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

## VOLUME I: SUMMARY

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

## VOLUME I: SUMMARY*

KAUAI, HAWAII

Sponsored by:

U.S. Agency for International Development
Bureau for Science and Technology
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and

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*Volume II: Cane Energy Utilization Papers

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CANE ENERGY SYMPOSIUM

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* VOLUME II CANE ENERGY UTILIZATION PAPERS
Volume II can be obtained on request from:
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# CHAPTER I

# EXECUTIVE SUMMARY

# CANE ENERGY PRIORITIES AND OUTLOOK

## Executive Summary

The Cane Energy Utilization Symposium, co-sponsored by U.S. Agency for International Development (USAID) and the Hawaii Natural Energy Institute (HNEI), provided a unique opportunity for cane energy and sugar industry experts to share their experiences in cane residue collection, storage and use[1]. The Symposium was the first such conference to bring together field, commercial, and research experience of cane energy experts throughout the Asia-Pacific and Caribbean regions. Participants visited successful commercial facilities, compared field experiences in different countries and discussed applied research on high yielding cane varieties and new cogeneration systems. They reviewed field data and technologies that have proven successful for different countries and circumstances, and noted obstacles as well as inducements to replication.

The Symposium confirmed the importance of this new resource base for energy production in developing countries where sugar is an important crop. The increased cost of energy and the need to conserve scarce foreign exchange have drawn the attention of energy and sugar-industry experts to the enormous quantities of residues that are currently treated as a waste product in most regions of the world (see Table II.1).

Preliminary evidence, brought together at the Symposium from various experimental programs and analyses, suggests that cane residues (primarily tops and leaves) can be harvested, transported, stored and prepared for combustion at a price ranging from $8 to $16 per metric ton, the equivalent of approximately US$ 0.80 - 1.60 per million BTU (at 35% moisture). This compares favorably with fuel oil at some $2.70 per million BTU--even at the low oil price of $15/barrel.

As Symposium experts pointed out, this suggests that the development of effective harvest and delivery systems will make available an economically attractive fuel in significant quantities. Sugarcane is the largest crop in the world, with some 600 million tons harvested annually. If only ten percent of the 2/3 tons of field residues produced for every ton of cane were to be harvested, this would make available the equivalent of some

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[1] Cane residues can be classified into two categories - field residues and bagasse. Field residues, also known as cane trash or barbojo are the sun-dried sugarcane tops and leaves that are separated from the millable canes upon reaping, either by hand cutting or by mechanical harvesters, and which may be recovered from the fields for use as a biofuel or chemical process (i.e., furfural, etc.) feedstock; the approximate field moisture of barbojo is less than 35% and can be as low as 20 percent. Bagasse is the fibrous residue of sugarcane crushing and contains about 50% moisture on a mill-wet basis; approximately 30% of the prepared cane crushed will end up as bagasse on a weight basis.

66 million barrels of oil at a price ranging from one-half to one-third that of the least expensive alternative. This amounts to nearly one billion dollars of foreign exchange saved. The provision of this renewable fuel source would also create a large number of farm and off-farm jobs while increasing the returns to farmers growing the cane.

Another notable finding of the Symposium concerns the significance of state-of-the-art biomass combustion technologies, particularly the new steam-injected gas turbine systems under development at General Electric Corporation and several other locations. A Princeton team funded by A.I.D. has evaluated these systems. Evidence suggests a far-reaching impact in developing countries due to the high efficiency and low cost of such systems at scales that make dispersed electricity generation in association with process industries much more attractive, especially when they rely on low-density fuels such as bagasse and cane field residues. The potential benefits of cane energy systems are shown in Table I.1.

Table I.1

Benefits of Cane Energy Use

| Private Sector | Public Sector |
|---|---|
| ° electricity sales | ° cheaper energy |
| ° new by-product markets for sugar industry | ° deferring new public utility investment |
| ° lower on-site energy bill for firm | ° reducing future import energy bill |
| ° reducing sensitivity to fluctuations in sugar prices | ° net foreign exchange savings |
| | ° new private sector investment |
| | ° rural industry, income and employment generation |

Symposium discussants concurred on the need for additional research and trials to make these technical options acceptable to private investors in developing countries--in the process pinpointing important opportunities for U.S. foreign assistance programs. In particular, participants agreed, research should focus on the following:

- the technical and economic attributes of alternative methods of harvesting, densifying, storing, moving and processing cane residues;
- the impact of residue use on soils, crop systems, and the rural environment;
- the feasibility and efficiency of combustion of residues in various existing and new boiler systems;
- the technical and economic feasibility of growing and harvesting new, high-tonnage cane and cane-grass varieties for cane/energy systems; and,
- alternative arrangements that producer and utilities may agree upon to manage the delivery of electricity to national grids and to compensate producers for energy produced.

