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Bioenergy Systems Report

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

April 1989

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

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BSR NEWS FLASH

First Commercial Power Sales to the Grid By Central American Sugar Factory

It was announced on May 7, 1989 that the privately owned El Viejo sugar factory in Guanacaste, Costa Rica began trial sales of excess power to ICE, the Costa Rican national electric utility, in mid-April. Based upon recommendations from the BST report, Electric Power from Sugarcane in Costa Rica, published in July 1988, and continued technical support by this office and USAID/San Jose, El Viejo power sales are the first on an extended, commercial basis by a major sugar company in Central America.

The mill is supplying over 900 kW continuously to ICE for a three-month test period. ICE pays 3.2 colones/kWh (US 3.9¢/kWh) for the electricity, which represents surplus power production from the mill. El Viejo has been stockpiling bagasse to use as boiler fuel beyond the end of the current cane crushing season. The mill is negotiating a longer term contract with the utility upon successful completion of the current test period. It also has applied to a local bank for $1 million to finance new improvements that will increase its electricity sales.

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

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SYNOPSIS

A new Agency for International Development (A.I.D.) initiative, the Biomass Energy Systems and Technology Project (BEST), is being designed to follow the work begun during a previously funded A.I.D. project titled the Bioenergy Systems and Technology Project (BST). The new work will assist developing countries in utilizing biomass resources for the production of energy and related by-products. Effort will be concentrated on the agricultural and wood processing industries. BEST intends to:

- Promote environmentally and financially sound biomass energy systems as alternatives to conventional energy systems;
- Draw upon U.S. experience and technical capabilities in biomass energy;
- Involve the private sector, both as project investors and as sources of commercial technology;
- Support priority research related to developing country bioenergy applications;
- Improve agricultural and wood resource management;
- Increase total value of products produced per hectare;
- Displace petroleum use in developing countries;
- Stimulate economic development in rural areas;
- Increase rural employment and incomes; and
- Promote knowledge and understanding concerning biomass options for economic development, for use by farmers, processors, technology vendors, financiers, and bi-lateral and multi-lateral donors.

BACKGROUND

Traditional View of Biomass Energy

Biomass in the form of wood, animal waste or crop residues has for centuries been a basic source of energy. In developing countries over two billion people still rely heavily on biomass for cooking and heating fuel. These 'traditional' uses of biomass are often associated with the increasing scarcity of hand-gathered fuelwood as well as with the problems of deforestation and even desertification. New evidence indicates, however, that agricultural expansion to meet food needs of increasing populations is the largest contributor to the loss of forested land in developing countries. Furthermore, there is

growing recognition that use of biomass energy in larger commercial systems based on sustainable, already accumulated resources and residues (as is done in the more developed countries) can help improve natural resource management.

When the oil crisis began in the early 1970s, bioenergy strategies were perceived as a panacea for developing countries' energy needs because they tap indigenous renewable fuels to substitute for fossil energy and alleviate foreign exchange costs of energy imports. Some applications of these technologies do provide low cost energy in a variety of rural and peri-urban settings. When successfully implemented, biomass strategies can be powerful and cost-effective ways to create rural employment, new income, and new marketable commodities from an already existing resource base. But 15 years after the first energy crisis, bioenergy systems and strategies have not been widely accepted nor commercially disseminated to the degree originally anticipated.

The New A.I.D. Approach to Biomass Energy

Beginning in 1979, A.I.D. began to target the possibilities of mobilizing biomass resources for energy production through the creation of a specific project titled the Bioenergy Systems and Technology Project (BST).

The evolution and efforts of that project over the past nine years have led to the initiation of an exciting new approach which mobilizes natural resources, private sector expertise, and financial support to integrate the conversion of biomass into marketable energy products at existing agro-processing facilities. The new project will refine and continue A.I.D.'s efforts to maximize the use of renewable, indigenous resources to stimulate energy availability and rural economic development.

A.I.D. BEST Project emphasis will be on private sector investment in sugar cane, rice, and wood residue energy systems, both for power and for ethanol. Designation of these three sectors for intensive attention and investment of project time and funds resulted from previous years' efforts to identify the appropriate "niches" within which maximum results can be obtained from biomass energy systems. Sugar, rice, and wood processing plants often operate at a scale generating significant captive feedstock in the form of biomass wastes. These businesses have extensive and usually costly energy needs which can be met by on-site power/heat generation. The technical personnel are sophisticated enough to handle cogeneration equipment, and the financial requirements for capital investment can often be managed by the parent company. Such mills have the added advantage of being located in rural areas so that power/heat produced in excess can be fed either to the national grid or to local users. Increasing energy availability in these rural areas creates many new jobs, produces new income, and stimulates economic activity in areas where badly needed. These benefits are of importance to both A.I.D. and to the host countries.

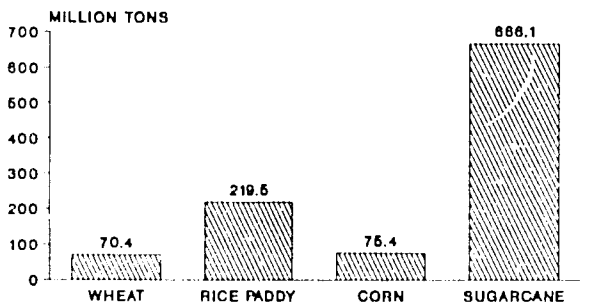
The ultimate objective is for A.I.D. to assist private sector investment in rural economic activity based on residue energy by reducing risks to the private sector inherent in applying new systems in new environments. To accomplish this, A.I.D. must work with new institutions and organizations and evolve better relationships with the private sector to

create mechanisms whereby project identification - prefeasibility - feasibility - private financing can be completed for innovative projects.

RATIONALE FOR COMMODITY FOCUS

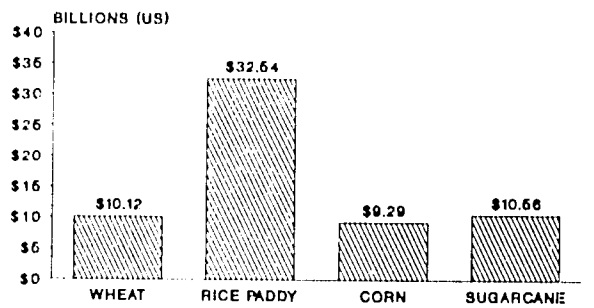
Cane, rice, and wood sectors are targeted by A.I.D. because these products are the most abundant in many of the developing countries assisted by A.I.D. Cane is the most significant in terms of volume produced, and rice is most significant in terms of product value (Figures 1 and 2). In many A.I.D.-assisted countries sugar cane and rice are the basis of the agricultural economy and account for a very high percentage of rural jobs (Figure 3). Providing options to these agricultural industries is therefore crucial to maintaining national economic health.

FIGURE 1: CROP PRODUCTION IN A.I.D. - ASSISTED COUNTRIES (1984)



SOURCE: WORLD INDICIES OF AGRICULTURAL AND FOOD PRODUCTION 1976-84, USDA: ECONOMIC RESEARCH SERVICE, STATISTICAL BULLETIN NUMBER 73'

FIGURE 2: CROP VALUE IN A.I.D. - ASSISTED COUNTRIES (1984)

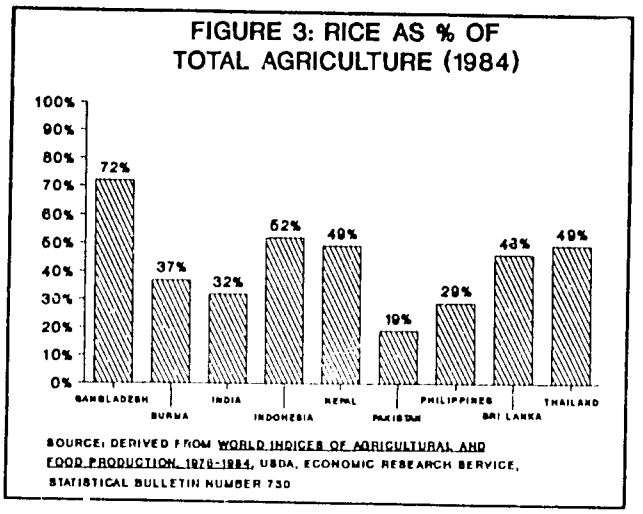


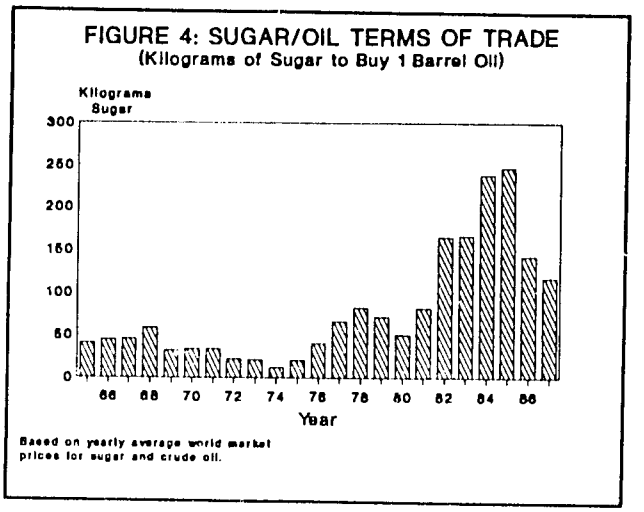
SOURCE: WORLD INDICIES OF AGRICULTURAL AND FOOD PRODUCTION 1976-84, USDA: ECONOMIC RESEARCH SERVICE, STATISTICAL BULLETIN NUMBER 730

Sugar Cane

During the 1980's the sugar cane industry worldwide suffered from oversupplied markets and low prices, with concomitant decreasing export earnings and trading power (Figure 4). The A.I.D. Cane Energy program offers the industry a diversification of products which can stimulate new revenue.

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; at 660 million metric tons annually, cane production is more than three times that of rice paddy and more than five times that of wheat and corn. Consistent employment data in the sugar cane industry is difficult to obtain, but some seven million people are employed full-time in A.I.D. countries, with over 30 million directly dependent on sugar industry income. Further, in many areas rural infrastructure systems are synonymous with cane infrastructure systems.





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 has suffered consistent financial and employment losses, which has led to declines in foreign exchange earnings and government revenues, and reduced stability in agricultural regions.

Labor Intensive Cane Harvesting

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 the expanding sectors of 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.

In addition, new technologies are being actively developed that would greatly increase the amount of electricity that could be produced by the sugar industry. Figure 5 illustrates the cane electricity potential worldwide with one advanced system under development.

From an agricultural point of view, sugar cane is one of the most photosynthetically productive plants on earth. In the long term the cane plant may be the factory for a wide

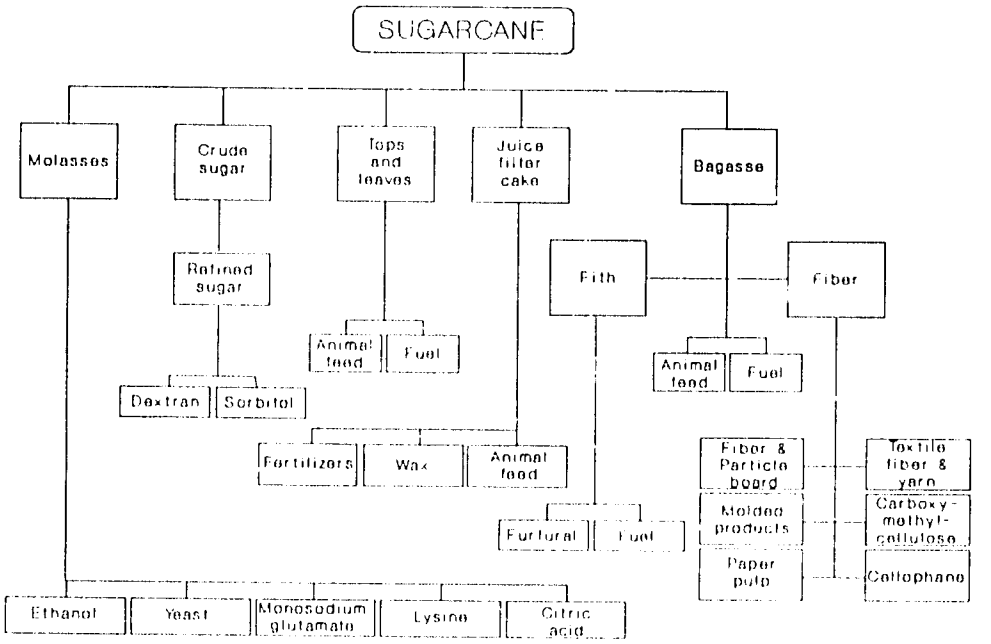
range of industrial and chemical feedstocks. Maintaining the cane infrastructure as this new industrial opportunity emerges could yield large benefits. Figure 6 illustrates some of the products available from sugar cane. Markets for many of these products and by-products are expanding and will expand further as environmental impacts associated with petroleum products received greater attention.

