.26 million kWh at $0.078/kWh and would save about $102,000.

The proposed burning of 50,000 tons of cane trash at the Central Azycarera de Tarlac (CAT) complex in the Philippines (which includes a refinery, distillery, and carbon dioxide and yeast plants) was expected to produce savings in fuel oil costs of about $600,000.

All cane power projects tend to protect present income from sugar production by increasing the overall viability and profitability of sugarcane production and processing. Some projects would increase profitability by increasing sugar production. The plan for the Monymusk cane power project was developed as a major component of a broader effort to rehabilitate and expand sugar production at Monymusk. The feasibility study indicated that the addition of a cane power plant owned by the sugar company would double the firm's profits in the 1990s; the highest levels of profitability would be reached if sugarcane production were expanded to 850,000 tonnes/year.

3. Increased Rural Employment and Personal Income

Cane power systems provide increased employment security for present mill and estate workers, create many new mill and field jobs, and provide additional sources of income for private farmers growing cane.

The Monymusk feasibility study indicated that the total project would create over 200 construction jobs, 100 jobs in irrigation improvement, 20 additional permanent jobs, and 200 seasonal jobs for the collection of cane trash.

The BST team in Costa Rica estimated that a new 10 MW cane power plant would generate about 10,000 days of annual employment with gross additional wages of $92,000 per year. Cane trash collection would add 200 days of work for each 1,000 tons of trash collected.

The proposed trial year program at Nong Yai in Thailand, which would include the harvesting and use of 20,000 to 24,000 tons of cane trash, would generate a total of 11,164 man days of additional employment including 4,760 days of unskilled labor and 6,404 days of skilled labor (drivers). Total labor costs for the trash utilization experiment were estimated at $34,739, exclusive of additional payments to farmers. In the Philippines CAT estimated that the harvesting of 50,000 tons of trash would generate additional labor income of $300,000.

Farmers producing cane for the mill on their own land would also receive payments for cane trash collected in their fields. The BST team in Costa Rica assumed payments of $1 per ton for trash collected from land not owned by the mill. The estimate of trash collection costs by the team in Thailand included payments to farmers of $1.15 per ton or about $11.50 per hectare. The Nong Yai plan for trash utilization included the payment of $2 per ton, adding $41,311 to the income of farmers.

4. Reduced Oil Imports

In most countries a cane power system reduces the nation's oil imports by generating with biofuels power that would otherwise have been generated in steam plants burning imported fuel oil or in diesel-powered plants. The extent of the petroleum savings depends on the size and type of cane power plant and on the percentage of its output that is generated with biofuels.

The BST team in Costa Rica estimated that burning excess bagasse in existing power plants at 15 sugar mills to produce power for the grid during the milling season would save fuel oil worth an average of $125,000 per mill or a total of $1.88 million per year.

Despite conservative assumptions regarding the percentage of power generated with biofuels, the team in Costa Rica estimated that the net annual petroleum savings from the operation of five new cane power plants would be $1 million per plant or a total of $5 million.

The relationship between supply of biofuels and use of fuel oil was clearly demonstrated by the Monymusk feasibility study in Jamaica. If cane production were only 600,000 tonnes/year, the new power plant would require 287,500 barrels of oil costing $4.3 million. If cane production rose to 742,050 tonnes, oil use would drop to 134,900 barrels costing $2 million. If cane production reached 850,000 tonnes/year, the power plant would need only 23,470 barrels of oil costing only $351,900.

5. Net Reduction in Foreign Currency Expenditures

Most cane power systems do not generate foreign exchange earnings. However, cane power plants reduce the nation's foreign currency expenditures by reducing the nation's use of imported fuel oil and/or diesel fuel.

The BST team in Costa Rica examined net foreign exchange savings (avoided petroleum imports minus imported capital) over twenty year project lifetimes for several types of cane projects; the savings ranged from $3 million to $35 million, depending on the size and type of plant.

In most countries the construction of a cane power plant would require major inputs of foreign capital, but the foreign currency component of the capital cost of the plant would be of about the same order of magnitude as for an oil-fired steam power plant built in the same country.

A few proposed projects (notably the proposed Monymusk plant in Jamaica) would also improve foreign exchange balances through the export of additional sugar and/or molasses or by reducing imports of these sweeteners.

EXPANDED USE OF CANE RESIDUES FOR POWER GENERATION

A.I.D.'s initial interest in cane power began with an examination of measures to increase the production of biofuels per acre or hectare of cane field through the use of cane varieties and cultivation techniques selected to maximize biomass production. This interest evolved in part from research between 1977 and 1983 on the production of high fiber "energy cane." Research projects in Puerto Rico, Louisiana, and Florida funded by the U.S. Departments of Energy and Agriculture demonstrated that the volume of biomass fuel produced per acre of cane field could be multiplied by the use of cane varieties and cultivation techniques which maximized overall growth rather than the sugar content of the cane stalk.

The initial BST cane energy assessment in 1984 analyzed the technical feasibility and economic attractiveness of this new approach to cane production as a means of revitalizing the sugar industry in Jamaica. The BST team proposed the gradual introduction of new sugarcane varieties as one element of a cane power project at the Monymusk sugar mill and estate in Jamaica. The team estimated that cane production on the 12,000 acre (4,856 ha) estate could ultimately increase from the present 23 tonnes/acre (57 tonnes/ha) to 65 tonnes/acre (160 tonnes/ha) by the tenth year of the project. While the concepts of increased power and sugar production were welcomed in Jamaica, it was noted that considerable time would be needed to identify high performance varieties suitable for use in Jamaica and to develop commercial-sized plantations of this cane.

In 1986 the feasibility study on the proposed cane power project at Monymusk de-emphasized the role of new cane varieties, while stressing the importance of increasing cane production per acre by about 50 percent. The concept of trading increased calorific value for a reduction in the sweetener value of the cane was not considered to be economic at the 1986 prices of energy (oil, electricity) and of sweeteners (sugar, molasses) in Jamaica. The study indicated that most of the needed cane production gains could be achieved by improved farming techniques such as better drainage, improved tillage, effective and timely irrigation, proper crop nutrition, a growth environment free of weeds and pests, and proper techniques for harvesting and transporting the crop. All of these techniques are important for the entire Jamaican sugar industry.

Although expanded biofuel production might be an appropriate feature of cane power systems in some countries in the future, the BST project has given priority to efforts to provide better utilization of biofuels that are already available. The cane energy assessments carried out under the BST project have concentrated on two major opportunities for expanding the use of cane residues for power generation:

a. The expanded and more efficient use of bagasse as a boiler fuel, to permit the generation of surplus power for the grid during the milling season and/or the generation of grid power during the non-milling season; and

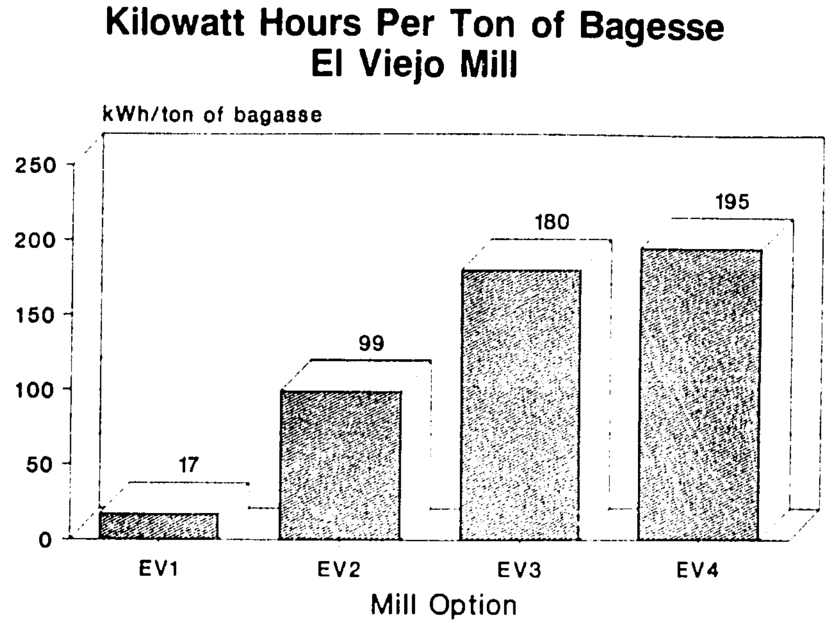
b. The recovery of cane field residues (tops and leaves) for use as a boiler fuel for power generation during the non-milling season.