## Findings

The exchange of technical experiences at the Symposiums helped clarify the priorities for future work to develop cane energy systems. The following sections summarize many of the conclusions reported by cane energy users and researchers at the Symposium.

- Residue Harvest

  Field experiments in the Dominican Repubilc and Puerto Rico have demonstrated the technical and economic feasibility of harvesting cane field residues--also known as barbojo or trash--using conventional foraging systems. However, some modifications to these systems can improve their trash removal capacities and extend equipment life. The Tarlac Mill in the Philippines plans an experimental collection program involving conventional rectangular baling of the chopped residues left by cane harvesting machines as well as stationary baling of hand-gathered tops and leaves. In addition, A.I.D. Thailand plans a demonstration program at the Nong Yai Mill in the Eastern region of Thailand involving rectangular and round baling of more than 20,000 tons of residues. Finally, A.I.D., in cooperation with the Government of Jamaica, plans to test a newly designed baling machine which will produce large square bales. The results of these field trials are eagerly awaited by experts interested in more detailed information on the methods appropriate to different farming systems and on the costs of different approaches to residue harvesting.

- Storage

  To provide adequate cane residue supplies for year-round energy production, many countries will need to store fuel supplies for the off-cropping season with on-site or in-field storage systems. Data on the technical and economic



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feasibility of various systems, including densification (pelletizing and cubing) and baling (round and rectangular), were presented in several papers and talks. Densification appeared costly compared to alternative systems due to problems with die integrity. As noted above, experiments with different forms of baling reported by the Dominican Republic and Puerto Rico, indicate that both round and rectangular baling is technically feasible. This suggests that optimal choice for a country or company will depend more on costs of labor and capital, size and configuration of landholdings and ability to serve equipment than on technical feasibility.

° Transportation

Residue transportation systems generally relied on conventional cane or forage systems and technologies. Cane residues are transported at the Dominican Republic's Central Romana using the railroad system installed for the cane harvest.

° Conversion

Cane residues have been converted to a number of products including paper, fiber board, and chemicals among others. For example, the mili in the Dominican Republic uses some residues for furfural production. Economics for these processes vary from place to place and depends on access to markets and on prevailing world prices for the product produced.

For mills crushing more than 3000 metric tons of cane per day, investments in efficient electricity production are usually attractive if arrangements can be made to sell the electricity at prevailing prices. In Hawaii, power plants at sugar mills have been supplying electricity to the utility grid since the 1950's, with sugar mills presently producing anywhere from 33 to 58% of the outer islands' electricity generation. The plants installed in Hawaii are conventional steam boilers designed for use with solid fuels (bagasse). They are, however, far more efficient than the boilers found at most sugar mills in the world because they are designed not only to meet process needs in the factory but to produce surplus electricity for sale. Research sponsored by A.I.D. at Princeton University shows that advanced gas turbine systems currently being developed in the U.S. could significantly decrease capital costs for power equipment and increase the amount of electricity that can be produced for a given quantity of fuel.

Although further tests are needed, cane field residues can generally be burned in boilers designed to burn bagasse without significant boiler modifications. Mixing fuels presents different problems. Researchers in Puerto Rico found that bagasse to residue ratios of 6:1 (86% bagasse/14% trash) can be burned with little problem but a 1.2:1 ratio (55% bagasse/45% trash) created instability in the boiler.

- Costs

  Experience to date with the collection, transport, storage and preparation of cane residues for combustion reveals a wide range of costs. The lowest are those of the La Romana mill in the Dominican Republic, which has been able to deliver this fuel to its boilers at $7.10 per metric ton. Estimates from other locations, based primarily on analytical studies, range as high as $16 a metric ton for Thailand. As noted earlier, these prices are competitive with the lowest available alternative fuels.

- Utility-Industry Interface

  To realize the highest returns from export power sales, private power generators need firm power contracts with utilities, which are contingent upon their ability to deliver firm power. In Hawaii, the passage of national legislation facilitated negotiations between the utility and industry by establishing specific guidelines. However, even without these laws Hawaiian mills were already selling electricity to the utility grid. In other countries, such as Jamaica and the Dominican Republic, utilities appear willing to accept private power generation if industries make a firm commitment to produce a stable supply of electricity for the national grid.

- Biomass Production

  Species trials for high yielding herbaceous crops on five islands in Hawaii conducted by the Hawaiian Sugar Planters' Association have been initiated to determine the potential for producing other sources of fuel on marginal cane lands. Meanwhile, Puerto Rico is testing the production characteristics of different high yielding cane varieties. Researchers in Puerto Rico have found that bagasse to residue (leaves and tops) ratios of 6:1 (86% bagasse/14% trash) can be burned with little problems but a 1.2:1 ratio (55% bagasse/45% residue) give boiler stability problems.