FIGURE 5: PERCENTAGE OF ACTUAL TOTAL ELECTRIC UTILITY GENERATION IN 1982 THAT COULD HAVE BEEN PRODUCED FROM SUGAR CANE USING ADVANCED GAS TURBINES (Based on the 1985 Cane Production Level)

WORLD TOTAL (SUGAR PRODUCING DEVELOPING COUNTRIES) 27.05%

ASIA						14.86%
India	24.4%	Iran	5.1%	China	5.8%	
Vietnam	47.9%	Thailand	66.7%	Burma	29.6%	
Indonesia	63.9%	Bangladesh	14.1%	Philippines	42.5%	
Malaysia	2.9%	Pakistan	43.0%	Nepal	42.3%	
Taiwan	7.6%	Sri Lanka	3.4%			
CENTRAL AMERICA						65.00%
Cuba	328.7%	Jamaica	72.3%	Mexico	21.4%	
Panama	26.6%	Dominican Rep.	176.5%	Belize	753.8%	
Guatemala	162.0%	Barbados	132.7%	El Salvador	82.8%	
Trinidad & Tob.	15.7%	Nicaragua	116.4%	Haiti	65.3%	
Honduras	96.2%	St. Chris.-Nevis	n/a	Costa Rica	41.3%	
SOUTH AMERICA						45.14%
Brazil	66.2%	Guyana	431.4%	Colombia	28.6%	
Bolivia	55.7%	Argentina	15.2%	Paraguay	63.3%	
Peru	45.5%	Uruguay	6.6%	Venezuela	5.4%	
Suriname	28.6%	Ecuador	42.1%			
AFRICA						19.16%
South Africa	10.5%	Mozambique	8.0%	Egypt	21.5%	
Somalia	320.0%	Mauritius	968.8%	Nigeria	3.1%	
Zimbabwe	50.5%	Angola	15.8%	Sudan	219.8%	
Uganda	26.4%	Swaziland	2400.0%	Congo	56.4%	
Kenya	92.5%	Mali	112.5%	Ethiopia	140.8%	
Gabon	9.4%	Malawi	168.3%	Burkina Faso	40.7%	
Zambia	6.2%	Chad	61.5%	Ivory Coast	29.4%	
Guinea	14.0%	Tanzania	65.3%	Sierra Leone	14.7%	
Madagascar	131.6%	Benin	125.0%	Cameroon	14.9%	
Liberia	2.6%	Zaire	20.3%	Rwanda	15.2%	
Senegal	47.5%					
OCEANIA						200.00%

FIGURE 6: PRODUCTS FROM THE SUGARCANE PLANT

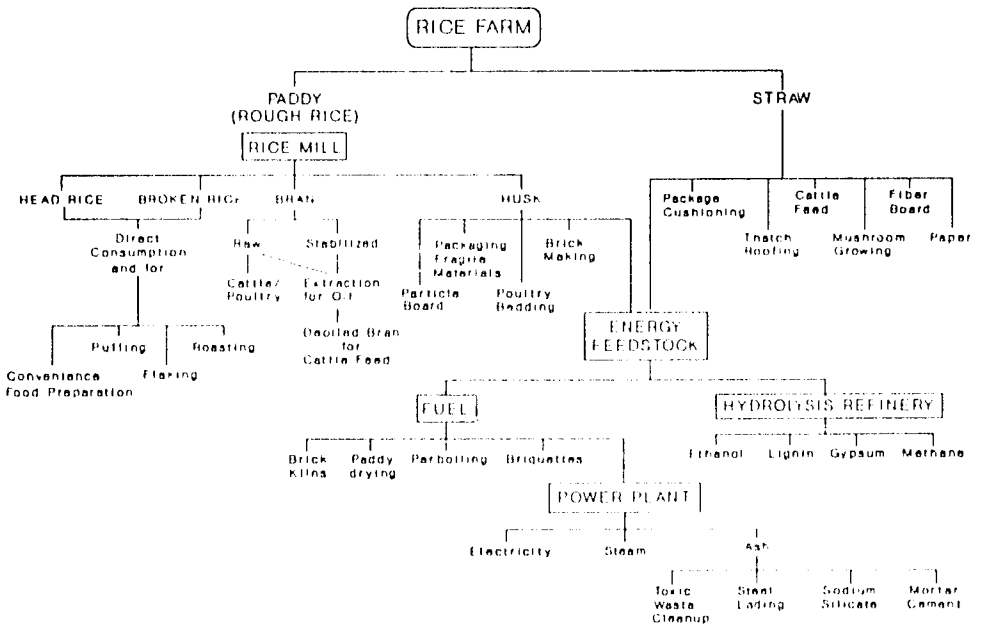


Rice

The rice industry faces a different but equally serious future. To meet projected rice demand beyond the year 2000, both rice growing and rice processing will need capital to increase productivity and efficiency. Diversification of rice processing through the conversion of rice residue into energy products can increase income and capital accumulation for re-investment. Creation of these new income streams will also result in new jobs, new rural infrastructure, and new economic activity in rural areas. Ultimately rice farmers will benefit as the value of rice husk and straw filters down to the rice producer. The A.I.D program will stimulate development and implementation of systems to convert rice residue (husk and straw) into energy and other commercial products (steam, ethanol, lignin, gypsum, chemicals). Figure 7 outlines residue product possibilities.

U.S. companies involved in successful rice residue system development and potential developing country users alike are just beginning to gather experience in international technology transfer and in international finance. The BEST program will attempt to provide the institutional framework needed to identify and coordinate rice residue use opportunities. In collaboration with groups such as the International Rice Research Institute (IRRI), the Tennessee Valley Authority (TVA), the U.S. Trade and Development Program (TDP), the Overseas Private Investment Corporation (OPIC), and the international business community, A.I.D. can reduce risk and stimulate innovation.

FIGURE 7: RICE RESIDUE AND BY-PRODUCT UTILIZATION SCHEMATIC PERSPECTIVE



One MT/day Indonesian Rice Mill

Weighing and Selling Rice in an Indonesian Field

Wood

Forests, the most valuable biomass resource in many A.I.D. countries, are seriously threatened by ineffective forest policies and/or by weak incentives for sustainable management. The wood products industry is often criticized as the catalyst for destruction because it creates the initial infrastructure which facilitates agricultural development. Poor logging techniques can also set the stage for environmental catastrophes. The overriding theme of BEST's wood energy strategy is to work with the environmental groups, local communities, national governments and the wood products industries to develop and sustain good wood management practices.

Product diversification and better management practices could significantly increase revenues per hectare of forest land and reduce environmental degradation. Through innovative planning and research, residue energy projects associated with the wood products industry can provide alternate income from forest land as the quality and value of the forest increases under improved management. Working forests also make better buffers for biologically important forest conservation areas than does agricultural land.

The international donor community has avoided dialogue with the forest products industry on how to improve forest management over the last fifteen years as emphasis was placed on reducing the demand or increasing the supply of wood fuels for cooking.

With global warming trends being linked to destruction of the world's major tropical forests, innovative projects that provide incentives to local communities, the private wood sector, and governments to encourage responsible forest practices must be explored and implemented.

The Energy Context

A lack of energy in all forms (electricity, heat, steam, and liquid fuels) is increasingly recognized as the major constraint facing the developing world as it attempts to expand agricultural and industrial production, improve standards of living, and increase higher-value exports. In many developing countries power demand already exceeds existing generation capacity by over ten percent. Based on current trends in demand, investment requirements in the developing world for power systems could be as high as $2.6 trillion between 1988 and 2008. This implies an annual investment of over $125 billion, which is more than twice the current annual expenditure. (Power Shortages in Developing Countries, U.S.A.I.D., A Report to Congress, March 1988, p. iv.)

Public funds from bi-lateral and multi-lateral sources are not available for the scale of investment required. In any case, the debt service that would be required on this amount of investment is beyond the capability of most developing countries. As a result, increasing attention is being placed on the possibility of private investment/ownership/operation of power systems. To attract these new sources of funds for energy production requires a new orientation that is built upon sound technical evaluation, rigorous site-specific financial and

economic analysis of opportunities, a supportive legal and institutional environment provided by both government and the utility, tax benefits and other incentives, as well as new skills in international project development. The BEST project is designed to mobilize the resources for all these elements to create sound private power investment opportunities in A.I.D.-assisted countries.

For the cane, rice and wood industries, energy products represent only one category of diversification opportunities. Because of the size and stability of electricity markets, diversification into production of electricity often yields high returns on investment. Markets for liquid fuels are less stable but also large. In either case, returns from investments in enery products must compare favorably with returns from investments in other products to attract investors.

Since many successful investments in commercial biomass energy systems have been made in the U.S., the BEST project creates overseas business possibilities for U.S. companies. Integrating proven technologies from U.S. systems into international projects will require partnership between A.I.D. and the private sector, both in the U.S. and in the countries where the projects will be created.

RELEVANT U.S. EXPERIENCE AND TECHNICAL CAPABILITIES

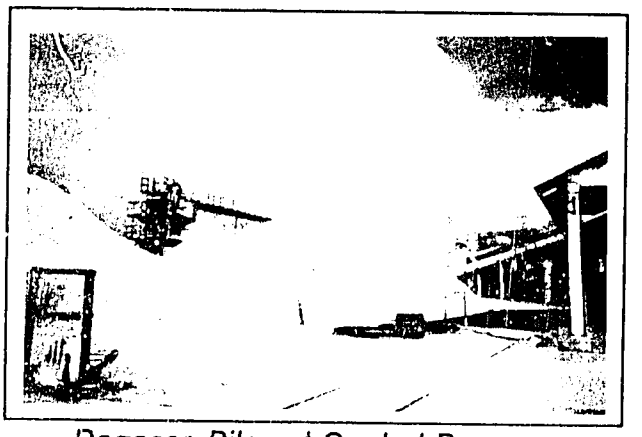
The BEST project draws upon years of successful U.S. experience in biomass energy systems research, development, and application. This section summarizes that experience in cane, rice, and wood residue energy conversion systems for power, heat, and ethanol production.

Cane Energy Experience

Electricity Production and Sale to Utilities

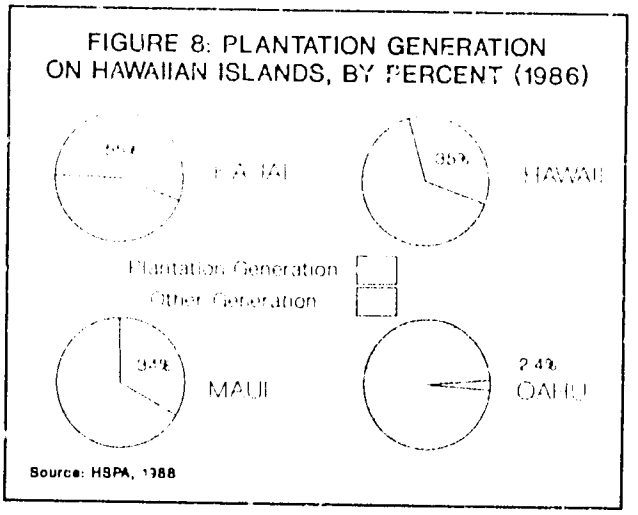
For nearly a century, the Hawaiian sugar industry has produced most of the steam and electricity needed to process sugar cane and to power its factories and irrigation pumps. It also played a major role in establishing electrical utilities on the three largest islands and produced much of the electricity those utilities distributed in their early years. The association continues; today Hawaiian sugar cane plantations produce more than 775 million kWh annually, or about ten percent of all electricity generated in the state from a nameplate capacity over 200 MW. As much as two-thirds of the electricity produced in some areas is generated by plantations, and in certain counties roughly one-half of the electricity distributed to the general public by the utility companies originates from the industry. About ninety percent of this electricity is produced by sugar factory cogeneration facilities (the remainder is produced by hydroelectric installations). Bagasse (the fibrous by-product of milled sugar cane) is the principal fuel burned to produce steam and electrical power, and represents nearly ninety percent of all boiler fuel burned (First Quarterly Report to A.I.D., Cane Energy Program, Hawaiian Sugar Planters' Association, January 1988).

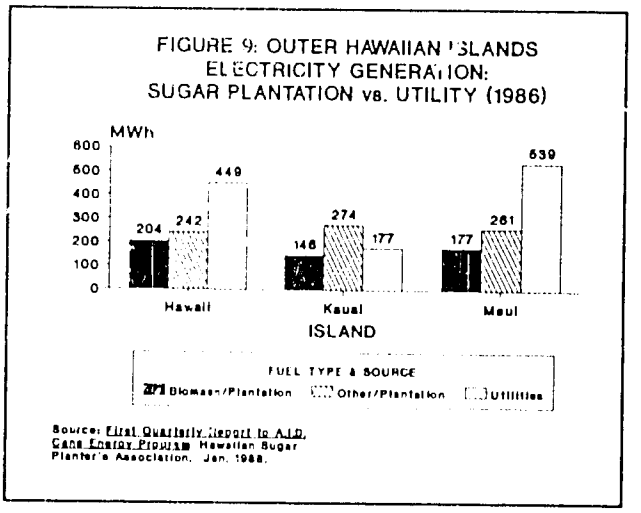
Closeup of Sugar Cane Bagasse from a Small Indian Mill



Bagasse Piles at Central Romana Sugar Mill in the Dominican Republic

Today, approximately 15 sugar mills in Hawaii ranging in size from 2 to 40 MW capacity provide approximately 10 percent of the state's power (63 percent of the power on Kauai, 40 percent of the power on Hawaii, 29 percent of the power on Maui and two percent of the power on Oahu) (See Figures 8 and 9). Power plants at sugar mills run 24 hours per day and in some cases are the most reliable power plants serving the grid. Six mills have contracts to provide firm power to the grid. Others provide power on an unscheduled basis. Revenues from sales of power provide between 5 and 20 percent of the net revenue to the sugar industry.