1. Better Utilization of Bagasse

All cane power proposals rely heavily on the more complete and efficient utilization of sugarcane bagasse, the residue of the cane stalk after the juice has been extracted.

Most sugar mills in developing countries were designed to consume virtually all of the bagasse produced during the milling season, with little concern for efficiency in the combustion of bagasse or in the use of steam. The typical mill burns bagasse in low pressure boilers (200 to 300 psig, 13 to 20 bar) to produce steam for mill drives, process heat, and electricity generation. Electric power output is usually only 10 to 20 kWh per ton of cane processed, although 90 kWh/ton or more can be generated in efficient sugar mills with high pressure boilers. While most mills in developing countries generate enough power to meet mill and factory needs, quite a few mills must buy additional power from the grid or generate additional power with fossil fuels.

The amount of electric power which can be generated with each ton of bagasse depends primarily on the efficiency of the boiler and the turbogenerators. The chart on p. 6 shows expected outputs under four options for the El Viejo mill considered by the BST team in Costa Rica. Using a recently purchased medium-pressure boiler and an existing 1500 kW turbo-generator (EV 1), output would be only 17 kWh per ton. The installation of a new 3500 kW topping back pressure turbogenerator (EV 2) would increase output to 99 kWh/ton. Adding three 3750 kW condensing turbogenerators (EV 3)



Source: Report of BST Team, Costa Rica, 1988.

would raise output to 180 kWh/ton. A completely new power plant, including a new high-pressure boiler and a new double extraction condensing tubogenerator (EV4), would generate 195 kWh per ton of bagasse.

Through improvements in the efficiency of bagasse utilization during the milling season, a sugar mill can produce a considerable quantity of excess bagasse in addition to the quantity needed to produce steam for the operation of the mill and factory. Such a surplus of bagasse can result from improved boiler controls, other boiler modifications, more efficient turbogenerators, and/or the more efficient use of steam. Opportunities for conserving bagasse through the more efficient use of steam are indicated by a study in 1983 which showed that the average sugar factory in the Philippines required 1200 lbs of steam to process a ton of cane; efficient modern sugar factories use less than 950 lbs/ton.

A mill's ability to accumulate surplus bagasse depends in part on the extent of the down time during the milling season. Even if crushing stops, boilers must still be fed bagasse so that sugar processing can continue. Too much down time erode the accumulated supply of bagasse.

There are two options for the use of surplus bagasse to generate power for the grid: (a) It can be burned during the milling season to produce surplus power for sale to the grid. (b) It can be stored and used later to generate power during a part of the non-milling season.

Because of its high moisture content and residual sugar content, stored bagasse is subject to deterioration and possibly spontaneous combustion. The Sugar Industry Research Institute in Mauritius measured a 22 percent loss of dry matter in stored bales of bagasse. Experience with the storage of bagasse is not extensive, and the BST assessments have noted the need for the careful study and development of techniques for bagasse storage.

Baling the bagasse somewhat increases its bulk density and decreases space requirements for storage. At the 2,760 ton/day Constance sugar factory in Mauritius, a 40-year old American baler with a capacity of 5 tons/hr is used to bale wet bagasse so that it can be used as a boiler fuel at the beginning of the next milling season. Under one of the options considered by the BST team in Costa Rica, surplus bagasse from several mills would be transported to a central baling station and fed to a commercially-available baler with a capacity of 22 tonnes/hr. The baled bagasse would be shipped to the power plant and stored there until needed. The moisture content of the bales would decrease to about 20 percent after 90 days in storage.

Storage problems can be reduced by lowering the moisture content of the bagasse before baling. Research in Mauritius indicates that the deterioration of stored bagasse is substantially arrested if the bagasse has been dried to less than 25 percent moisture.

There is substantial experience in several countries with the drying of bagasse in flue gas dryers, but the dried bagasse has usually been burned immediately in boilers and has rarely been stored.

Sponsored by the BST project, the Hawaiian Sugar Planters' Association collected data on the use of flue gas dryers at four large mills in Hawaii. The dryers cost from $875,000 to $2.2 million and use from 10 to 40 percent of the flue gas from boilers producing from 200,000 to 300,000 lbs/hr (90,720 to 136,000 kg/hr) of high pressure steam. The bagasse is dried to a moisture content of around 40 percent. The drying of some of the bagasse is considered essential for maintaining the reliability of baseload power generation with bagasse in Hawaii.

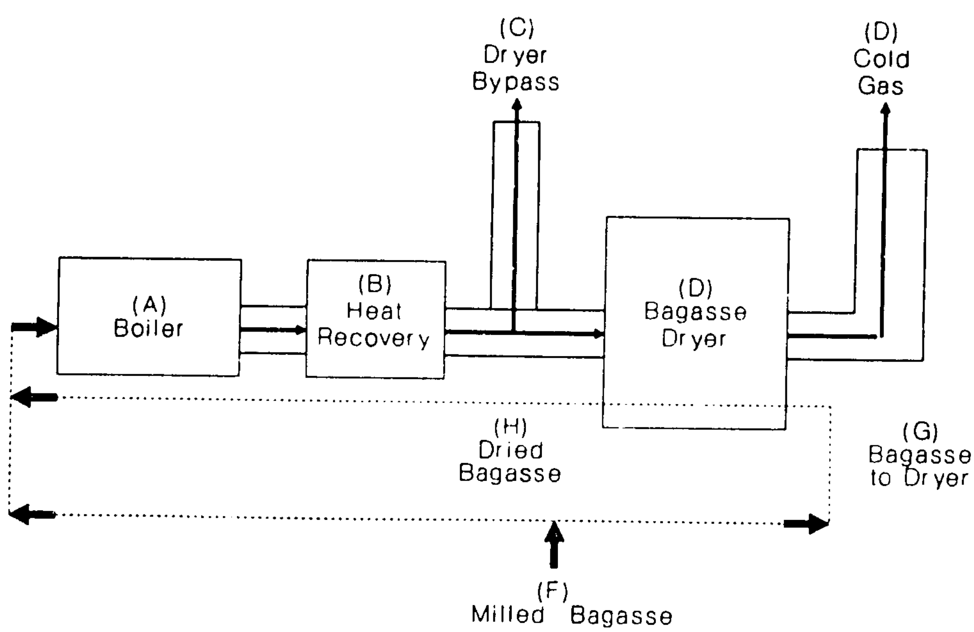
In three of the plants the HSPA found that the increased power output due to bagasse drying was twice as large as the power consumed by conveyors and fans in the dryer system. Since most sugar factories outside Hawaii have much higher flu gas temperatures (about 500° F, 198° C), the HSPA Experiment Station concluded that the potential energy and cost advantages of flue gas-drying would be substantially greater for sugar factories in developing countries than for those in Hawaii.

A typical system for bagasse drying with flue gas in Hawaii is shown below.

Bagasse has been dried to about 10 percent moisture in flue gas dryers as the first step in bagasse pelletization projects operated for several years at the Hamakua Haina mill in Hawaii and at the Beau Champ mill in Mauritius. The pelletization plant in Mauritius cost $5 million and was designed for an output of 14,000 tonnes/year. At both plants the pelletization process proved to be very expensive because of the need for frequent replacement of the extrusion dies; the productivity of both plants was limited by the inadequate supply of surplus bagasse. Both plants have now been closed.

A biochemical process for the drying of bagasse, known as the "Bagatex 20" system, has been developed at the Santa Lydia sugar factory in Sao Paulo, Brazil. A proprietary biochemical catalyst is sprayed on the bagasse as it enters the feed chute of the baler. The bales are stacked in a conditioning warehouse for a maturing period of 20 days, during which heat is generated by the fermentation of residual sugars in the bagasse. The moisture content of the bales reportedly declines to only 20 percent. A preliminary economic evaluation by the HSPA Experiment Station for the BST project indicated that, with 1988 prices of fuel oil and labor, investments in

Bagasse Flue/Gas Dryer System



Source: HSPA Quarterly Report, April 1988.

the Bagatex process in Brazil or Hawaii would not produce positive returns. The Bagatex system was considered by the BST team in Costa Rica for use in a cane power option at the Taboga mill (p. 19), but was found to be too expensive due to a very high initial licensing cost.