- Alternative Energy Products

  The Symposium focused primarily, though not exclusively, on electric power generation from cane residues. In the meantime, electric generation offers the sugarcane industry the most reliable new market. Testing of methanol for transport fuels by California State (see Biofuels Workshop Proceedings 1987), may spark interest to convert cane residues to methanol for a new motor fuels industry.



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## Issues and Concerns

Throughout the Symposium, Biofuels Workshop, and field trips, many issues and areas of concern emerged that need to be addressed. Although cane energy production systems already exist in the U.S., the Dominican Republic, and Reunion, they are not widely accepted. Critics point out perceived or real problems with feedstock harvest, preparation, storage, and conversion, or utility-industry interface requirements. Others worry about environmental impacts from trash removal, the effect of the feedstock's high moisture content on energy conversion systems, changes required to make year-round production of energy possible, and the character of utility-industry contracts and rate schedules (see Table I.2).

While most of these concerns have been or are currently being addressed, more field experience and data will help clarify risks and benefits. For instance, long term agronomic data is required to quantify the soil nutrient effects of cane trash removal. Currently A.I.D.'s Cane/Energy Assessment Program and the Hawaiian Sugar Planters' Association are collaborating on a program to collect such data.

Each interested country and industry can be expected to tailor its cane energy systems to meet its specific needs and resource endowments. While many aspects of these systems can be transferred, country representatives at the conference felt strongly that each system be designed to meet the needs of different sites. The representative from the Dominican Republic, where cane trash collection currently takes place, indicated that his greatest need is for improved mechanical trash harvesters and guidelines for selling power to utilities. Given the current proposal for a power plant fueled with cane residues at the Monymusk Estate in Jamaica, private investors and the government are looking for information with which to size the power plant given a projected level of sugar production and guidelines for power purchase agreements. Engineers from Puerto Rico's cane energy project echoed the call by those from the Dominican Republic, the Philippines and other countries for modified cane trash harvesting equipment and storage techniques, but had less concern with utility arrangements. In contrast to other countries, both Thailand and the Philippines stressed a sensitivity to the need for labor intensive harvesting and storage systems. Serious labor surpluses and land reform issues in the Philippines' rural areas must be accounted for in any cane energy strategy. Baling and harvesting techniques that utilize rather than replace labor are preferred. Similarily, Thai government officials and industry experts at the workshop noted their need for labor intensive collection and storage systems given the large number of small landholdings that dominate their sugarcane industry.

In conclusion, the technical modifications needed in collection and storage of the cane trash residues seemed to be the highest priority. Of almost equal importance are public utility agreements to support private power production. If the history of cane energy use in Hawaii (and more recently in Jamaica) is instructive, agreement between the utilities and industry can often be reached most easily after the private sector has demonstrated its willingness to make investments in cane energy production.

Table I.2
Cane Energy Utilization Issues

| Stage | Issue/Concern | Solution |
|---|---|---|
| Production | Predictable Adequate Supply | For every ton of cane grown, approximately 20% becomes bagasse and 40% trash. How much of this residue is needed for on-site energy use depends on the efficiency of equipment in a particular sugar mill. Power plants needs to be correctly sized to insure adequate fuel supply. |
| Harvest | Environmental | Trash removal systems can leave 50% or more of the residues on the field. Experiments in Puerto Rico suggest that 30 to 50% is adequate to maintain organic content of their soil. A.I.D. plans to support additional research at other locations to measure impact and estimate any potential costs of necessary remediation. |
| | Equipment | Current work is being carried out in Puerto Rico and the Dominican Republic (see summary of papers in Chapter IV) to improve trash harvesting equipment. Work is planned with A.I.D. support in Jamaica and Thailand. |
| Storage | Year Round Supply | In order to provide firm power for a utility, year-round operation is necessary. Currently, research on different baling systems for fuel storage is underway in Puerto Rico and is planned in the Philippines, Thailand and Jamaica. |
| | Moisture Content | At harvest, field residues average about 50% moisture content but if left in the field for a week dry to 20%-35%, depending on water conditions. Moisture must be reduced below 35% mcwb to prevent spontaneous combustion in storage. |
| Conversion | Efficiency | Older boilers not designed to maximize electricity production are not very efficient. Without new investment economics will be heavily influenced by fuel costs. |
| | Contaminants | To lower field contaminants in the feedstock supplys (such as stones, dirt and irrigation tubing) cane trash harvesters adjust the height of the equipment and some mills use separators at the plant. |

Table I.2 Con't.