Traditionally, sugar mills consider bagasse more of a nuisance than a resource. The average sugar mill in A.I.D.-assisted countries produces only 10 to 20 kWh per tonne of cane processed, generally enough to meet mill and factory demands. They use low pressure boilers (150 to 300 psi) to produce steam for mill drives and electricity generation and use

exhaust steam from mill drives and steam turbines to meet remaining processing needs. The objective of the mill is to use up all of the bagasse produced during the season so there is no fire or disposal problem. In a surprising number of cases, sugar mills are forced to import large amounts of electricity from the grid to supplement the power they produce.

As demonstrated in Hawaii, it is possible to dramatically increase the amount of electricity produced in association with sugar operations. The more efficient Hawaiian mills produce some 70 kWh per tonne of cane. Hawaiian mills use higher-pressure boilers (from 800 to 1250 psi) and separate sugar operations from power generation to enable power production to continue even if the mill or factory shuts down. The power plant provides all process steam needed for sugar processing. A.I.D. has a cooperative agreement with the Hawaiian Sugar Planters' Association to access Hawaiian expertise in efficient energy production.

To help examine the potential fc the global sugar industry to produce electricity, A.I.D. developed a model to predict the quantity of electricity that could be produced by an efficient sugar operation using an 865 psi boiler and modern turbo-generator equipment. By using input parameters for a particular situation, the model predicts the technical and economic performance of a mill producing multiple products. For example, a hypothetical mill with efficient equipment grinding 4600 tonnes per day working 44 weeks per year could expect to export an average of 10.5 MW of electricity, after satisfying its own needs for electricity,. At $0.09/kWh, the revenues from electricity would equal $7.5 million annually.

If sugar mills add cane tops and leaves collected from fields after harvest to bagasse, the quantity of electricity that could be produced jumps. For the hypothetical mill discussed above, adding about half the cane tops and leaves currently left in the field after green harvest per tonne of cane stalks harvested to bagasse would increase the electricity produced per tonne of cane stalks processed to 200 kWh. The mill would be able to export an average of 27.5 MW to the grid and obtain revenues of $19.6 million annually.

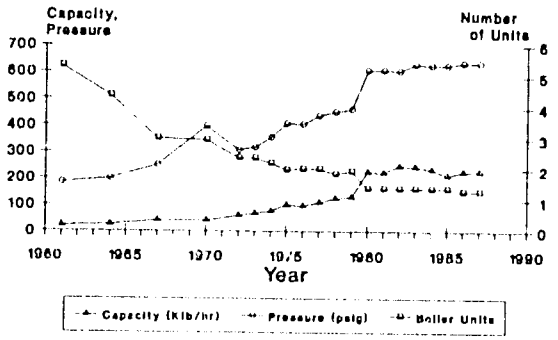
Energy Efficiency at Sugar Factories

In Hawaii from 1960 - 1988, industry-wide average boiler capacities increased eight-fold (from 25,000 to 200,000 pounds steam per hour) and average boiler pressures more than tripled (from less than 200 to over 600 psi); at the same time, the average number of boilers per sugar factory fell from five to slightly over one and power production jumped. These indicators demonstrate important improvements in energy management in the sugar industry over a long period. In addition, the advent of new economic opportunities in energy conservation and power production can be seen in the abrupt jump after the energy price rises of the mid- and late 70s in oil-dependent Hawaii and the consequent opportunity to sell power to utility companies (see Figures 10 and 11).

Most cane factories lack incentives to improve energy efficiency because more efficient equipment only increases the bagasse disposal problem. The Princeton University Center for Energy and Environmental Studies looked at commercially proven efficiency measures that could be adopted if surplus bagasse were to be converted to electricity for sale. Investments in devices not widely used in the cane industry such as waste vacuum pans

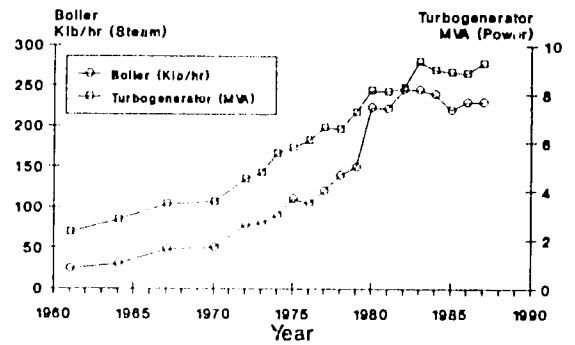
become lucrative and could reduce process steam demand from about 400 to 250 kg per tonne of cane processed. If a high pressure steam turbine system were installed, these retrofits would boost export electricity production by about 15 percent.

FIGURE 10: AVERAGE BOILER CAPACITY, PRESSURE, AND NO. OF UNITS PER FACTORY



Source: HSPA, "Review of Cogeneration in the Hawaiian Sugar Industry," Project #6600, (Draft), October 1988.

FIGURE 11: AVERAGE UNIT CAPACITIES OF BOILERS AND TURBOGENERATORS



Source. HSPA, "Review of Cogeneration in the Hawaiian Sugar Industry," Project #6600, (Draft), October, 1988

Increasing Power Production from Cane Residues

- Bagasse Dryers

The Hawaiian Sugar Planters' Association is accumulating and evaluating data on the Hawaiian experience with flue-gas bagasse drying installations. In 1988 data was collected on the Waialua Sugar Company and Hamakua Sugar Company (Haina) boiler and flue-gas dryer systems, including detailed schematics of the bagasse drying and handling systems for the four installations. Data indicate that properly designed bagasse dryer systems yield net energy gains.

Drying rate (which affects installation and operating costs) and amount (which affects the magnitude of energy saved) vary directly with the temperature of the flue-gas used to dry bagasse. The flue-gas temperatures measured at the inlet of the four dryer systems analyzed averaged about 390°F, significantly lower than for most sugar factory boiler systems outside of Hawaii (typically greater than 500°F at the boiler exit); thus, the potential energy and cost advantages of flue-gas drying would be substantially greater for most factories outside Hawaii.

- High Fiber Cane

Research on high-fiber cane (as opposed to high tonnage cane) has been carried on for nearly a decade at the Audubon Sugar Institute (ASI) of Louisiana State University, and a program of studies has recently been established at the West Indies Sugar Cane Breeding Station in Barbados (CBS). Sugar cane breeders have in the past sought to produce varieties with the most extractable sucrose per MT of harvested material, and thus discarded cane types with fiber content above about 15 percent. They also selected against

canes with large amounts of leaves and tops. Spurred by an interest in biomass production for energy, researchers at ASI crossed a commercial cane variety (CP-52-68) with a species imported from Argentina (Tinian 96). This produced a number of clones, two of which, L79-1002 and L79-1003, formed the basis of studies of production and processing alternatives.

The varieties cultivated at Louisiana produced enormous quantities of biomass: green matter in excess of 89 MT per acre for five years in a row, or more than double the yields of standard sugar cane varieties. Because they also contained twice the fiber, they produced more than four times the amount of bagasse per acre. As might be expected, sugar percentages were lower than was the case in commercial varieties in use (8.6 percent sucrose in juice, compared to 14.3 percent), although the total quantities of sugars (11.1 percent soluble solids, compared to commercial levels of 16.1 percent) still make them interesting for the production of fuel alcohol.

Significantly, the high-fiber canes proved about half as expensive to produce per acre. While the plant crop cost about the same, succeeding crops required neither herbicides nor further cultivation to attain their higher yields, and continued to produce well for six or more ratoons. (Mike Giamalva, Stephen J. Clarke and Jeanie M. Stein, "Production of Saccharum Genotypes for Maximum Biomass Yield and to Determine its Potential as a Source of Fuel," Baton Rouge, Louisiana: Audubon Sugar Institute, p. 107.)

Researchers at CBS in Barbados tested a set of eight varieties. The fiber content of these ranged from 17.5 percent to 30.2 percent, and they, too, proved highly productive, with cane yields ranging from 62 to 86 MT per acre. Fiber yields increased 400 percent over those obtained from commercial varieties. Like the canes in Louisiana, these contained less recoverable sucrose per MT of cane. Overall yields of sucrose and reducing sugars per acre, of course, tended to be higher because of the tremendous amount of cane produced.

Although experimentation with high-fiber canes and energy grasses is just beginning, work to date has clearly identified an important resource base which has heretofore been ignored: the production of very large quantities of lignocellulosic material on a sustainable basis at a relatively low cost. From this research it is clear that lands currently used for sugar in the tropics and subtropics can continuously produce yields of more than 30 MT of dry biomass (60 MT of bagasse equivalent) per acre per year while at the same time producing five or more MT of fermentable sugars. If burned efficiently, this material could produce from 300 to 400 kilowatt hours of electricity. Put differently, 300 acres could be expected to generate one megawatt of electricity on a continuous basis.

Further investigations into higher fiber cane may become useful to cane energy producers after power production is incorporated into the worldwide sugar industry.

- Energy Cane

The most widely publicized research in the production of cane for energy purposes is that completed by Professor Alex Alexander and his colleagues at the University of Puerto Rico (UPR) between 1977 and 1982. Supported by U.S. government grants, the UPR team

focused primarily on the effects of revised agricultural management on total biomass growth. By providing generous fertilizer and irrigation water, researchers were able to obtain significant yield increases for commercial varieties in Puerto Rico. Then they further revised cultivation methods, chiefly by much more intensive soil preparation, and at the same time included in their trials several known, but non-commercial, clones that had demonstrated great growth potential. Among the latter was the variety US 67-22-2, a cane with a normal fiber content and good sugar-producing qualities, but which also tends to produce large stool compiexes and a generous foliar canopy. (A. G. Alexander, et.al. Production of Sugarcane and Tropical Grasses as a Renewable Energy Source, Final Report. Rio Piedras, Puerto Rico: Center for Energy and Environmental Research, 1982, pp. 58.)

Using this high-tonnage clone and the newly developed management techniques, the University of Puerto Rico team achieved yields of 113 MT of green matter (87 MT of millable cane) per acre per year in the plant crop under irrigated conditions. This measured a full 45.8 MT per acre of dry matter. The same crop yielded over seven MT of sugar per acre and 21.1 MT of trash.

These impressive yields were obtained under very carefully controlled conditions, and exceed the levels that could be expected by commercial cane operations. Nevertheless, they clearly establish the importance of cultivation techniques and variety selection in producing prodigious quantities of biomass. These yields also appear to sustain the basic thesis of the UPR researchers -- i.e., that well-managed commercial ventures should be able to produce cane in excess of 90 MT of green matter and 27 MT of dry matter, along with significant amounts of sugar, at a cost per MT lower than is normally incurred in conventional sugar operations.

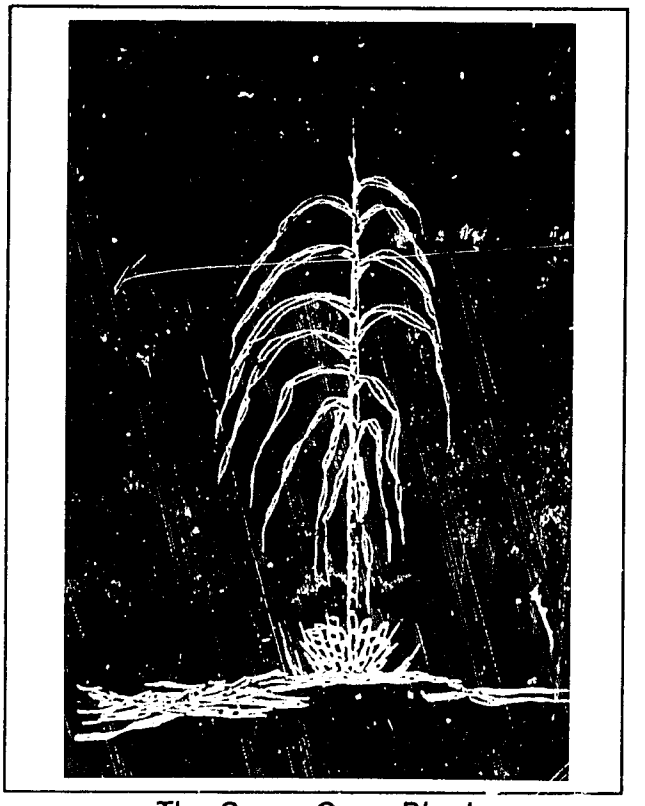
- Baling and Combustion of Cane Tops and Leaves

Most of the sugar in the cane plant is found in the stalk. Tops and leaves are not normally milled because they contain little sucrose and affect both the quantity and quality of sugar recovered from the stalk in the milling process. Where cane is harvested by hand as it is at virtually all sites in A.I.D.-assisted countries, the cane tops and leaves are most often burned in the field before and/or after harvest.

Research conducted by ABA International, Inc. for the government of the Dominican Republic across a range of unburned hand-harvested fields suggests that in general 0.67 tonnes of cane tops and leaves (at about 50 percent moisture) are produced for every tonne of cane stalks harvested. Each tonne of cane stalks (15 percent fiber) processed at a modern sugar factory yields approximately 0.3 tonnes of bagasse at 50 percent moisture. The tops and leaves left in the field therefore represent a much greater fuel potential than bagasse.