Effective measures to increase the supply of surplus bagasse and to facilitate the storage of the surplus would have a major favorable impact on the economics of year-round plants by reducing their use of imported fuel oil. Proposals for new cane power systems have usually assumed that fuel oil would be used during that part of the operating period when biofuels are not available. The BST team in Costa Rica showed that the returns from large investments for baseload power generation at new cane power plants would be much higher if the use of fuel oil were reduced through the utilization of surplus bagasse and/or cane trash. The team also indicated that the economics of larger investment options would be improved if low-cost imported coal was substituted for fuel oil.

Since 1984 a 21.7 MW year-round power plant burning bagasse and coal has been in operation at the 6600 ton/day Flacq United Estates Ltd. (FUEL) sugar factory in Mauritius. It has two 25 ton/hr boilers operating at 300 psig (20 bar) and one 110 ton/hr boiler operating at 600 psig (41 bar). The plant has become the principal baseload generating facility for the Central Electricity Board of Mauritius. Two new 10 to 20 MW bagasse/coal plants are included in the government and sugar industry action plans for the 1990s. A World Bank study indicated, however, that at mid-1986 prices for coal it would be economic to conserve bagasse at a number of sugar factories in Mauritius and substitute this bagasse for the coal now used at the FUEL plant in the non-milling season

2. Collection and Use of Cane Trash

The most innovative proposals for cane power systems are those in which cane field residues (tops and leaves) are collected, stored, and later burned as a boiler fuel for power generation in the non-milling season. The BST cane energy assessments in Jamaica, Thailand, and Costa Rica have included detailed analyses of the prospective use of these residues. The cane energy symposium sponsored by the BST project in Hawaii in 1987 included presentations on actual experience with the collection and use of these residues in Puerto Rico, the Dominican Republic, and the Philippines.

(a) Quantity of Recoverable Trash

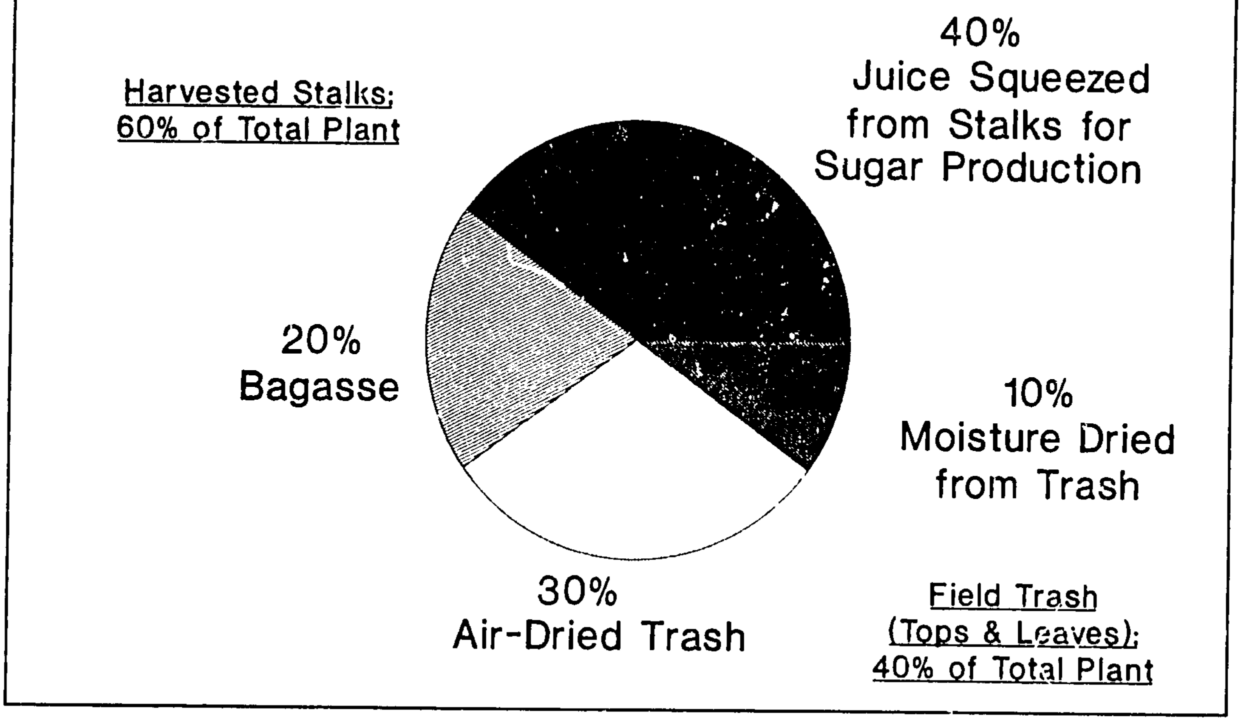
For each ton of cane stalks harvested by hand from unburned fields, about two-thirds of a ton of tops and leaves is left in the field. This field residue is called "barbojo" in Spanish-speaking countries and "cane trash" in English-speaking areas. The quantity of trash varies with plant varieties, climate and soil conditions, cultivation procedures, and harvesting practices.

In many regions the volume of trash is greatly reduced by burning the fields a day or two before the cane is harvested. Although a small fraction of the cane trash is used for animal feed in some countries, the only use of most unburned trash has been as a mulch and soil conditioner.

The agricultural benefits of a blanket of cane trash are widely recognized. These include retaining moisture in the upper level of soil (especially in areas subject to drought and/or having soils with low water-holding capacity), providing weed and erosion control, and enhancing soil fertility by the addition of organic matter. Experience in burned fields shows that these benefits can be obtained with only a fraction of the total volume of tops and leaves, but the size of the fraction which should be retained has not yet been clearly established. Experiments in Puerto Rico suggest that 30 to 50 percent of the cane trash is sufficient to maintain the organic content of the soil.

Studies on the agronomic impact of cane trash removal are being carried out in Jamaica and in Thailand; the research is being conducted for the BST project by the Experiment Station of the Hawaiian Sugar Planters' Association in cooperation with local agencies. Priority is being given to the effect on soil condition of the additional use of heavy equipment in the fields for trash recovery and baling. The increased traffic may increase soil compaction, reduce soil aeration and permeability, and increase soil erosion. Initial tests were conducted at Nong Yai in Thailand in March 1989; the soil was sandy and relatively dry. There were no significant differences in the bulk density of the soil in an area covered by a square baler loader, an area covered by a round baler and loader, and a control area with no residue collection. Additional tests are necessary to determine the impact on the soil of residue recovery in wet weather. Measurements will also be made of soil, aeration, porosity, strength, and permeability; these data will be compared with information on root distribution, cane growth, and yield. The agronomic impact studies will also examine the effects of residue recovery on plant nutrition, weeds, and insects.

Disposition of the Sugarcane Plant
(approximate fraction by weight, unburned cane)



Several other practical and technical factors limit the percentage of the cane trash which can be collected from a given field and/or the overall percentage of trash recovery from a given area. It may be impractical to collect trash from the fields of all the small farmers who deliver cane to a mill. The BST team in Costa Rica assumed that all of the trash to be used at the El Viejo mill would come from fields owned by the mill.

Experiments in Hawaii demonstrated that the percentage of trash which can be recovered with a given set of equipment is substantially lower in fields with furrows for irrigation or drainage than in flat fields. Equipment must be designed and adjusted to avoid the recovery of stones and dirt which would lower the calorific content of the fuel and increase boiler and ash handling problems. The maximum recovery rate in the Dominican Republic was 80 percent using hay rakes adjusted to a height which avoided the recovery of stones and dirt. Ash content tests by the HSPA Experiment Station in Hawaii in 1988 indicated that the problem of dirt recovery is most severe in furrow fields. Two samples of baled trash from furrow fields contained 21% and 29% ash, compared to only 7% for a trash sample collected by hand in the field. Trash baled from flat fields contained from 9 to 16% ash.

Due to present uncertainties concerning both the maximum technically feasible percentage and the agronomically acceptable percentage of trash recovery, the BST teams have used rather conservative estimates of trash recovery in their technical and economic analyses of cane power systems.

The base case scenario in the Monymusk feasibility study in Jamaica assumed that only 40 percent of the theoretically available cane trash would be recovered. The collection of 74,000 tonnes of trash per year would be concentrated in fields selected after consideration of crop cycle, field layout, variety, surface condition, and transport distances. In the best case scenario, 60 percent of the trash from an expanded Monymusk crop would be collected, with a total recovery of 127,500 tonnes per year.

The BST team in Thailand concluded that the collection of 50 percent of the available trash would be more than sufficient to sustain off-season power production at new cane power plants. The team in Costa Rica assumed, for purposes of the sensitivity analysis on trash utilization, that two-thirds of the available trash would be collected.

Since green trash loses up to 30 percent of its weight as it dries, the tonnage of field-dried trash recovered per hectare is only 20 to 30 percent of the tonnage of cane stalks harvested from the same fields. At the Central Romana estate in the Dominican Republic, about 12 tons of trash is collected from each hectare. The BST team in Costa Rica estimated that about 11 tons of trash would be recovered from each hectare of estate lands. In initial tests at Nong Yai in Thailand in March 1989, the residue measured in three fields was 5.5 tons/acre or 13.6 tons/ha; recoverable residue was estimated at 4 tons/acre or about 10 tons/ha. The current recovery rate at the Luisita plantation in the Philippines is 10 tons/hectare.

(b) Techniques of Trash Recovery and Storage

The BST project has funded a series of activities designed to increase the level of experience and information on cane trash recovery and storage. They have been coordinated and/or evaluated for BST by the Experiment Station of the Hawaiian Sugar Planters' Association in cooperation with appropriate local agencies.

These BST-funded activities included (a) brief tests of a commercially-available baler with cane trash in Hawaii in late 1987, followed by tests of the storage of the baled trash; (b) development by CAMECO, a cane equipment manufacturer in Thibodaux, Louisiana, of a three-unit cane residue recovery system including a cane trash rake, a self-propelled trash loader/baler, and a bale handler; (c) testing of the CAMECO system in Texas in 1988 and in Jamaica in 1989; and (d) testing of commercially-available equipment in Hawaii in 1988 and in Thailand early in 1989. Additional information on these trash recovery and storage activities will be provided in the following sections.

Trash Raking

Four to six days after the unburned cane has been harvested the trash is raked into windrows. The windrowing is necessary to facilitate subsequent pickup of the trash by the baler, but it also facilitates drying. Although the cane trash could be raked by hand, all of the present and proposed trash recovery systems use commercially-available hay rakes (or modifications thereof) which are powered and pulled by tractors.

An Allen twin rake-windrower with an adjustable swath width of 6 to 15 feet was used to gather trash for a bale storage test in Hawaii in 1987/88. Several 9 foot swath John Deere Model 650 hay rakes are used at the Central Romana plantation in the Dominican Republic.

A Ford New Holland Model 258 straight bar hay rake was tested with cane trash in Hawaii in 1988 and in Thailand in early 1989. The rake requires 30 to 50 HP of power from the tractor hydraulics. It covers a 9.5 foot swath and operates at a speed of 2 to 7 miles per hour. The unit can be used with both square and round balers. In Hawaii the production rate was 1.3 acres/hr in flat fields and .6 acres/hr for furrow fields. Residue recovery was 70 percent in the flat fields and 49 percent in furrow fields.

The CAMECO cane residue recovery system includes a custom-designed wheel rake; hydraulically-powered wheels are mounted on the front of a CAMECO Model SP 1800 loader. The wheels cover a swath of about 8 feet. Although designed to float over alternating irrigation furrows and raised cane beds, the initial windrowing disks were too inflexible. Spring tooth tines were attached to the periphery of the wheels by CAMECO prior to shipping the equipment to Jamaica for further tests.

Trash Baling

Most of the actual or proposed trash recovery systems use standard or modified versions of commercially-available hay balers producing square or rectangular bales tied with twine. The use of twine, rather than wire, permits the tying material to be burned in the boiler with the fuel.

A Ford New Holland Model 505 hay baler was tested with cane trash by the HSPA in Hawaii in late 1987. The bales weighed about 120 lbs (54 kg); the average density of the bales was 15.3 lbs/ft^3 (245 kg/m^3).

Square bales weighing 40 to 75 lbs (18 to 34 kg) are produced by a Ford New Holland Model 326 square baler which was tested by HSPA in Hawaii in the summer of 1988 and at Nong Yai in Thailand early in 1989. The baler is operated with a power takeoff from the tractor, and requires 60 to 80 HP. In Hawaii the baler covered .5 acres/hour (.23 ha/hr) in a flat field and .3 acres hr/(.12 ha/hr) in a furrow field; in one test in Thailand the unit covered .4 acres/hr (.16 ha/hr) in a furrow field.

Approximately 20,000 tonnes of cane trash have been baled annually during the past two seasons at the CAT Luisita plantation in the Philippines, using six Ford New Holland balers and two CLASS balers. The bales are quite small, measuring about 14 x 18 x 20 inches (35 x 45 x 50 cm) and weighing about 15 lbs (7 kg).

The self-propelled baler used in the CAMECO cane residue recovery system is a customized version of the Ford New Holland Model 2000 hay baler. The baler is powered by a 165 HP Caterpillar diesel engine. Overall dimensions are about 13' (4m) by 26' (8m); the unit weighs about 12.5 tons. The pickup mechanism on the front end of the baler has been redesigned by CAMECO for maximum recovery of cane trash.

The baler produces large rectangular bales which are 4' (1.22m) wide and 3' (.91m) high; the length of the bale can be varied from 4.5' (1.28m) to 7.5' (2.3m). In tests in Texas the average bale weighed 554 lbs (251 kg). In preliminary tests in Jamaica a 4.5' long bale weighed 374 lbs (169 kg). In the tests in Texas the baler operated at the rate of 9.2 tons/hr and recovered 4.8 to 5.9 tons of trash per acre (11.8 to 14.5 tons/hectare). Further tests of the CAMECO system were conducted in the spring of 1989 at the Bernard Lodge Sugar Estate in Jamaica.

Cane trash can also be used in balers producing large round bales. A typical round bale is 6 feet (1.85 m) in diameter. A Ford New Holland Model 853 round baler was tested by HSPA in Hawaii in 1988 and in Thailand in early 1989. This baler is also operated with the power takeoff from the tractor, and requires 45 to 65 HP. An alarm alerts the operator when it is time to eject the bale, which can weigh up to 1,200 lbs (544 kg).

In initial tests in Hawaii there were repeated difficulties in forming the core of the large round bales, perhaps because of the high percentage of cane stalks left in the trash by mechanical harvesting. The baler covered .4 acres/hr (.16 ha/hr) on flat fields. In Thailand there were few cane stalks in the trash and no problems were encountered in starting the bale core. In one furrow field the baler covered about 1 acre/hr; the residue recovery rate varied with field conditions, especially the depth of the furrows which ranged from 5 to 10 inches (13 to 25 cm).

Handling and Storage of Baled Trash

In the tests at Nong Yai in Thailand, the relatively small square bales were manually loaded and stacked. A mechanical loader is required for handling larger bales.

The CAMECO system uses a modified version of the CAMECO Model SP 1800 grab loader; the regular grapple is replaced with a rigid grab with horizontal slats. The loader can stack four layers of bales in 12 foot high stacks.

If round balers are used, the heavy bales must be handled with a front-end loader equipped with a special round-bale attachment. A Farm Hand Model 190 loader with bucket and spear attachments, mounted on a 50 to 90 HP tractor, was used for large bales in the tests in Hawaii and Thailand.

Due to the large volume of the baled residues, the BST teams in Thailand and Costa Rica assumed that the bales would be stored at outdoor storage sites near the cane fields until needed as boiler fuel. This practice would minimize storage requirements at the power plant and permit transportation of the bales to the plant in the non-milling season in the same trucks used to haul cane to the mill in the milling season. Round bales will shed water, but it is necessary to cover rectangular bales with plastic to reduce absorption of moisture during wet weather.