The amount of tops and leaves produced by the cane plant will vary by variety. Barney Eiland and others at USDA in Florida measured tops and leaves in fields that have been burned and then mechanically harvested. Even in fields burned before harvest, two to three tonnes of dry matter (equivalent to about five tons of material at 50 percent moisture)

can be recovered from fields that yielded 20 tonnes/acre at harvest. As Eiland stresses, however, the challenge is in collecting the material at a cost that makes economic sense (B.R. Eiland and J.E. Clayton, "Unburned and Burned Sugarcane Harvesting in Florida," Transactions of ASAE, Vol. 26, No. 5, 1983). Alexander in Puerto Rico estimates that on a dry weight basis, each 7.2 tonnes of millable stalks has associated with it 6.1 tonnes of green tops and attached and detached leaves. (Alex Alexander, The Energy Cane Alternative. New York: Elsevier, 1985, 46).



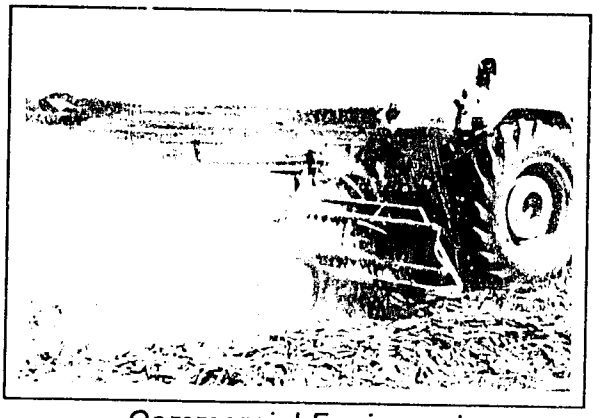
The Sugar Cane Plant

The actual collection of cane tops and leaves presents a number of practical problems with which few have had experience. The cost of collection and the quantity and quality of the material recovered will determine the value of tops and leaves as fuel. The giant La Romana complex in the Dominican Republic has collected cane field residues for furfural production over the past several years using field choppers and reports collection costs less than US$10 per tonne. University of Puerto Rico researchers made large circular bales after allowing the tops and leaves to dry in the field for several days. These bales can be stored outside for periods of six months or longer without serious degradation. The Tarlac mill in the Philippines began using small square balers to bale and store cane field residues last year for use as boiler fuel. A.I.D. in conjunction with private sugar cane companies is currently testing various baling and storage configurations in Jamaica and Thailand.

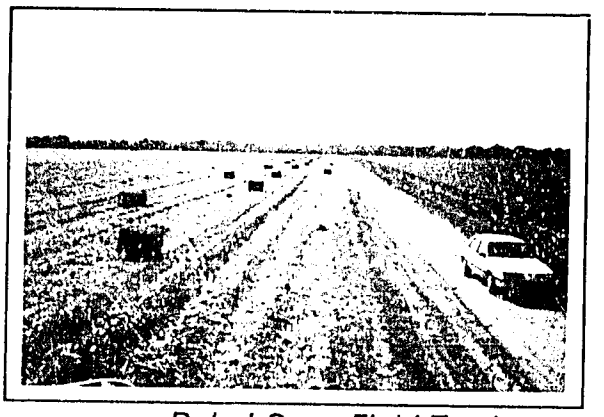
Harvested Cane Stalks Ready for Transport to the Mill

Cane Trash and Tops Left in the Field

Any separate entry to the field during harvest is both expensive and logistically difficult to manage. It may prove easiest to harvest whole cane and separate the tops and leaves from millable stalks at the mill site. Separators have been developed in Hawaii that may be suitable for this purpose.



Commercial Equipment Raking Cane Trash

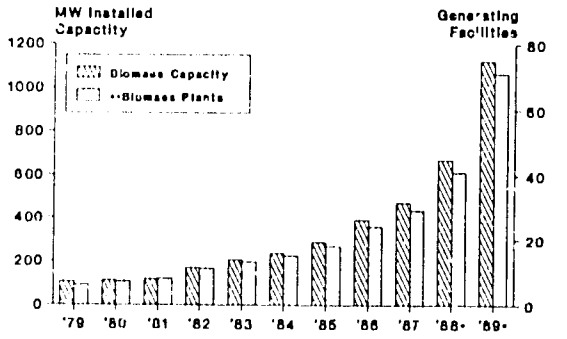


Baled Cane Field Trash

California Private Biomass Power Experience

As a result of innovative financing, tax laws, and contract procedures, California is one of the most forward-looking states in the U.S. in private power development. In California, the on-line installed capacity from biomass power plants increased from 104 MW in 1979 to an estimated 1,123 MW for 1989 (See Figure 12). The number of biomass generating facilities (typically 15-20 MW) increased from six to over seventy plants during the same period. The California Energy Commission has conservatively estimated that by the end of this year, Californian biomass power plants will have generated more than 7.8 billion kWh for 1989 compared with less than 800 million kWh in 1979. Ninety-five percent of this biomass power is derived from lumber and pulp mill wood wastes, three percent is from urban wood waste, and two percent is from agricultural wastes.

FIGURE 12: BIOMASS POWER GENERATION THE CALIFORNIA EXPERIENCE



SOURCE: Estimates from California PUC
*Under Construction or in Planning
**Most Facilities are 15-20 MW

NOTES: 95% Biomass Power Generation is from lumber/pulp mill wood waste, 3% from urban wood waste, and 2% from agricultural waste

Utility Contracting

After the Public Utility Regulatory Policies Act (PURPA) was enacted, California developed four basic types of private power contracts: Standard Offers 1, 2, 3, and Interim

Standard Offer 4. Generally, surplus or intermittent electricity is sold to the utility under Standard Offers 1 to 3, while Standard Offer 4 deals with firm or baseload power sales to the grid.

Interim Standard Offer 4 stimulated large interest among prospective private power producers. In 1986, proposals to supply electricity for the favorable fixed energy prices that could be obtained under Interim Standard Offer 4 exceeded the need for additional capacity and the program was suspended. The new Standard Offer 4 being developed for introduction next year is expected to introduce some form of bidding to ensure that electricity purchased from private sources is obtained at the lowest price.

Payments for Electricity

Electricity purchase prices paid by the utility to the private producer are based by U.S. law on the utility's avoided costs although the law does not define precisely how to calculate what the avoided cost should be. Consequently, implementation of the law resulted in significant debate among California utilities, the California Public Utility Commission and private producers. According to the Public Utility Commission, payments made according to avoided cost calculations are typically broken down into two or three components: 1) energy payments that reflect fuel saved by the utility through the purchase of private power, 2) capacity payments that reflect investment savings because by buying private power the utility does not need to maintain as much capacity in its own system, and 3) sometimes an additional payment based on the type of generation system that is displaced.

The payments for which private producers are eligible depends upon the type of power sold Standard Offers 1 to 3 typically allow for energy or fuel charges only, since these contracts are for intermittent or surplus power sales. In contrast, Interim Standard Offer 4 originally set fixed capacity and energy prices to encourage banks to finance firm power producers. Energy prices were set based on forecasts of long run fuel costs. In retrospect, actual petroleum costs during the period were less than forecasted.

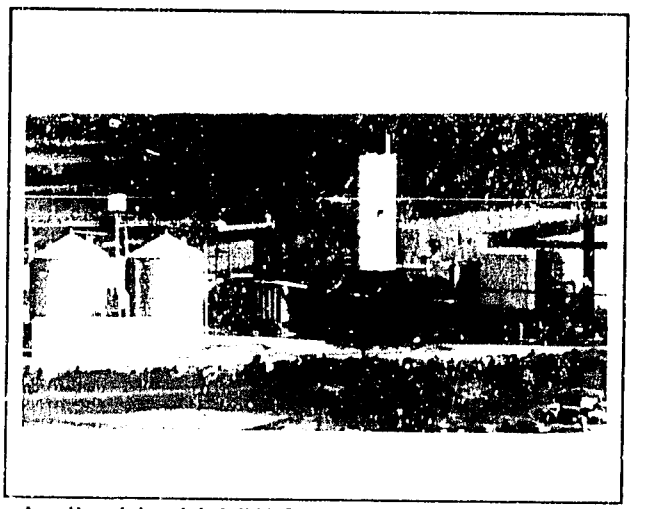
Payments made by utilities to private power producers are substantial. For example, payments by Pacific Gas and Electric in 1987 were $362.2 million.

U.S. Experience with Rice Residue Utilization

Louisiana - Agrilectric, Ltd., Lake Charles

A steam power plant produces more than 11 MW of electric power from rice husks at Lake Charles, Louisiana. The Agrilectric plant uses all of the husks generated by the adjacent Farmers Rice Milling Company, which processes about 1,000 tons of rice per day in a 290-day season. The power plant receives 200 tons of finely ground husks per day from the Farmers Rice mill via a pneumatic conveyor; up to 100 additional tons of husks are purchased daily from other large mills.

The husks are burned in suspension in a cyclonic furnace. Combustion is controlled to keep silica content of the ash high and carbon content low to meet requirements of steel producers who buy the ash as an insulating material.



Agrilectric 11 MW Rice Husk Power Plant
Lake Charles, Louisiana

The boiler island was installed by McBurney Corporation of Atlanta, Georgia. The watertube boiler was manufactured by Deltak Corporation of Minneapolis, MN. Erosion from the entrained ash in the combustion gases is minimized by the straight-through design of the tubes, superheater, evaporator, and economizer. The boiler has modular bundles of tubes that permit easy removal of the bundles and easy replacement of any bundle. The system produces about 112,000 lbs/hr (50,400 kg/hr) of steam at 650 psig and 750°F (398°C).

The steam is used in a General Electric turbine-generator rated at 12.5 MVA. The turbine is often operated at five percent overpressure with valves wide open and produces from 11.2 to 11.8 MW. Exhaust steam from the turbine is condensed in a 22,000 gallons/minute (83,600 liters/minute) condenser. Cooling water is obtained from an artificial lake supplied by deep wells.

The operation of the power plant and the adjacent rice mill consumes about 15 percent of the gross power output. The remaining power is sold to the regional electric utility company, Gulf States Power. Income from the export of rice husk ash to European steel mills also contributes significantly to profitability.

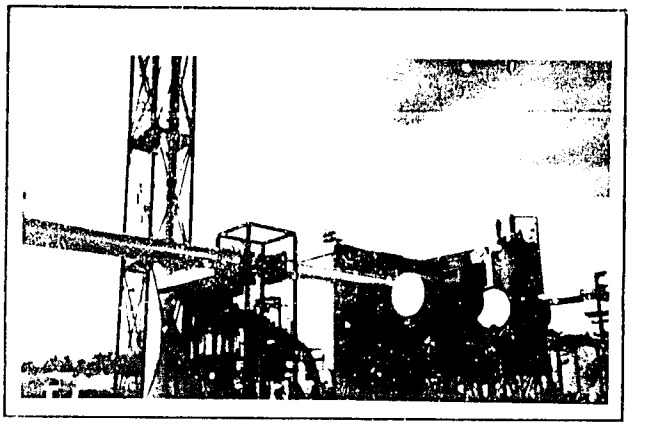
Agrilectric is preparing a feasibility study with co-funding from the U.S. Trade and Development Program for a similar system in the Philippines.

Arkansas - PRM Energy Systems, Stuttgart

A husk combustion system developed by PRM Energy Systems at the large Producers Rice Mill in Stuttgart, Arkansas, burns 1.75 tons of husks per hour to provide 15,000 lbs/hr of steam for rice parboiling. A second unit uses 2.5 tons of husks per hour to produce hot gas for rice drying. The two units are saving a million dollars a year in natural gas fuel costs; sales of ash to steel companies at $100/ton generate another million dollars in revenue.

The PRM two-stage gasifier/combustor is specifically designed for high silica, high ash, low grade waste fuels. The gasification process takes place on a fixed bed. A unique method of mechanical fluidization requires less underfire air and less power than a conventional fluidized system. Problems of glassing and clinkers experienced in many

systems have been eliminated. Controlled combustion allows variable carbon burn-out as the ash is automatically and continuously discharged without need for drying. PRM's ash quality control system permits ash production to meet market requirements for the ash residue in U.S., Asia and Europe. Second-stage combustion of the gases delivers a clean hot air stream at 2000°F that can be directed to any heat or steam application. The introduction of combustion air in the second stage reaction allows thermal cracking of tars and hydrocarbons to enhance the heating value of the combustible gases and to eliminate the need for expensive pollution control equipment. In steam raising applications, the boiler stack is clean enough to be used for drying paddy rice.



PRM System Installed at Rice Mill in Malaysia

PRM has recently built three systems in Malaysia for the Rice Padi Board to displace diesel fuel and handle disposal problems. Currently producing steam for parboiling, the three systems will be retro-fitted to provide 500 KW electricity generation in late 1989.

TVA Agrirefinery

The Tennessee Valley Authority is developing a process that efficiently converts the cellulosic portion of feedstocks to sugars that can be subsequently fermented to ethanol. The process is a two-stage sulfuric acid hydrolysis process which operates at low temperatures (less than 100°C) and low pressure (atmospheric). Results in laboratory tests with over 25 feedstocks have shown similar conversion efficiencies provided the feedstock is reduced to a size suitable for efficient processing. A.I.D. supported analysis of rice hulls and straw for use with this process.