Tests of the storage of baled trash were conducted by HSPA in Hawaii for A.I.D. in 1987/88. The rectangular bales weighed about 120 lbs (55 kg). Bales stored in the open which had dried to 20 percent moisture during the very dry initial 100 days were found to contain 7[illegible] percent moisture after heavy rainfall during the remainder of the 165 day test period. The fuel value of the bales had climbed to 5077 BTU/lb (2821 kcal/kg) during the first 100 days, but dropped to only 1656 BTU/lb (920 kcal/kg) at the end of the test period. The ash content of the uncovered residues increased from about 10 percent to 13 percent during the total storage period, indicating some microbial decomposition of the trash which also contributed to the drop in fuel value. Covered bales dried to 13 percent moisture and 5344 BTU/lb (2969 kcal/kg) in the dry season; during the rainy season the moisture content of these bales increased to 33 percent and the fuel value dropped to 4037 BTU/lb (2243 kcal/kg).

Tests of cane trash baled in Hawaii in July 1988 have confirmed that round bales retain their fuel value during storage much better than square bales. During the dry fall months the large round bales dried more completely (to 11% moisture when covered, 18% when uncovered) and the increase in moisture content during the heavy December rains (to 26% when uncovered, 30% when covered) was much less than in the square bales. The square bales contained more moisture in October (19% covered, 27% uncovered) and the moisture increased during the rainy season to 65% in covered bales and 79% in uncovered bales.

HSPA reported that by January there was noticeable fungal growth in the square bales. Due to deterioration of the twines, the bales could no longer be lifted by the twines. Deterioration of the fuel was confirmed by tests showing that the ash content had increased from below 12% in October to about 16% in January. Due to increased moisture and degradation of the biomass, the heating value of the fuel dropped sharply. Between October and January the heating value dropped from 5,763 to 2,284 BTU/lb (3,202 to 1,269 kcal/kg) in covered bales and from 5,033 to 1,238 BTU/lb (2,796 to 687 kcal/kg) in uncovered bales.

Storage tests are being conducted with trash baled at Nong Yai in Thailand early in 1989, and additional tests are planned with trash baled at the Bernard Lodge Estate in Jamaica.

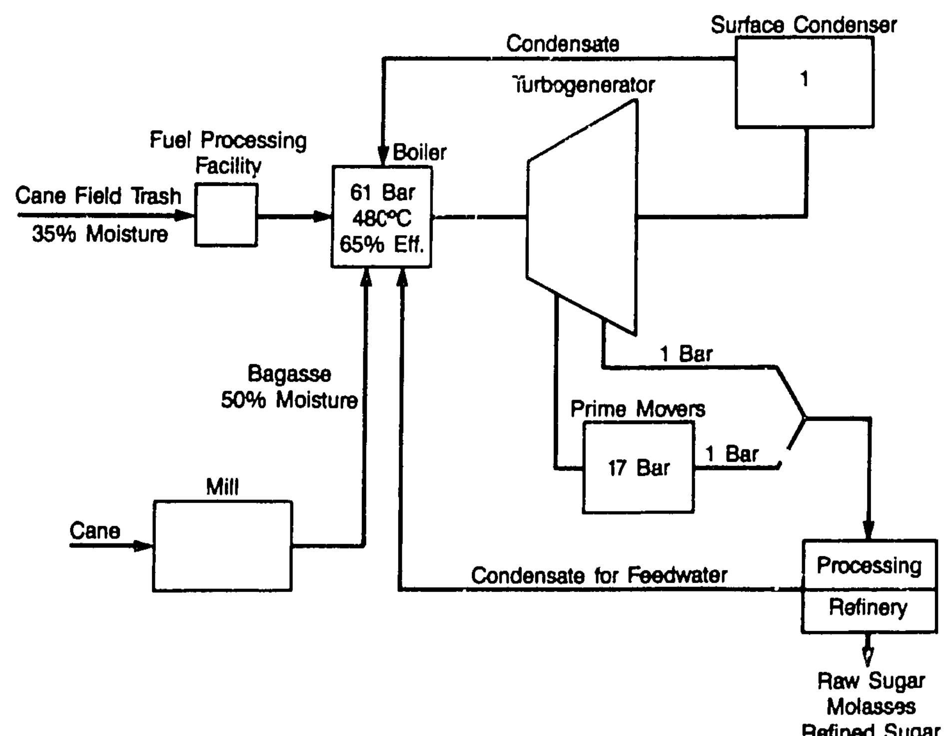
(c) Costs of Trash Recovery

All of the cane power proposals with trash utilization include substantial capital costs for the equipment needed to rake, collect, bale, transport, and prepare the trash. Comparison of these costs is complicated by variations in methodology. Some estimates include the rental of tractors, while others provide for the purchase of tractors. In some cases equipment costs are budgeted on a per day or per ton basis with the cost of the operator included.

The BST proposal for the collection of 20,000 to 24,000 tons of trash at the Nong Yai mill in Thailand contained estimated capital costs for trash collection totaling $149,618, including six hay rakes, four round balers, two twine balers, and six bale-handling attachments for front-end loaders. Estimated capital costs for the harvesting of much larger quantities of cane trash at four existing Thai mills and two proposed new plants ranged from $604,000 to $1,534,000. The Monymusk feasibility study in Jamaica included capital costs for trash collection and handling ranging from $1.2 million for 74,000 tonnes/year to $1.5 million for 127,500 tonnes/year. These estimates include the purchase of tractors, rakes, balers, trailers, loaders, cranes, roofing for storage areas, and a large shredder.

Estimates of the cost per ton of cane trash collection and preparation can be based on the actual experience with trash recovery in several countries and on detailed cost estimates prepared by BST teams in several other countries. These unit cost figures reflect wide variations in collection and handling techniques, scale of trash collection, type of transport, labor costs, and the

Mill with New Power Plant



Source: Report of BST Team, Thailand. 1986.

extent to which fuel preparation costs are included in the calculations. Moreover, the relative costs from country to country, stated here in U.S. dollars, may have been somewhat distorted by fluctuations in exchange rates.

At the Central Romana mill in the Dominican Republic, the collected trash is chopped rather than baled. It is brought to a rail line in ox-drawn carts and transported by rail directly to the mill for immediate use. The costs of this form of trash collection (which includes no baling or motor transport) were $7.10 per tonne exclusive of rail transport costs in 1987, in an operation recovering 25,700 tonnes per year. In the same year Central Azycarera de Tarlac (CAT) in the Philippines prepared an estimate which was based on experience gained in a large trash collection experiment in 1983-84. The cost of collecting, baling, and transporting 50,000 tons of trash was estimated at about $18 per ton.

The Monymusk feasibility study in Jamaica estimated that the cost of 74,000 tonnes of trash per year would be $10.44 per tonne; if 127,500 tonnes of trash were recovered annually, the unit cost would drop to $8.47/tonne. The BST team in Costa Rica calculated that delivering 33,000 tons of trash per year to the El Viejo mill would cost about $11.80/tonne. The BST proposal for a trial year program at the Nong Yai mill in Thailand included an estimate that collecting 20,000 to 24,000 tons of trash per year would cost about $16/ton. These figures indicate that there can be substantial economies of scale in trash collection systems.

(d) Use of Cane Trash as a Boiler Fuel

The use of cane trash in a new power plant with a high-pressure boiler is shown in the sketch on p. 12. Equipment is usually needed at the power plant to open the bales of trash and to shred the trash so that is can be fed to the boiler by the same fuel feeders which are used for bagasse.

The BST team in Thailand indicated that trash utilization in existing mill power plants would require a bale processor/separator costing $8,500 and either a 10 to 15 ton/hour shredder costing $15,000 or a 25 to 30 ton/hour shredder costing $29,000. The trial year proposal at Nong Yai in Thailand included the installation of a tub grinder (shredder) costing $102,000. The feasibility study for the larger Monymusk project in Jamaica assumed the installation of a large shredder at an estimated cost of $250,000.

Shredders have been developed and built at the CAT Luisita plantation and factory in the Philippines to open small bales of cane trash. The latest model has a hammermill design with four hammers, each weighing 37 lbs (17kg). Two of the shredders have been used to process over a million small bales in the 1988/89 season.

Boilers in sugar mills have been designed to burn bagasse, which usually has a moisture content of at least 50 percent and a calorific value of around 4,000 BTU/lb (2222 kcal/kg). Air-dried cane trash has a higher calorific value, depending on moisture content and ash content. The percentage of ash depends on the amount of dirt recovered with the cane trash. Selected data on the fuel value of air-dried cane trash and of baled trash are provided on the accompanying chart on p. 14.

The higher calorific values of dried cane trash compared to bagasse can be mixed blessing. On the one hand, burning trash with 25 percent moisture significantly increases the heat release rate in the boiler, reduces excess air requirements, and improves boiler performance. On the other hand, the resulting higher furnace and exhaust gas temperatures may require modifications in equipment and/or operating procedures. In traditional boilers, the equipment most affected by higher temperatures are the refractories and the grate. High temperature refractories can be installed at low cost, but modifications in grates are much more expensive. The extent of the necessary modifications must be determined individually for each boiler.

In some situations it may be feasible to control furnace temperatures by burning a mixture of dry cane trash and bagasse. A mixture of two-thirds bagasse (51 percent moisture) and one-third cane trash (14 percent moisture) is used at the CAT Luisita mill in the Philippines. Cane trash mixed with bagasse and wood chips was burned in tests at an ethanol plant in Jamaica in 1988.

The amount of electric power which can be generated from each ton of trash depends primarily on the efficiency of the boiler/turbine system and on the moisture content of the fuel. The BST team in Thailand estimated that trash burned in existing low-pressure boilers at sugar mills would produce 180 kWh/ton if the moisture content was 35 percent and 245 kWh/ton with 25 percent moisture. If the trash is burned in efficient high-pressure boilers, the output would be tripled; the output in new power plants was estimated at around 575 kWh/ton with 35 percent moisture and about 750 kWh/ton with 25 percent moisture.

FUEL VALUES OF CANE FIELD TRASH

(Initial data = BTU/lb; data in ( ) = Kcal/kg)

Source of Data	Approximate Moisture Content 35%	30%	25%	20%	Oven Dried
Air-Dried Trash Before Storage:					
BST Team	4337	--	5147	--	--
Thailand	(2410)	--	(2860)	--	--
BST Team	5000	--	6400	--	--
Jamaica	(2778)	--	(3000)	--	--
BST Team	--	--	6053	--	--
Costa Rica	--	--	(3363)	--	--
Central Romana	--	6128	--	--	7640
Dominican Republic	--	(2850)	--	--	(4180)
CAT Luisita	--	5040	--	--	--
Philippines	--	(2800)	--	--	--
Baled Trash: (Selected data from HSPA, Hawaii)					
Small Square Bales:					
Before Storage	--	--	--	4934	--
1987	--	--		(2741)	--
Before Storage,	3954	--	--	--	6200
1988	(2197)	--	--	--	(3445)
Uncovered	--	--	--	5078	--
3 Months, 1987	--	--	--	(2821)	--
Covered	--	--	--	5763	7171
3 Months, 1988				(3202)	(3984)
Large Round Bales:					
Before Storage,	--	--	--	5150	6347
1988	--	--	--	(2861)	(3527)
Uncovered,	--	--	--	5718	6974
3 Months, 1988	--	--	--	(3177)	(3875)
Uncovered	--	--	5128	--	6941
6 Months, 1988	--	--	(2849)	--	(3857)
Covered	--	4657	--	--	6653
6 Months, 1988	--	(2587)	--	--	(3697)

FACTORS INFLUENCING THE FINANCIAL ATTRACTIVENESS OF CANE POWER SYSTEMS

The BST assessments in Jamaica, Thailand, and Costa Rica identified a number of potential cane power projects which would be attractive, least-cost options for power generation under relatively favorable conditions. The keys to the financial viability of these projects include setting fair prices for the purchase of electricity by utilities, minimizing capital costs and interest payments, obtaining full capital utilization by maximizing the annual output and sale of power, and reducing fuel costs in the non-milling season.

1. Price of Electricity Sold To The Grid

The financial attractiveness of a cane power system is highly dependent on the price at which power is sold to the electric utility. There is very little experience, legislation, or procedure in developing countries applicable to the purchase of power by utilities from private companies. The BST assessments have stressed that the development of viable cane power systems will require carefully developed agreements between the utilities and the sugar industry, so that the potential benefits of these systems can be equitably shared.

The price paid by the utility may reflect two types of costs avoided by the utility as a result of the purchase of the power: (a) At the minimum, the price should reflect avoided energy costs (i.e., the price per kWh which the utility currently pays for fuel). If the cane power system provides only surplus power, the price the utility will be willing to pay should be close to the avoided energy cost. (b) If the cane power system can reliably provide substantial baseload capacity or substantial power at periods of peak demand, the utility may be able to avoid investments in additional baseload or peakload generating capacity. In such cases, the price paid for the power by the utility should reflect these avoided capacity costs as well as the avoided energy costs. By making a commitment to supply baseload power, sugar mills in Hawaii were able to attract higher payments from utilities than they received earlier for the sale of surplus power.

The economic impact of variations in electricity prices depends on the type of cane energy project. The BST team in Thailand found that lower power prices had less of a negative impact on the expected returns from large investments in efficient new power plants than on much smaller investments in systems utilizing existing boilers and generators. In contrast, a sensitivity analysis by the BST team in Costa Rica showed that three medium- and high-investment options using fuel oil during most of the 6-month non-milling season would lose money if power prices were low, but could be profitable investments with high power prices that include capacity payments.

2. Levels of Capital Costs and Interest Rates

The costs of equipment and money are primary factors determining the viability of investments in new cane power plants. The expected rate of return from a 35 MW power plant in Thailand costing about $666 per kW was twice that from a plant of the same size in Jamaica costing about $1,371/kW. A 33 percent reduction in the cost of the plant in Thailand reduced the cost of power by 18 percent. The BST team in Thailand found, however, that efficient new plants were far less sensitive to variations in capital costs than smaller cane power investments to expand the use of existing mill power plants.

The BST team in Costa Rica noted that the rate charged for loans is the key to the ability of sugar mills to invest in baseload power production for the grid. The base case scenario assumed a moderate concessional rate of 11 percent. The team's sensitivity analysis showed that three principal cane power options would be unprofitable if loan rates for the full capital investment ($10 to $20 million) were those presently charged by national banks (26 percent) or by private banks (31 percent). At a proposed new plant in Thailand, a reduction of the interest rate from the base case assumption (15 percent) to 10 percent resulted in a 13 percent reduction in the unit cost of power.

3. Seasonal Patterns of Cane Milling

The financial attractiveness of a cane power system is substantially influenced by (a) the length of the cane milling season at the specific mill, (b) the number of annual days in which power is sold to the grid, (c) the total period in which power must be produced with fossil fuels, and (d) the utility dispatch factor (the percentage of the generated power which is actually dispatched to the grid).

The length of the milling season varies considerably from mill to mill and country to country depending on climatic factors, the supply of cane available to the mill, and the size and efficiency of the mill. The extent of the season determines (a) the period in which the cane power plant can operate with the least expensive fuel (bagasse); (b) the period in which cane trash can be collected for use as a fuel in the non-milling season; and (c) the number of days in which power must be generated with fuels other than bagasse (i.e., cane trash or fossil fuels).

In any power plant, the cost of power per kWh will be significantly reduced if the fixed capital costs can be spread over a larger annual output. Achieving a large annual output requires operation for the maximum possible number of days each year. Large investments in efficient high-pressure power plants will rarely be justified unless the plants can operate virtually year-round.

Data from several BST teams support the general conclusion that new cane power plants are most economically viable and profitable at mills with comparatively long milling seasons (150 to 200 days). Such plants can maximize the use of biofuels and minimize the use of fossil fuels. However, the team in Thailand indicated that new plants can also be profitable at mills with short milling seasons if a sufficient supply of cane trash fuel can be collected for use in the non-milling season.