FIGURE 13
COMPOSITION OF VARIOUS FEEDSTOCKS ON A PERCENT DRY BASIS

Component	Rice Hulls	Rice Straw	Corn Cobs	Bagasse
Hemicellulose	11	16	40	19
Cellulose	37	38	38	38
Lignin	21	12	8	22
Ash	19	16	1	3
Other	12	18	13	18

Conversion of hemicellulose to xylose has averaged above 90 percent, and conversion of cellulose to glucose has averaged above 85 percent. Sugar yields can be calculated using these efficiencies and the feedstock composition. For example, average compositions of four feedstocks which would be available in the Philippines for processing to sugars are shown in Figure 13.

TVA has also conducted extensive fermentation tests with hydrolyzates to optimize conversion efficiencies and determine ethanol yields. Theoretically, 0.51 pounds of ethanol

can be produced from each one pound of sugar. Glucose hydrolyzates have been successfully fermented to ethanol at an efficiency of 85 to 95 percent of theoretical. Xylose hydrolyzates have been fermented to ethanol at efficiencies of 60 to 70 percent of theoretical. Using an average composition for the four feedstocks of 28-percent hemicellulose and 38-percent cellulose, about 70 gallons of ethanol can be produced per dry ton of feedstock.

Products of the processing facility include ethanol, lignin for steam and electrical generation, gypsum, CO_2, stillage, and a waste effluent. Some of these products have markets in A.I.D.-assisted countries.

USDA - Stabilization of Rice Bran for Commercial Oil/Fiber Production

Rice bran oil demonstrates characteristics that make it highly valued among all other vegetable oils, in both the food and pharmaceutical industries. High in Vitamin E, rice bran oil also reduces cholesterol levels more efficiently than oat bran. In addition, because this oil has no odor or taste, it is a more suitable base for medicinal, cosmetic, and other applications.

Until very recently, however, rice bran products could not be processed at commercial scale. During the milling of white rice, bran is removed. The abrasion required to remove bran destroys the outer cell layers in such a way that the bran destabilizes and becomes rancid very quickly. Historically, rice bran has been disposed of as an animal feed. The U.S. Department of Agriculture Laboratory at Albany, California recently designed an extrusion cooking process which stabilizes the bran permitting it to be accumulated for use in commercial scale processing plants. Many of the large rice mills in California are installing extruders and will add bran to their product lines. Other mills will produce bran oil for the far eastern markets. U.S. companies with the patents for commercial application of bran technology are in discussion with the U.S. rice husk power system companies for the development of joint venture applications of bran oil and husk power integrated systems. Immediate targets for this work are India and Pakistan. Figure 14 illustrates current commodities that can be produced from rice bran oil.

FIGURE 14
RICE BRAN OIL USES*
(December 1988 Prices)

	Price/Pound
Moderate Emulsifier	$0.75
Hypoallergenic Infant Formula Base	$1.00
Low-fat Milk Replacer	$1.25
Imitation Meat Paste	$1.00
Whole Milk Replacer	$2.50
Artificial Cream Cheese	$2.50
Artificial Egg Yolk Powder	$1.95
High Fat Emulsifier	$0.85
Ice Cream Base	$0.90
Rice Protein Isolate	$1.10
Malted Rice Milk	$0.75
Imitation Parmesan Cheese	$2.50
High Protein Emulsifier	$1.75
Skim Milk Replacer	$0.80
Artificial Whole Egg Powder	$1.25
Artificial Yogurt	$1.25
Hypoallergenic Products	$1.85
Protein-Lipid Dough Improver	$1.10
Rice Bran Oil	$0.60
Rice Bran Fiber	$0.60
Aquaculture Feed	$0.25
Chicken/Swine Feed	$0.125
Milk Replacer for Calves	$0.60
Oryzanol	$15.00
Inositol	$12.00
High Protein Baby Cereal	$0.80
Phytic Acid	$4.50

*Information from Helix International, Baton Rouge, LA, December 1988.

In a more recent development, bran processors have demonstrated that rice bran is more effective in cholesterol reduction than oat bran. Within 12-18 months it is expected that rice bran will begin significant penetration of U.S. bran market for cereals, fiber supplements and other health food uses.

Production of Alcohol from Biomass

Background

Since the mid-1970s, the production of fuel alcohol or ethanol from sugar and grain has achieved significant scale in Brazil, the United States, and several African and South American nations. Expansion of ethanol coincided both with massive increases in world agricultural production of sugar and cereal grains, which produced large surpluses of these commodities, and with energy price shocks of the mid- and late 1970s, which brought forth serious economic and energy security problems for energy importing nations. Like some other biomass energy sources, ethanol has been able to substitute for imported high quality energy (gasoline) while offering a reliable market for indigenous products.

On a purely economic basis, ethanol requires a low cost fermentation feedstock and low production costs in order to compete with gasoline refined from crude oil. With oil costing $35 per barrel, this translates into corn at roughly $2 per bushel, molasses at $45 per ton, and sugar at 6¢ per pound (assuming wholesale gasoline @ $0.90/gallon, ethanol from corn @ 2.5 gal/bu., from molasses @ 70 gal/ton, and from sugar @ 185 gal/ton). With the relaxation of oil prices to $15 to $20 per barrel over the past two years, the economic justification for ethanol production has narrowed to fewer settings. For example, in developing countries this occurs where the delivered cost of gasoline and diesel is high, the value of feedstock such as cane molasses is low, and foreign exchange is at a premium. Beyond simple economics, however, ethanol production often has strategic importance and spin-off development, factors important to the ethanol programs in Zimbabwe, Malawi and Brazil. Ethanol by-products with lucrative developing country markets include single cell protein, cattle feed, shrimp/prawn feed and organic fertilizer.

Because of current low oil prices and significant premiums being paid for octane enhancers to displace lead in the gasoline pool, the economics of ethanol have changed in many gasoline markets. As an octane enhancer, ethanol has a value beyond gasoline replacement. For ten percent blends, ethanol adds about four octane points to commercial grade gasolines. For twenty percent blends, ethanol adds about seven octane points. In current retail markets in the U.S., each octane point is worth about 2.5 U.S. cents.

U.S. Experience

In the United States, financial incentives established in 1979 to promote alternatives to petroleum-based fuels have stimulated the growth of a large and diverse fuel ethanol industry, with a present capacity of one billion gallons per year (compared to Brazil, 3.5

BGY). The rush to create a new industry provided opportunity for the installation of plants with a range of sizes, feedstocks and technologies. Corn (maize) is the dominant ethanol feedstock for economic reasons, stemming from continued large surpluses, but production from sugar, molasses, barley, wheat, potatoes and industrial sugar wastes has also contributed to provide a strong base of commercial and technological experience.

In technical areas, U.S. industry holds a leadership position in commercial scale batch fermentation, batch with yeast recycle, cascade systems, and true continuous fermentation. In distillation, the U.S. offers competitive azeotropic systems using cyclohexane, ethyl ether and benzene, as well as commercial applications with molecular sieves and corn grits absorbents. There has been significant progress through the use of innovative process improvements, resulting in improved plant reliability, reduction of operating costs, and increased ethanol yields. In new technology areas, U.S. industry and research institutions lead the way in development of alcohol from wood and other non-starch biomass through both acid and enzymatic hydrolysis.

Of particular relevance to energy-conscious developing countries, U.S. expertise with electricity cogeneration, anaerobic waste treatment with methane recovery, and maximum efficiency in process energy use has been successfully exploited by the ethanol industry and incorporated in its commercial approach. Further, the lack of support by the automotive and petroleum industries has forced the U.S. ethanol industry to develop comprehensive knowledge of the role and performance of ethanol in petroleum blends in order to achieve acceptance of the product. Combined with the wide variety of technologies applied in the expansion of the industry, the U.S. can provide proven process, engineering and project development options to the prospective ethanol producer.

U.S. Experience with Utilization of Wood Residues

Dramatic increases in wood-fired base load power plants have occurred in the U.S. since 1978. Currently, biomass energy provides anywhere from 80 to 100 percent of the thermal and electricity needs for most of the U.S. and developed countries' forest products industry. Most plants use direct combustion of their wood wastes, with gasifiers being the exception rather than the rule in the industry. The commercial feasibility, technical capability, and financial advantages of wood combustion systems based on captive feedstocks are no longer major concerns for the industry. Rather, newer plants have adopted multi-fuel systems that give them the flexibility to shift between feedstocks, such as wood, coal and/or oil, based upon delivered fuel costs.

Over 3,500 wood-fired plants in the U.S. produce steam or steam and electricity. Almost 40 percent of such plants are producing electricity. In total, about 3,200 MW of electricity are produced, with two-thirds of these plants selling electricity to the grid. The remaining one-third is produced primarily by the paper industry for internal consumption.

Increasing popularity of wood-fired power plants is common throughout the U.S. in all major U.S. wood producing regions. All plants are under 80 MW. Of plants selling to the grid, the sizes cluster in the 15-25 MW range. In contrast, the paper industry tends to have larger systems ranging from 50 to 80 MW, sized to their internal steam/electric needs.

Most plants have come on-line since 1978 at which time tax credits and the institution of PURPA laws created financial and regulatory incentives for independent power systems. The U.S. wood products industry, as well as many independent power producers, have seen the financial benefits of shifting from fossil fuels, even with recent oil price trends.

A.I.D. EXPERIENCE WITH FIELD APPLICATION OF BIOENERGY SYSTEMS

Electricity from Sugar Cane Residues

A.I.D. activities to develop projects for production of electricity from cane residues are most advanced in Thailand and Costa Rica. Following cane energy assessments in these countries, project implementation is proceeding with cooperative ventures by government, utilities, A.I.D. and the cane industry. Activities in Jamaica and the Philippines are proceeding more slowly.

Costa Rica

The overall conclusion of the Costa Rica Cane Power Report (July 1988) is that the production and sale of electricity into the national grid could be an excellent investment opportunity for the sugar industry of Costa Rica and would provide important benefits to the national economy. Further, selected mills could commence electricity sales soon enough to help the national electric utility handle the surprising recent surge in demand that has materialized at the same time as hydropower reserves have been reduced by drought. Depending on the options selected, the industry could contribute from 17 to 500 million kilowatt hours of electricity while creating additional jobs in rural areas, diversifying the sugar cane industry into attractive new by-product markets and (in the short term) displacing up to $7 million now spent for imported petroleum. There are, however, important uncertainties or risk factors that need to be addressed. The availability and cost of supplemental fuels for energy production in the off-season is of critical importance. The attractiveness of investments in private power production and the amount of power that mills choose to produce also depend heavily on decisions by public authorities concerning matters such as loan rates, import duties, and the prices they are willing to pay for power.

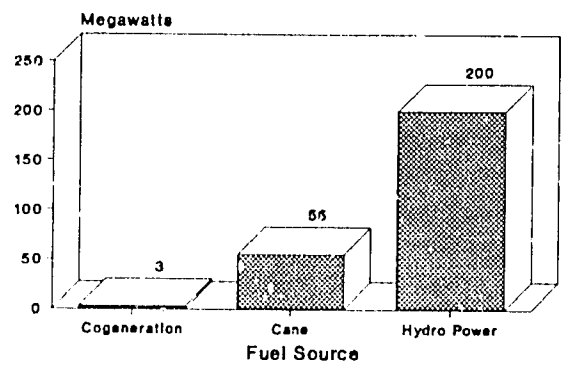
The study team chose three existing mills (Quebrada Azul, El Viejo and Taboga) to form the basis for its analysis and developed technical projections for four levels of investment and for each level estimated capital costs, electricity production and sales, and fuel options. The technical projections range from the simple sale of surplus power, without any new investments, to the installation of entirely new boiler-turbogenerator systems for year-round electricity production. A key conclusion of the sensitivity analyses is the importance of domestically produced biomass fuel, principally sugar cane field residues (trash) and/or plantation wood, in permitting mills to produce larger amounts of power at a cost that is competitive with other sources of electricity available to the country.

Extrapolating from surplus power scenarios analyzed in detail in the report, the Costa Rican sugar industry could, with minimal investment and little or no risk, produce some 17 to 19 million kilowatt hours per year (the equivalent of two to three megawatts annual capacity) for sale to the grid. But this surplus power production from bagasse (mill residue) would be available only during the dry season when the cane is being crushed. This timing is still advantageous to Costa Rica since the dry season is when there is the greatest need for additional generation capacity because of the seasonal reduction in hydropower output. Such an approach would result in annual petroleum savings from surplus power production of $120,000 to $165,000 per mill studied in this report.

For all-year electricity production, higher capital investments and additional off-season fuel supplies are needed. With supportive public policies on private power sales and larger investments ($9 to $20 million per mill), the industry might produce as much as 400 to 500 million kilowatt hours of power per year (the equivalent of 50 to 55 megawatts annual capacity), with several larger mills providing electricity on a firm basis for the entire year. The value of net national petroleum savings produced by each of these larger mills studied would range from $1.1 to $2.2 million per year, a substantial economic benefit to the country.

The precise pattern of production, of course, would depend heavily on local conditions and the investment decisions of mill owners and managers. In either case, the power produced could be sold for a price at or below that available from alternative new sources of electricity (diesel, gas, geothermal), and would provide additional economic benefits to the nation. Among the latter are increased rural employment and farm income as well as the displacement of imported fossil fuels. The exact amount of power that can be produced and the extent of national economic benefits, however, both depend partly on the extent to which mills are able to harvest and burn cane field residues or identify other biomass sources of fuel - the major technical uncertainty affecting the prospects for cane power production in Costa Rica. Figure 15 illustrates the cane power potential.

FIGURE 15
COSTA RICA COGENERATION POTENTIAL



Sources: Hagler/Bailly, 1987, A.I.D., 1988. Financially viable potential.

Thailand

In mid-1986, a team of cane energy specialists visited over a dozen sugar factories and examined a number of potential sugar industry products and their markets in Thailand. The study concluded that the most attractive option in the near term is the generation of electricity for sale to the national grid during the seven- to eight-month non-grinding season, when sugar factories do not use installed power equipment. National potential is estimated

at over 200 MW using existing installed capacity in the sugar industry, thus requiring no new capital investment.

Although the equipment in most factories is not highly efficient, it could be improved with minor investments. Combined with an inexpensive fuel source, this underutilized capital could provide electricity to meet national development needs quickly and without putting additional pressure on foreign borrowing. One potential fuel source available in Thailand in large quantities is cane field residues. Projected electricity generation costs are about four U.S. cents per kilowatt-hour, considerably less than current costs in Thailand. Once electricity markets are opened to the sugar industry, investments in more efficient power equipment will become attractive with a power generation potential using technologies currently being developed of over 1000 MW.

The Electricity Generating Authority of Thailand (EGAT) plans to publish regulations and procedures for purchase of electricity from cogenerators and small power producers and to issue a solicitation for 300 MW of power in 1989. A.I.D. has been cooperating with the Royal Thai Government, EGAT and a private sugar factory in Thailand to examine the economic and technical viability of collecting cane field residues to use as an off-season fuel for production of electricity at sugar factories.

Jamaica

A.I.D. supported preparation of an in-depth feasibility study, completed in September 1986 by Bechtel National, Inc. and RONCO Consulting Corporation, for a private sector 35 MW power project at the Monymusk sugar factory in Jamaica. Jamaica Sugar Holdings (JSH), Ltd., manager of the government-owned factories at both Monymusk and Frome (two largest sugar factories in Jamaica), cooperated in preparation of the study. Proposed fuels for the project are sugar cane bagasse, oil and possibly cane field residues (trash). The project would provide an additional source of revenues to the financially troubled Monymusk factory eliminating the need for government subsidy and boosting employment in the region.

Based on the projected returns of the proposed project, Bechtel made a proposal to the Government of Jamaica in December 1986. Although the GOJ did not act on this proposal, they have expressed support for the installation of improved electricity generation equipment at Jamaican sugar factories and for sale of power to the Jamaican grid. JSH, Ltd. remains interested in upgrading the Monymusk facility and also has begun discussions about replacing boilers and power generation equipment at the Frome factory.

Elsewhere in Jamaica, Petrojam, operators of the sugar factory at Bernard Lodge and producers of alcohol from molasses, requested bids for new more efficient boilers and power generation equipment in 1988. Implementation has been delayed by changes in available financing, but Petrojam still plans to procure improved equipment as soon as possible.

A.I.D. continues to work closely with Petrojam, JSH, Ltd., the Sugar Industry Authority, the Sugar Industry Research Institute (SIRI) and the GOJ to examine the potential for collection and preparation of cane trash for use as a boiler fuel. The use of trash could substantially improve the financial returns of year-round electricity generation at Jamaican sugar factories. Equipment specially designed by Cameco Industries for collection of cane trash under Jamaican conditions is currently being tested in Jamaica.

Philippines

One part of a comprehensive analysis of the sugar industry in the Philippines prepared in the spring of 1986 reported on the potential for power generation and sale of excess electricity. The Philippines sugar industry has been particularly hard hit by changes in global market conditions and internal mismanagement. Many of the mills rely on old boilers that need to be replaced or refurbished.

Electricity production by the sugar industry appears most attractive on the island of Luzon where the sugar industry is relatively strong and demand for power is growing more rapidly than the addition to capacity Cancellation of the planned opening of the nuclear power plant on Luzon in 1986 exacerbates the anticipated problem. The team found that investments in new boilers and generators at sugar factories offer attractive rates of return at electricity prices well below the current wholesale levels in the Philippines.

As in most countries, the sugar industry only crushes cane part of the year, 120 to 180 days. Existing capacity at sugar factories on Luzon is about 130 MW. Investment in new boiler and generator units at exisiting factories would add an additional 100 to 150 MW.

Alcohol from Sugar Cane and Molasses

The attractiveness of producing fuel alcohol from sugar cane in A.I.D.-assisted countries depends on world prices for petroleum, sugar and molasses, as well as on local and regional economic factors and trade relationships. The recent fall in oil (and alcohol) prices and sugar price increases illustrate the volatility of these markets. Through the BST project, A.I.D. has sought to perform careful analyses of the costs and benefits of alcohol production by sugar industries under various price scenarios and with a view toward promoting diversification of the sugar industry into a variety of commercial products. A.I.D. supported detailed alcohol assessments in Honduras, the Philippines and Malawi that are summarized below.

While debate in the U.S. centers around the continuation of subsidies for ethanol, it is clear that there are A.I.D.-assisted countries where new ethanol developments make sense without subsidies. Some of these are Zimbabwe, Swaziland, Sudan and Malawi; should world energy prices rise, other countries become candidates as well. Further, as new technology becomes commercial and by-product markets expand, it is likely that feedstocks other than molasses will become cost-effective sources for conversion to high-grade liquid fuels.

Honduras - Fuel Alcohol Production

In the first half of 1986, a team of specialists conducted an economic, financial and technical analysis of alcohol production for export by the sugar industry in Honduras. As in other countries covered by the Caribbean Basin Initiative (CBI), interest in alcohol stemmed from the prospect of duty-free export to the growing U.S. market. During the course of the study, the estimated returns from alcohol dropped as its price fell with the fall in oil prices, and alcohol was projected to be only slightly better than world market sugar over the short term, making major investments risky. The study recommended against a Honduran subsidy or incentives for domestic alcohol use, but recommended investment by the sugar industry in a 120,000-150,000 liter/day distillery so that Honduras could take advantage of subsidized U.S. alcohol markets when world sugar prices were poor. The report also examined applications for production of yeast, bagasse-based animal feeds and carbon dioxide for local markets from the sugar industry.

Philippines - Sugar Industry Diversification

A second part of the sugar industry analysis in the Philippines looked at opportunities to produce ethanol from molasses and/or sugar for blending with gasoline for domestic consumption. It concluded that the market potential for ethanol was not promising without subsidies or higher world energy prices unless the government of the Philippines was willing to pay a premium for a domestic octane additive to displace lead in the gasoline pool in Manila. Lead levels in the air in Manila, primarily from automobile exhaust, greatly exceed commonly accepted world standards. However, in strict financial terms (no credit given for foreign exchange savings, employment benefits or domestic multipliers) without consideration of potential byproduct benefits, lead could be displaced more cheaply with MTBE from refineries in the region than with ethanol.

Malawi - Ethanol Expansion Feasibility

In late 1988, the Government of Malawi (GOM) requested A.I.D. help to assess the feasibility of increasing the production and use of ethanol from molasses as a transportation fuel in Malawi. Because of high freight costs, the delivered cost of petroleum products in September 1988 was over US $1.20/gal in Malawi. Molasses has negligible value since the cost of shipping it to a port for export exceeds world market price. Conversion of low value molasses to ethanol clearly makes sense and currently saves some US $3 million per year in foreign exchange. Malawi has had a blend program since 1982 and now produces approximately 10.5 million liters of ethanol per year that yields about a 14 percent blend at current levels of gasoline consumption.

At present sugar production levels, ethanol produced from all surplus molasses in Malawi would be more than can be absorbed by a 20 percent blend with gasoline at present gasoline consumption levels in the country. Blends above 20 percent ethanol require other additives or modifications to engines.

In its preliminary conclusions, the team recommended that the blend level be increased to 20 percent and found the use of neat fuel (100 percent ethanol) in sugar cane estate

tractors and in some GOM fleet vehicles to be a profitable and economically sound strategy for expanded ethanol consumption. The final report will recommend a least cost expansion strategy, compare two proposed sites for new ethanol production and recommend steps to continue private investment and management for a larger industry.

Electricity and Process Heat from Rice Residues

India

The Punjab Agro Industries Corporation (PAIC) of northern India is proposing to establish a commercial scale (2.5 MW) biomass power plant fueled by rice straw. In partnership with PRM Energy Systems, Inc., of Stuttgart, Arkansas, and supported by local engineers (ICB Private Ltd. of New Delhi), PAIC intends to demonstrate the commercial viability of power production from agricultural wastes using a system requiring collection, baling, storing, and processing of rice straw as a combustion fuel.

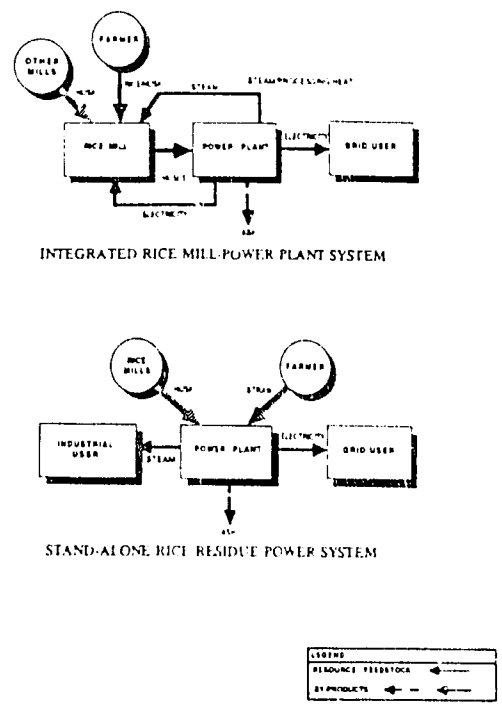
Upon demonstration of technical and system viability, PAIC intends to replicate this project throughout the Punjab using 1.5 to 10 MW versions of the facility at an average cost of $5 million/plant and producing 1000 MW throughout the region. Anticipated steam and electricity sales from the first plant will average $2.5 million/year with ash sales profits of over half a million dollars/year. Annual fuel costs for straw @ 200 Rps/ton will average $900,000. Net profit before taxes should average over $1.0 million per year.

Given the extraordinary volume of agricultural wastes available in India, the success of this project could open the door for extensive mobilization of biomass resources for energy production in India.

Indonesia - Potential for Private Investment in Rice Residue Power Generation

Rice residue electric power systems can either be associated with a rice mill, utilizing the mill's captive feedstock, or stand alone as power plants that purchase part or most of their feedstock from farmers or mill owners in the surrounding area. (See Figure 16.) A.I.D. supported examination of resource availability, costs, and policy impacts for both models in Indonesia in 1987.

Figure 16



Commercially proven rice husk electric power systems in the U.S. depend primarily

on captive feedstocks of 80,000 to 120,000 MT/year. With the exception of the few large mills on Java, the current average size of rice mills (1 ton paddy [gabah]/hr) in Indonesia does not allow for sufficient accumulation of captive rice husk feedstock for these mills to depend exclusively on their own feedstock for power systems of even 600 kW to 1.5 MW. Adequate surplus husk and straw, however, are available in enough rice growing/milling areas (even at a 25 percent availability rate) to suggest that collection-based systems are an option.

The analyses conducted in Indonesia suggest that rice residue power systems which incorporate efficient technology and use collected husk or straw (though not necessarily as mixed fuel) may be profitable over a wide range of feedstock costs - up to three times current market prices - given 1) dependable electricity sale prices of 90 Rp or more per kWh, 2) high load factors (over 75 percent) at the power plants, and 3) guaranteed ash markets. Potential benefits of rice residue power systems to the agricultural sector include waste utilization and ash sales, reliable rural electricity, additional farm and off-farm jobs, and increased "value-added" to the rural economy of Indonesia. Balanced against these economic incentives is the current high risk for investors in private power systems due to the lack of clear legal guidelines and institutional support in Indonesia.

Current Low Value Use of Rice Husk as Brick Kiln Fuel

Although private investment in collection-based residue power systems may be attractive for particular sites, the need to organize a reliable supply of husks makes it unlikely that private investors will try to develop projects without guarantees or additional incentives.

Philippines

In late 1986, a team of rice power consultants examined the potential for generating electricity from rice residues in the Philippines. The team found:

- Several areas with extensive cultivation of rice and an infrastructure to support plants;
- Experienced local contractors with a demonstrated construction capability;
- Supportive business environment; and
- Readily available qualified local partners.

After the completion of the study, the Agri-Energy Roundtable more closely examined risks associated with advanced rice residue utilization technology as part of a meeting for local

agribusiness leaders in the Philippines. Dialogue in the Philippines and with U.S. companies continues. In early 1989, the U.S. Trade and Development Program agreed to co-fund analysis of specific opportunities for generating power using rice husks with Agrilectric.

Electricity and Process Heat from Wood Residues

Indonesia

Indonesian exports of wood products have greatly increased in the past few years. Although as much as 50 percent of the raw lumber entering a plywood factory remains as waste, the industry routinely uses diesel fuel for primary or supplementary power generation. Most of the wood products factories are located off Java where local electric power grids do not yet exist. The waste is either piled in heaps and burned, used for landfill, or dumped in rivers and the ocean.

Most wood products plants in the U.S. obtain the majority of their energy requirements (steam and electricity) by burning their wastes. The Indonesian industry could reduce energy costs, mitigate the environmental consequences of waste disposal and increase revenues by adopting similar systems. The team estimated the total market for energy equipment sold to the wood products industry could be as high as US $400 million.