4. Cost of Cane Trash Fuel

Due to the wider utilization of equipment for harvesting, transporting, and preparing the cane trash, the cost of this fuel per ton tends to drop as the total quantity of recovered trash increases. The significance of the delivered cost of trash at the mill depends on the type of cane power system. The BST team in Thailand noted that in projects involving small investments to permit the burning of cane trash in existing mill power plants, the cost of the trash fuel is the most important cost component for producing electricity. On the other hand, the sensitivity analysis by the BST team in Costa Rica showed that net present values of proposed investments in new cane power plants are relatively inelastic to trash price increases, since these fuel costs are a small fraction of the total cost of such projects. Similarly, the Monymusk feasibility study in Jamaica indicated that a 50 percent increase in the cost of providing cane trash to the power plant would result in only a 2.5 percent increase in the cost of power per kWh.

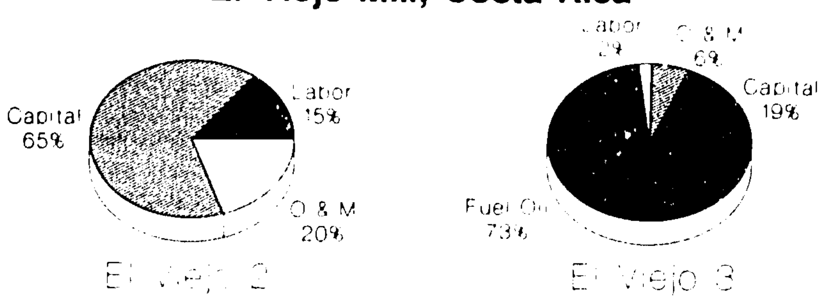
5. Cost of Fossil Fuels

The financial attractiveness of those systems that use fuel oil or coal for substantial portions of the non-milling season is very dependent on the delivered price of these fossil fuels.

The significance of the cost of fossil fuels in such plants is dramatized in the chart below comparing annual power costs under two options for the El Viejo mill considered by the BST team in Costa Rica. Under Option EV 2 the mill would produce power only with bagasse and mainly during the milling season; although the investment would be relatively small ($1.5 million), two-thirds of the power costs would be capital costs. Under Option EV 3 three new turbogenerators would be installed and the plant would operate all year, burning fuel oil during most of the non-milling season; although this investment would be much larger ($9.6 million), three-quarters of the total power costs would be fuel costs.

The BST team in Costa Rica found that all of the cane power options it considered were profitable with oil prices around $14 per barrel. All options except a completely new power plant at El Viejo (p. 19) were profitable at a constant price of $18 per barrel assuming concessional financing. None of the proposed investments in new power plants would be profitable in the event that oil prices increased at or over 2 percent per year over the life of the project. The net present values of investments in new power plants would be substantially higher if wood or low-cost imported coal were substituted for the fuel oil burned in the non-milling season.

Annual Cane Power Costs
El Viejo Mill, Costa Rica



Source: Report of BST Team, Costa Rica, 1988

FINANCIAL EVALUATION OF INVESTMENT OPTIONS

The BST assessments in Thailand and Costa Rica included the comparative analysis of several levels and types of investments for the production of surplus or baseload power for the grid at sugar mills. The Monymusk feasibility study in Jamaica provided a detailed analysis of one level of investment involving the construction of a new power plant. The results of these evaluations are summarized in the following sections.

1. Minimum or Moderate Investments to Produce Surplus Power for the Grid During the Milling Season

Some sugar mills that have relatively efficient boiler and turbine systems can produce more power than is needed in the mill and factory during the milling season and can sell the surplus power to utility companies. For example, the sugar industry supplied 72 million kWh to the national grid in Mauritius during the milling season in 1986. The financial investments required are typically minimal, consisting mainly of improved boiler controls and necessary electrical interconnection equipment.

The BST teams in Thailand and Costa Rica identified a number of opportunities for the sale of surplus power to the grid during the milling season without major changes in the boiler/turbine systems. A preliminary analysis by the team in Thailand suggested that 6.3 million kWh could be generated at four mills by burning excess bagasse during the milling season. However, the team suggested that it may be preferable to store the excess bagasse and burn it along with cane trash for power generation during the long non-milling season.

The team in Costa Rica concluded that with minimal investment and little or no risk Costa Rica's sugar industry could produce 17 to 19 million kWh for sale to the grid during each milling season (December to April). Additional generating capacity is needed in this dry season due to the reduction in output by hydroelectric plants. These investments would be highly profitable. Using the team's base case assumptions, the net present values of the projected minimal investments required at two mills were $.82 million and $1.1 million respectively.

In a few cases, dramatic increases in power output during the milling season can be achieved with a moderate level of investment. The BST team in Costa Rica examined the addition of a new 3500 kW topping backpressure turbogenerator at the 3,000 ton/day El Viejo mill, which recently purchased a new 200,000 lb/hour medium-pressure boiler which will operate at 455 psig (40 bar) and 660° F (349° C). The $1.5 million investment would enable the mill to oroduce 9.6 million kW in 121 days in the milling season, a fivefold increase over the power which could be exported without the new generator. The net present value of this investment was estimated at $2.96 million, the highest of any option examined by the team other than those involving the harvesting and use of cane trash.

The El Viejo mill is currently taking steps to implement this BST proposal. The mill has applied to a local bank for financing for the new turbogenerator and will negotiate a power sales contract with the Costa Rican electric utility (ICE) after completion of a test period of power sales described in the section below.

2. Moderate Investments for Power Production in the Non-Milling Season With Stored Bagasse and/or Cane Trash

A relatively efficient boiler/turbine system at a sugar mill can also be used without major modifications to produce power in the non-milling season using stored surplus bagasse and/or cane trash. In some mill situations power can be produced during a part of the non-milling season using only stored surplus bagasse.

In mid-April 1989, at the end of the milling season, the El Viejo mill in Costa Rica began producing about 900 kW of power for sale to the utility using surplus bagasse accumulated during the milling season. This sale of power is the first on an extended, commercial basis by a major sugar company in Central America. The agreement with the utility calls for the best efforts of the mill to maximize power output but provides no guaranteed level of power production; the utility is paying $0.039/kWh for this "surplus" power. Following the projected installation of a new turbogenerator as indicated above, all of the bagasse produced at the El Viejo will be burned during the milling season.

The most important options for power production during the non-milling season involve the harvesting and use of cane trash. The necessary investment in equipment to harvest, transport, and prepare the trash has been reviewed on page 12 above.

The BST team in Thailand examined the attractiveness of the minimum investments needed at five Thai mills to permit the harvesting of cane trash and the use of the trash for power generation in the off season.

Under the team's base case assumptions, net present values were positive for all of the investments except the one involving the smallest power output (2.5 MW). The other four proposed projects involved investments for cane trash collection ranging from $604,000 to $1,534,000 and for power plant modifications ranging from $400,000 to $512,000. The level of total investment was roughly proportional to the expected power output (9.6 MW, 12 MW, 17.5 MW, and 24 MW).

Using the base case assumptions, the cost of power from the four plants ranged from $0.037 to $0.045 per kWh, well below the Thai utility's transfer price. Internal rates of return ranged from .59 to 1.25 percent; payback periods were from .77 to 1.44 years.

The team found that these moderate investments were more vulnerable to negative changes in key variables than larger investments in new power plants. In the team's worst case scenario only one of the proposed investments at existing plants showed positive net present values, although new cane power plants could still produce electricity at competitive rates under the worst case assumptions.

An experiment with off-season power generation at the Nong Yai mill in Thailand was proposed in 1987. The mill's present power plant would generate 4 MW in a 210-day off season period using 100,800 tons of excess and purchased bagasse and 20,000 to 24,000 tons of cane trash. Improved boiler controls would increase the efficiency of the existing 120 tonne/hour boiler using bagasse from about 55 percent to 65 percent. Total investment for trash harvesting and preparation equipment, electrical equipment, and boiler controls would be $350,550. The plant would sell 18.9 million kWh of power at $0.044/kWh; income from power sales and savings from avoided power purchases at $0.081/kWh would total about $933,000 in the trial year. Total annual capital and operating costs were estimated at $843,410. The capital payback period would be about 4.25 years.

3. <u>New Plants For All-Year Power Production Using Bagasse, Cane Trash, and/or Oil</u>

Several BST assessments have examined the economic feasibility of building new high pressure power plants at sugar mills to produce power for the grid in both milling and non-milling seasons as well as steam and power for the mill and sugar factory. The primary rationale for these larger investments is to achieve the much higher power outputs per ton of bagasse or trash which are obtainable only with high-pressure boilers and turbines (See p. 6).