Wood Waste Accumulated at an Indonesian Mill

Wood waste currently produced at Indonesian sawmills and plywood factories is sufficient to power some 1,000 MWe of distributed small steam power plants. The team found that even with the present 50 percent subsidy of diesel fuel in Indonesia, small (ca. 2.5-3 MWe) integrated standardized wood waste-fired power plants are economically attractive.

The widespread use of this technology ultimately could; 1) provide significant power for economic and social development on Indonesia's outer islands; 2) establish new private sector initiatives for the production, sale, installation, and maintenance of wood waste power systems; 3) increase the stability of the private wood products industry; 4) increase diesel fuel exports; and 5) improve the environmental and health conditions of the plywood manufacturing industry.

The team report discussed broader environmental issues associated with the development of the wood products industry in Indonesia. The report only examines use of wood waste presently produced by the forest products industry; wood is far too valuable in the form of

exported products to be used in its primary form as fuel. However, revenues produced by utilization of wastes will help increase the total value of wood products per hectare of land and may provide opportunities for creative approaches to improved forest management.

Costa Rica

The BST project initiated a remote location biomass gasification project near the town of Horquetas, Costa Rica in 1983. The intention of the activity was to produce electricity for Horquetas using residues from forest management activities planned in the adjacent forest. The project planned to install and operate a 150 kW wood gasifier.

The project in Horguetas was not successful. Two separate attempts to procure and install commercial gasification equipment failed undermining the planned forest management activities. From this experience, A.I.D. concluded that gasification equipment was not commercially ready for installation at remote sites. The limited number of manufacturers and lack of sufficient operating experience make costs and performance predictions unreliable.

The experience also highlighted the confusion that often exists between pursuit of development objectives and choice of technology. Subordinating broader project objectives to the choice of technology requires the technology be proven before the project can proceed. For future projects concerning energy from biomass where A.I.D. wants to support technology development, project objectives and funding will be broken into phases. With defined phases, failure to choose a viable technology does not discredit broader objectives.

ECONOMIC AND FINANCIAL ANALYSES OF BIOMASS ENERGY SYSTEMS

In many of the studies prepared by A.I.D. on bioenergy systems, detailed economic and financial analyses have been prepared to identify project risks so that steps can be taken to enhance the likelihood of success and to quantify both macroeconomic and microeconomic benefits for both the private and public sectors. Economic analysis can help quantify and clarify the impacts of various policy decisions. The following summaries illustrate how these analyses have been used.

Cane Energy Systems - The Example of Costa Rica

The analysis for cane energy systems in Costa Rica examined four capital investment and power output assumptions for target mills. Present value analyses of the mills show cane energy production to be attractive at a variety of investment levels. From a financial perspective, mills could expect to receive anywhere from US $1 to $3 million in net returns before taxes.

Beyond the net returns on investment, the report compares the capital and foreign exchange requirements against the amount of power to be sold to the grid for the various options. Levels 1 and 2 require little or no capital, and similarly have zero or low foreign exchange needs. In contrast, Levels 3 and 4 often have NPVs near Level 2, but require US $10 to $20 million of capital, US $6.7 to $8.7 million of which is foreign exchange.

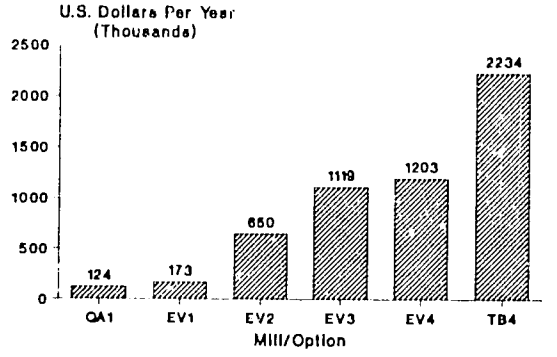
Figure 17 presents results for one factory that show buying more efficient equipment does not always yield better financial and economic returns for all factories. The investments for both Level 3 and 4 at El Viejo factory increase the total power produced but have lower NPV's than the Level 1 and 2 investments.

FIGURE 17: EL VIEJO MILL, COSTA RICA: IMPACT OF CAPITAL INVESTMENT ON NET PRESENT VALUE AND POWER EXPORT (1988)

Capital Investment Level (M US $)	NPV (M US $)	Power Export (M kWh/yr)
0.00	1.10	1.6
1.54	2.86	9.6
9.59	2.62	91.9
17.31	-0.09	101.6

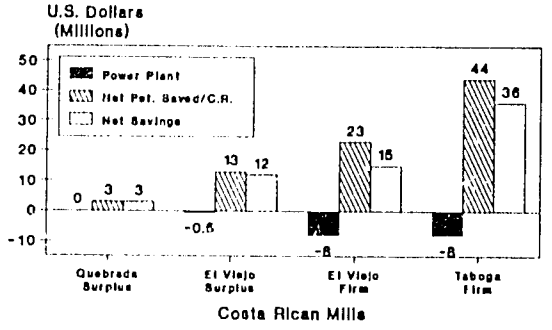
Sugar mills that contract to sell electricity throughout the year will need to supplement bagasse produced at the factory with some other fuel source. To be conservative, the financial and economic analyses presumed this supplemental fuel would be oil. Figure 18 shows annual petroleum savings projected per mill for several scenarios reviewed in the report. Figure 19 gives the net foreign exchange savings that result from development of sugarcane power systems.

FIGURE 18: COSTA RICA ANNUAL NET PETROLEUM SAVINGS BY MILL



Source: A.I.D./TVA 1988 Assumes $18/bbl
Quebrada Azul, El Viejo, Taboga Mills

FIGURE 19: TOTAL NET FOREIGN EXCHANGE SAVINGS FOR SUGARCANE POWER SYSTEMS IN COSTA RICA



Source: A.I.D./TVA 1988. For 20 yrs.
Surplus (1-3MW) & Firm Power (12MW)

Beyond the benefits to specific mills, the country reaps important foreign exchange savings through petroleum displacement from cane power production. Benefits occur from the (1) displacement of previous electricity and direct petroleum use at the mill and (2) displacement of central station diesel use from the portion of exported cane power based on bagasse use. Net annual savings to the mills in this study range from $123,000 to $2.2 million per year, which over a twenty year life amount to significant foreign exchange savings to Costa Rica (Figure 18). Generalizing from these findings to the broader potential for cane power in the country gives annual petroleum import savings of as much as $7 million per year.

Energy from Rice Residues - The Example of Indonesia

A similar sensitivity analysis for rice residue power systems conducted in Indonesia in 1987 found the financial soundness of rice residue power production using commercially proven technology to depend more on power sales price and on successful marketing of power plant ash than on collection costs associated with mobilizing the amounts of rice husk or straw required to fuel even the smaller scale versions of proven systems. This finding was a surprising contrast to prevailing wisdom which usually asserts the need for biomass energy systems to operate on site-collected wastes, presuming prohibitive collection costs.

The smaller units (600 kW) were competitive even against the current utility tariffs (103 RP/kWh) which are low by world standards. Larger systems (1.5 MW), however, were competitive only when the utility's purchase price accounts for actual electricity production costs incurred on the outer islands.

Energy from Wood Residues - The Example of Indonesia

Wood waste, which represents up to 50 percent of the total raw lumber entering a plywood factory, is typically piled in heaps and burned, used for landfill, or dumped in rivers and the ocean in many developing countries. This waste constitutes a potential energy resource for on-site power generation. A pre-feasibility study was conducted for BST of its use as a fuel in generating power within the Indonesian wood products industry at plywood industry sites to mitigate the environmental consequences of its dumping and displace diesel use at these factories.

The preliminary financial analysis of 3 MW wood waste power plants suggests (Figure 20) that even with the present 50 percent subsidy of diesel fuel in Indonesia, a 2.5 MWe wood waste-fired power plant could be fully paid for in six years or less, with a 25 percent return on equity. This return primarily reflects the savings in diesel fuel costs, assuming that the wood waste is available at no cost for use as fuel. If operation, maintenance, and diesel generator replacement costs are included in the analysis, the effective payback time becomes even shorter. If the Indonesian government were to phase out the present diesel fuel subsidies over a five-year period (starting in 1990 - the projected first year of plant operation), the payback period would decrease to three years and the return on equity could be 60 percent.

Diesel prices are the key factor affecting project economics. By contrast, if the price of diesel fuel is at the world market price, the fuel price savings are so great that the payback time is relatively insensitive (1.0 vs 1.25 years) to whether or not there is a $3/m^3$ charge for the wood waste. The before-tax return on investment is well above 100 percent (the owner's equity is repaid in the first year!). For purposes of analysis, it also was assumed that the price would be gradually raised over a five-year period to the world market price. Under this condition, the payback time is 3.0 years (if wood waste is free) or 4.25 years (if wood waste costs $3.00/m^3$ to the plant operator), and the respective before-tax return on equity is either 60.7 or 44.3 percent.

FIGURE 20: FINANCIAL SENSITIVITY ANALYSIS
24 MW WOOD WASTE POWER SYSTEM IN INDONESIA[1]

Price Scenarios		Financial Impact	
Wood Diesel Price ($/Liter)	Waste Price[2] ($/ton)	Payback Time[3] (Years)	Pre-Tax Return on Equity
0.13	5.43[4]	12.5	12.9 %
0.13	0.00	6.25	25.2 %
0.26	5.43[4]	1.25	> 100 %
0.26	0.00	1.0	> 100 %
Subsidy Phaseout[5]	5.43[4]	4.25	44.3 %
Subsidy Phaseout[5]	0.00	3.0	60.7 %

1. Source: A.I.D./TVA, A Prefeasibility Assessment of the Potential of Wood Waste Power Systems for the Indonesian Wood Products Industry, 1988
2. It is assumed that all of the wood waste could be sold at this price. In practice only 5 - 30% of the wood waste is sold for firewood and as scrap for building huts.
3. On equity.
4. Equivalent to $3.00/m^3$ of green wood (23% moisture content).
5. Present 50% subsidy phased out linearly over a 5-year period beginning in 1990.

BST PROJECT RESEARCH INITIATIVES

Development of Off-Season Fuels for Sugar Mills

Bagasse Drying and Storage

Bagasse (the fibrous by-product of milled sugar cane) typically has high and variable moisture content. Reducing the moisture content of milled bagasse would improve both its effective fuel value so that each unit of bagasse could generate more steam and electricity and its combustibility reducing operational difficulties and opacity.

Several methods to reduce and stabilize the moisture content of bagasse have been proposed and/or used, most notably, drying bagasse with hot flue gas (as is being practiced at four Hawaiian raw sugar factories) and dehumidifying bagasse via chemical or biological treatment (as is being practiced in at least one sugar factory in Brazil). However, questions relating to these processes continue to be raised: Do these practices result in net energy savings when viewed on a total-system basis? Does induced drying (with chemical/biological treatment) substantially accelerate the natural drying process and improve recovery of the original fuel?

The Hawaiian Sugar Planters' Association in a cooperative agreement with A.I.D. will evaluate 1) bagasse drying, densification, storage, and preservation practices; 2) flue-gas drying; and 3) use of chemical/biological treatment to accelerate drying and/or preserve bagasse.

Residue Collection Field Tests

Given the duration of cane harvest seasons (from three to seven months in most locations), sugar mills must identify fuels to supplement bagasse if they hope to generate and provide electricity to the grid throughout the year. Year-round generation is necessary to receive the higher prices for electricity sold to public utilities and/or industrial customers, and to justify capital investments in new equipment with higher efficiency.

When sugar cane is harvested, the tops and leaves are separated from the millable cane and left behind in the fields. In most instances this material is burned in the fields either before or after the harvest of the cane stalk. These tops and leaves are a large potential source of biomass fuel with combustion characteristics similar to bagasse.

In both Jamaica and Thailand, A.I.D. is sponsoring trial year programs to collect a reasonable quantity of tops and leaves to be used for boiler fuel to demonstrate the technical, economic, and environmental feasibility of this technology under existing conditions. A major objective is to obtain cost and performance data that an investor will need before deciding to invest in a cane energy system based on the use of tops and leaves. Baling equipment has been procured and operated in these programs.

Advanced Biomass Conversion Systems

Steam Injected Gas Turbine Cogeneration for the Cane Sugar Industry

Under a research grant from A.I.D., the Center for Energy and Environmental Studies (CEES) at Princeton is evaluating the impact cogeneration systems using advanced gas turbines could have on the cane sugar industry specifically. Major improvements in the performance of gas turbines in the last decade come largely from advances in jet engine technology. Based on the 1985 level of sugar cane production CEES concluded that some 50,000 MW of gas turbines fired with sugar cane residues producing some 300 billion kWh annually could be supported globally.

In estimating potential for conserving steam, CEES shows that a typical sugar factory in the world today produces about 20 kWh per tonne of cane crushed. Modern factories operating in Hawaii can produce as much as 100 kWh per tonne of cane crushed. Advanced gas turbine systems could double this latter output at lower capital costs. In one analysis annual electricity revenues (at $0.05/kWh) equal sugar revenues ($0.23/kg) for an advanced gas turbine system.

Matching Biomass Gasifiers with STIG Units

Princeton University is also exploring the matching of biomass gasifiers with steam-injected gas turbines.

The steam-injected gas turbine (STIG), which to date has only been fired with natural gas or distillate oil, is a good candidate for firing with biomass. Most agricultural and forest product processing facilities only produce sufficient residues to fuel relatively small power plants (5-50 MW). In this size range, gas turbines are more efficient power generators than steam turbines, and unit costs are lower and less sensitive to scale than those for steam turbines or gas turbine/steam turbine combined cycles. The STIG is a recently-introduced modification of the simple-cycle gas turbine that offers significantly improved performance across a range of outputs. In a STIG, steam raised using the hot exhaust gases from the gas turbine is injected into the combustor or directly into one or more stages of the turbine, resulting in a significant increase in power and efficiency.

Among alternative biomass-fired STIG systems, the most promising in terms of high efficiency, low capital cost, and near-term commercial viability is one which couples the STIG to a gasifier. In the gasifier-STIG (GSTIG) system, biomass fuel is fed into a pressurized reactor, where it reacts with air and steam and is converted into a combustible gas. Contaminants are removed from the hot gas which is immediately burned in the gas turbine combustor. Although most of the steam raised from exhaust gases is injected into the combustor, some is used in the gasifier. In cogeneration applications of GSTIG, only steam not used to meet process needs would be injected.

The flexibility to use steam for process or for additional power makes the GSTIG well suited to cogeneration applications where process steam loads vary widely, as in

biomass-processing industries that operate seasonally, and where excess electricity can be marketed, e.g., sold to a utility. The GSTIG would thus be a serious competitor to condensing-extraction steam turbines, the traditional workhorse of process industries.

There are large potential markets for biomass-GSTIG systems. Initial applications might be for industrial cogeneration at biomass-processing facilities. Over 50 GW of capacity could be supported by residues available in the cane sugar industry alone. (Figure 21) Considering the residues from saw mills, pulp mills, and corn and rice production, over 250 GW of capacity could be supported worldwide. In the longer term, it is even conceivable that dedicated energy plantations might provide fuel for stand-alone GSTIG power plants.

FIGURE 21
ESTIMATED POTENTIAL WORLDWIDE GSTIG GENERATING CAPACITY AT SUGAR FACTORIES WITH THE 1985 LEVEL OF SUGAR CANE PRODUCTION[a,b]

Region	Potential Electrical Capacity (MW)
South America	17,800[c]
Asia	14,000
Central America	10,100
Africa	4,900
Oceania	2,700
United States	1,900
Europe	200
Total	51,600

[a] Sugar cane production, assuming ten tonnes of cane are required to produce one tonne of sugar. Sugar production data are from the International Sugar Organization.
[b] Assuming a 206 day season, 24 hour/day operation, 90% plant availability, and a GSTIG fuel requirement corresponding to 180 tonnes of cane per hour for a 53 MW unit.
[c] Includes capacity that would be installed at alcohol production facilities in Brazil.

Energy Efficiency in Sugar Factories

In other research CEES at Princeton is studying cane mill energy efficiency. A September 1987 report by Princeton University titled "Steam-Injected Gas Turbine Cogeneration for the Cane Sugar Industry" summarizes the focus of this research.

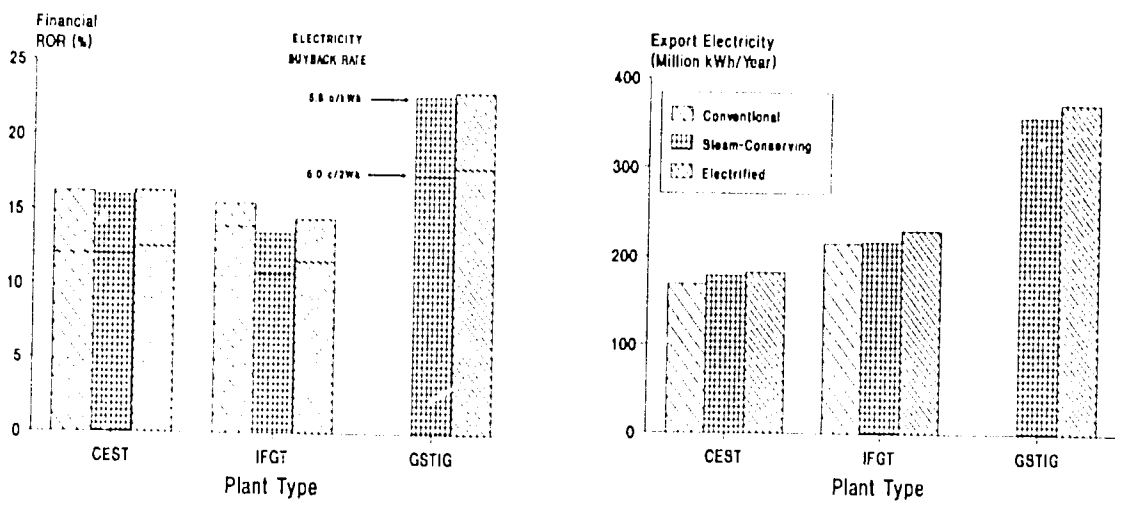
Regardless of the type of cogeneration technology installed, process-steam conservation appears worth considering because of the additional export of electricity this permits. Additional export electricity could also be made available if factory electricity demands

could be decreased, e.g., through the use of more efficient electric motors and variable speed motor drives. Industrial experience with such equipment is growing, although virtually no experience exists with such equipment in cane-sugar factories. However, given the extensive use of motors, pumps, and fans in the typical sugar factory, the potential savings may be substantial. As part of present studies an assessment of this potential is being undertaken, including on-site management of motor and motor-system performance in typical sugar factories.

To explore the costs and benefits of factory energy conservation, three plausible end-use scenarios with decreasing levels of steam consumption are used as the basis for subsequent financial analyses. In each case, the design cane throughput is nominally 175 tonnes per hour.

With steam-conserving retrofits, the rates of return for the Condensing Extraction Steam Turbine (CEST) and Indirectly Fired Gas Turbine (IFGT) systems do not change significantly, but for the Gasifier Steam Injected Gas Turbine (GSTIG) system, the rate of return would improve from 18 to 32 percent. In addition, the GSTIG plant would export about 60 percent more electricity than the IFGT plant and about twice as much as the CEST plant. Conserving more steam by electrifying the factory would improve the rate of return slightly in all cases, and lead to a small increase in export electricity production. Figure 22 shows financial rates of return and annual electricity exports for the three end-use scenarios considered.

FIGURE 22: FINANCIAL RATES OF RETURN AND ANNUAL ELECTRICITY EXPORTS FOR COGENERATION AND PROCESS-EQUIPMENT INVESTMENTS AT "CONVENTIONAL," "STEAM CONSERVING," AND "ELECTRIFIED" FACTORIES CRUSHING 175 TONNES OF CANE/HOUR, 206 DAYS/YEAR, WITH 90% AVAILABILITY



Source: Center for Energy and Environmental Studies, PU/CEES Report No. 217, 1987

ENVIRONMENTAL ASPECTS OF BIOMASS ENERGY

Environmental Agenda

An overriding goal of A.I.D. is the promotion of environmentally beneficial energy systems and resource use practices. Project selection focuses on biomass energy projects in the agro-processing sector that foster efficient and environmentally sustainable waste utilization. Waste utilization of this kind reduces the negative environmental impacts usually associated with waste disposal (air, water and soil pollution), while providing to the farmers increased value-added from resource inputs. Environmentally sustainable crop production practices, such as in the wood products industry, are in fact a prerequisite for continued success of biomass energy activity. A.I.D.-sponsored initiatives document the impact that the introduction of new systems will have on the environmental and sustainability.

Background

Two technical and two conceptual distinctions help set the background for a discussion of key environmental aspects of biomass energy systems. The first distinction is the difference between processing wastes and field wastes. Processing wastes are removed from the field with the food component and become a by-product during processing. Wastes from this activity are accumulated in large volume (i.e., 1000 tons of rice paddy processed yields 250 tons of rice husk and 1000 tons of sugar cane stalk processed yields 300 tons of bagasse). These wastes are seldom returned to fields and therefore do not contribute in any way to revitalization of the soil. They also constitute a disposal problem with large logistical and adverse environmental impacts. A.I.D. concentrates first on use of processing wastes. Field wastes, by contrast, are the biomass residues of the crop which are generally separated at harvest and left in the field. In the majority of cases field residues are either burned in the corners of harvested fields or torched across entire fields. Field burning is a major source of air pollution in some locations and an increasing problem, witness the cases of Po Valley rice in Italy where burning was banned in 1988 by the Italian government because of the resulting highway accident rate, and of prohibitions on cane trash burning in Maui, Hawaii.

Another technical distinction of importance is the difference between biomass residue energy systems and biomass plantation energy systems. In plantation systems biomass is deliberately planted as an energy crop. Energy crops must compete with food crops for land and water, although closer investigation often shows biomass energy plantations are appropriate for lands where food crops cannot be produced economically. In some cases, biomass energy plantations can provide revenues to support sound land management practice needed to sustain adjacent agricultural areas (e.g. watersheds).

An important conceptual distinction is the difference between fact and generally accepted opinion. In most cases, scientists do not fully understand the mechanisms by which residues left in the field affect future crop production or the sustainability of the agricultural system. These mechanisms will vary from crop to crop and from site to site. Despite the general assumption that plowing field residues back into the soil is beneficial, few attempts have

been made to assess actual benefits or to quantify the optimal quantity of residues that should be plowed under. Studies have produced conflicting results. Large quantities of residues plowed into the soil have been linked with high levels of biological activity in the soil that consume nutrients needed by the new crop. Soil percolation problems and the accumulation of herbicides and pesticides in soils have led some communities to ban the plowing under of field residues altogether.

The final distinction is derived from understanding the environmental criteria successful commercial systems in the United States have satisfied. Utilization of processing wastes for marketable energy products can improve the economic bottom line of processing facilities considerably. Where systems are successfully operating in the U.S., their performance meets current air and water quality standards.

Processing of agricultural and forest products produces various solid, liquid and gaseous waste products. Waste products obviously differ depending on the crop being processed and the processing system being used. Introduction of new systems will often alter waste streams. Careful consideration needs to be given to environmental impacts before proceeding.

Air and Water Pollution

Power generation technologies that convert current waste streams into electricity generally represent improvements over current practices at processing plants. For example, the sugar industry currently burns bagasse inefficiently to produce steam and electricity for the sugar factory. Introducing efficient equipment not only yields more steam and electricity per tonne of fuel but it significantly reduces particulate emissions. Stack emissions and opacity are much better for sugar mills in Hawaii than for the vast majority of mills in A.I.D.-assisted countries. Most biomass contains low levels of sulfur and temperatures of boilers that burn biomass can easily be maintained to avoid NOX problems.

The impact of biomass-fueled power plants on water quality is not fundamentally different from any other power generation technique. Ethanol facilities, however, produce distillery wastes that are often cited for negative impacts on water quality. Minimizing environmental impacts requires careful planning and the development of systems that provide incentives for improved resource management.

Agronomic Impacts

Systems that remove residues from the forest or field will affect nutrient cycling, soil characteristics, and water retention among other things. How removal of residues will affect the sustainability of production will vary from crop to crop and site to site.

As part of A.I.D. reasearch on cane field trash collection systems, specific and detailed data are being developed on the impact of the removal of cane tops and leaves. The long-term goal of biomass energy systems is to maximize the income of rural people who earn their living from the land. Biomass energy systems by definition are dependent upon the

continued vigor of biomass production; if residue removal were to reduce productivity, there would be no sense in pursuing this alternative as a means to assist the rural agricultural sector.

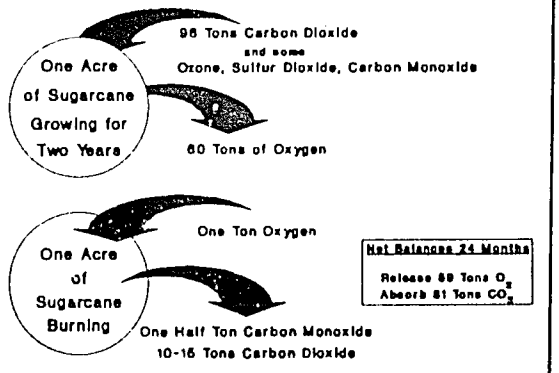
Carbon Dioxide and Global Warming

Recent attention on the excessive release of carbon dioxide to the atmosphere from fossil fuel combustion and clearing tropical forests highlights the long-term impacts on global climate. Scientists are increasingly in agreement that the increase of carbon dioxide and methane in the atmosphere will lead to increases in average global temperatures.

Use of sustainable biomass feedstocks to produce electricity and liquid fuels can increase the energy available for economic development without increasing carbon dioxide emissions. Carbon dioxide is removed from the atmosphere each year as part of the process of growing the next year's fuel. In addition, managed plantations offer a way to reduce the net carbon dioxide in the atmosphere in the short term. As long as new growth of biomass exceeds consumption of biomass for electricity or liquid fuels, biomass energy systems are part of a global solution.

In the case of sugarcane, for example, Figure 23 illustrates data provided by the Hawaiian Sugar Producers' Association; the net carbon dioxide absorption by one acre of sugar cane is 81 tons over a two-year period (the harvest cycle for sugar cane in Hawaii.) Biomass to energy systems use the fixed carbon from cane tops and leaves to produce energy as opposed to allowing the fixed carbon to return to the atmosphere as carbon dioxide after being left in the field, landfilled or dumped in the ocean. In other words, using biomass for energy is only an intervention on the inevitable road to the same carbon dioxide release.

FIGURE 23
NET CARBON DIOXIDE FROM SUGARCANE
(Two Year Hawaiian Cycle)



Source: Hawaiian Sugar Producers' Assn., January 1989

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