Following the initial BST cane energy assessment in Jamaica in 1984-85, a detailed feasibility study was made in 1986 on the installation of a large new cogeneration plant at the 4,000 ton/day Monymusk mill. The study assumed that the new power plant would consist of (a) two 165,000 lb/hour (75,000 kg/hr) spreader-stoker boilers operating at 900 psig (61 bar) and 900° F (480° C) and equipped to burn bagasse, cane trash, mixtures of cane trash and bagasse, or fuel oil; and (b) a single condensing-type turbine with automatic extraction at 200 psig (14 bar). The capital cost of the cogeneration plant, spread over a five-year period, was estimated at $47.7 million.

During the long (35-week) milling season, the power plant would operate at full load of 35 MW for 208 days and at half load (due to the use of only one boiler) for 30 additional days. In this season it would produce 21 MW of electric power for sale and 190,000 lbs/hour (86,200 kg/hr) of process steam which would be used in the crushing plant and boiling house. During the short non-milling season the plant would operate at full load for 65 days, producing 34 MW of gross power, and at half load for 10 additional days.

The pattern of fuel use by the power plant would depend on total cane production in the Monymusk area. The study's base case assumed cane production of 742,050 tonnes/year, although achieving this level would require an additional investment of $10 million in agricultural improvements. At this level of cane production about half of the total annual heat input for the power plant would be provided by 203,300 tonnes of bagasse, with 24 percent provided by 74,000 tonnes of cane trash and 25 percent provided by 134,900 barrels of No. 6 fuel oil.

The financial analysis indicated that the rate of return on the investments in the Monymusk power plant and related agricultural improvements would range from 16 to 20 percent depending on the level of cane production achieved at Monymusk.

BST's assessment of power from cane residues in Thailand included an analysis of two types of new power plants at a 10,000 ton/day sugar mill. Both plants would burn bagasse during a rather short (100-day) milling season and would burn cane trash during most of the long non-milling season. These proposals involved the most extensive use of cane trash (in terms of percentage of annual fuel utilization) included in any of the BST assessments.

Option A assumed that the new power plant would provide all of the steam and power needed by the large mill and sugar factory. The power plant would consist of two 250,000 lb/hour boilers or one 500,000 lb/hr unit, plus a 35 MW double extraction/condensing turbogenerator. Inlet pressure would be 850 psig (58 bar) at 900°F (480°C). The plant would sell 27 MW during the milling season and 34 MW during 240 days of the non-milling season. Total investment would be $21.5 million or $614/kW, which is less than the Thai utility's current capacity costs. Operation of this proposed plant is shown in the sketch on p. 12.

Option B assumed that the mill's existing boilers would be used in the milling season to provide steam for mill turbines. The new power plant would consist of a 275,000 lb/hour boiler and a new 25 MW single extraction/condensing turbogenerator. Exhaust steam from the turbine would be used for process heat in the sugar factory. About 17 MW would be sold to the grid in the milling season, while about 25 MW would be sold in the non-milling season. This option would involve a total investment of only about $12.5 million or $500/kW.

Since these plants in Thailand would require smaller investments than the proposed Monymusk plant in Jamaica and would operate nearly all year on biofuels, the results of the financial analysis of these plants were more favorable than for the Monymusk plant. Using the team's base case assumptions, the cost of power was estimated at $0.030/kWh from the Option A plant and $0.028/kWh from the Option B plant. Both of these unit costs were well below the $0.037 to $0.045/kWh estimated costs of power generated with cane trash in existing mill power plants (p.18).

Assuming that power was sold to the Thai utility at the current transfer price of $0.052/kWh, these new plants would be excellent investments. Internal rates of return were estimated at 33 percent for the Option A plant and 41 percent for the Option B plant; payback periods were estimated at 2.95 and 2.40 years respectively.

The BST team in Costa Rica analyzed two options involving completely new cane power plants. Due to the short milling season in Costa Rica (120 days) and the team's conservative assumptions regarding the use of biofuels during the non-milling season, both plants would be heavily dependent on fuel oil.

One option assumed a $17.3 million investment for a completely new power plant at the El Viejo mill. The plant would include a high-pressure boiler and a 15.6 MW double extraction/condensing turbogenerator, both operating a 850 psig (58 bar) and 825°F (440°C). The team's base case scenario assumed that 20 percent of this power would be generated with bagasse, mainly in the milling season, with 80 percent of the total power generated with fuel oil. The financial analysis showed that this investment would not be profitable unless electricity prices were set at a high level reflecting the full marginal costs of power production with fuel oil. A sensitivity analysis indicated, however, that the investment would be much more attractive if about 15 percent of the total power were generated in the non-milling season with cane trash and the percentage of the power generated with fuel oil dropped to about 65 percent. The net present value of this investment with trash utilization would be about $2 million.

A second option assumed a $19 million investment for a new high-pressure boiler, turbogenerator, and bagasse storage system at the Taboga mill. Surplus bagasse from nearby mills would be baled at a central station and stored at Taboga for use in the non-milling season. Under the base case scenario, about 35 percent of the power would be generated with surplus bagasse or purchased bagasse; the net present value of this investment would also be about $2 million. If about 10 percent of the power were generated with cane trash, reducing the dependence on fuel oil to about 55 percent, the net present value of the investment would increase to $2.8 million. If fuel oil were replaced with low-cost imported coal, the net present value of the investment would increase to $3.62 million.

A.I.D. TECHNICAL AND INSTITUTIONAL SUPPORT FOR THE DEVELOPMENT OF CANE POWER SYSTEMS

A.I.D.'s cane energy program concentrated initially on demonstrating the technical feasibility and economic attractiveness of cane power systems. While some of these activities are continuing, increased priority is being given to technical and institutional support required for the implementation of cane power projects.

This support is part of a broader effort by the A.I.D. Office of Energy to promote private power generation in developing countries by improving the institutional climate for private sector participation in power generation and by facilitating the development and financing of private power projects.

In most developing countries the electric power system is operated by a government agency which has little or no experience with the purchase of power from private companies. The United States, on the other hand, had a broad pattern of experience for over a decade with the implementation of the "PURPA" legislation of 1978. PURPA requires electric utilities to purchase power generated by other firms at a price equal to the costs which the utility avoids through the purchase. Much of this experience is highly relevant to private power generation in developing countries.

Following the report in mid-1988 of the BST team on electric power from sugarcane in Costa Rica, the BST Project organized a workshop for Costa Ricans on U.S. experience with private power which was held in San Francisco and Honolulu from November 9 to 18, 1988. The Workshop, attended by 12 officials and industry representatives in Costa Rica, provided a comprehensive introduction to U.S. legislation, regulations, and practices related to the generation of power for the grid by private firms.

On April 18, 1989, the President of Costa Rica and the Minister of Natural Resources, Energy, and Mining signed an executive decree which declares that the purchase of electricity from private firms is in the public interest and provides an institutional framework allowing the private sector to participate in the solution of electric energy supply problems. The decree establishes an advisory commission to assist with the development of private power generation, provides application procedures for firms offering to sell power to the Costa Rican utility, and establishes a framework for the determination of the prices to be paid for power in 1989.

Several types of technical and institutional support will be required by firms and organizations engaged in the development of cane power systems. In Costa Rica, the Costa Rican utility (ICE) and the sugarcane cooperative (LAICA) have requested technical advice concerning mill equipment options and electrical interconnection equipment. These institutions are expected to seek assistance relative to the development of firm power contracts and the establishment of prices for the purchase of power that benefit all parties.

A.I.D.'s commitment to the development of cane power systems will be continued under the new Biomass Energy System and Technology Project (BEST) which begins on October 1, 1989.

In order to expand its potential for assistance to the sugarcane industry in developing countries, the project staff has launched an outreach program to collect information on all types of diversification activities in the industry. Information is needed on all alternative uses of cane products and by-products including ethanol production, use of stillage and other by-products of ethanol production, collection and use of cane trash (tops and leaves) as a boiler fuel or for other purposes, and alternative uses of bagasse such as cattle feed, the production of paper and building materials, and other uses. Organizations and firms engaged in any diversification effort are urged to send information to Betsy Amin-Arsala at the address given on the inside front cover of the report.

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