| Stage | Issue/Concern | Solution |
|---|---|---|
| | Reliability | Power plants in Hawaii have demonstrated high reliability over many years of service and have in many cases out-performed fossil fueled installation. |
| | Fuel Mix | Auxillary fuels such as oil, woodchips, and coal are sometimes used to augment the fuel supply during the off-cropping cane season. On-going research into cane energy storage, may extend the biofuel supply at the mill. |
| Utility | Rate Structure | In order to obtain more than the avoided fuel cost in payment for electricity sold to the utility, sugar factories must produce firm power that allows the utility to avoid new investment. Failure to fulfill firm power contracts results in penalties. |
| | Buyback | Utility willingness to purchase power from sugar mills often depends on demonstrating economic and financial benefits at a national or state level. |
| Sugar Producton | Sugar Quality | Sugar quality and total production will often increase when new, more energy efficient cogeneration sytems are coupled with the plant. |

Future Outlook

Energy production from cane residues is an exciting new option for the developing nations of the world. With fifty-three of the seventy-five A.I.D.-assisted countries now producing sugar from cane, the potential exists for a significant impact on economic development around the world. Diversification of the sugarcane industry into energy markets will reduce the sensitivity of rural economies to sugar price fluctuations and improve the industry's profitability. The proven commercial success of Hawaii's cane energy venture, and field experiences in other countries discussed at the conference, demonstrates that cane energy is a viable option for the private sector in the near term. In the long run, new technologies such as advanced gas turbines and methanol plants, along with the development of high yielding cane energy crop varieties, may further expand the cane energy potential.

# CHAPTER II

# CANE ENERGY POTENTIAL AND EXPERIENCE

## Cane Energy Potential

Biofuels used for electricity generation, liquid fuel production or solid fuel substitutes often offer important financial, economic, and social benefits to a country. At a minimum, such use can diversify the country's energy and agricultural commodity bases. More often, it also provides intermediate product markets, greater private sector investment, additional rural development, net foreign exchange savings when displacing imported fossil fuels, and, if environmentally sound, better natural resource management.

In recent years, biofuel use by industrial-sized energy systems has been technically and economically successful for some key agricultural or forestry-based industries, such as sugarcane and paper. Because commodities like sugarcane are critical to the economies of many tropical regions yet are often plagued by cyclical price fluctuations and declining markets in the U.S. and Europe, profitable use of residues can be beneficial to the industry and country. To many developed and developing countries, cane-based energy systems can open new markets that improve the economic viability of the industry and region.

In contrast to many proposed uses of biofuel, i.e., small, decentralized systems that meet only low-level energy requirements, cane energy systems can produce industrial-sized quantities of energy. As shown by the Hawaiian sugar industry, successfully designed power systems that utilize bagasse and cane trash may contribute quantities of electricity that meet a substantive amount of regional energy needs. Electricity from Hawaiian sugar factories presently provides over 10% of the state supply, with over 33% and 58% of the total electricity used on the islands of Hawaii and Kauai, respectively, coming from the sugar industry. The estimated potential for cane energy varies from 1% to over 28% of A.I.D.-assisted countries' 1985 electricity production (Tables II.1 and II.2).

Historically, the rural economies in many tropical countries have been heavily dependent on the sugar industry. More than a dozen A.I.D.-assisted countries have expressed interest in exploring diversification alternatives such as energy from cane residues. In response to this interest, the U.S. Agency for International Development co-sponsored a Symposium on Cane Energy Utilization at the Second Pacific Basin Biofuels Workshop. The Biofuels Workshop was organized by the Hawaii Natural Energy Institute at the University of Hawaii and co-sponsored by various institutions including A.I.D.[1] The workshop provided a forum for presentation of recent research on commercially viable biofuel systems.

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[1] Proceedings from the Biofuels Workshop can be obtained from the Hawaii Natural Energy Institute, University of Hawaii, Honolulu, Hawaii (HNEI, 1987).

Table II.1
Cane and Sugar Production in A.I.D. Countries

| | Cane Area Harvested (000's ha) | Cane Production (000's MT) | Cane Yield (MT/ha) | Sugar Production (000's MT) | Sugar Yield (MT/ha) | Sugar Yield (As % Cane) |
|---|---|---|---|---|---|---|
| Latin American/Caribbean | | | | | | |
| Barbados | 15 | 863 | 58 | 100 | 6.67 | 11.6% |
| Belize | 24 | 1,000 | 42 | 102 | 4.25 | 10.2% |
| Bolivia | 56 | 2,500 | 45 | 250 | 4.46 | 10.0% |
| Costa Rica | 38 | 2,750 | 72 | 240 | 6.32 | 8.7% |
| Dominican Republic | 185 | 10,200 | 55 | 1,000 | 5.41 | 9.8% |
| El Salvador | 37 | 3,078 | 83 | 270 | 7.30 | 8.8% |
| Ecuador | 37 | 3,113 | 84 | 312 | 8.43 | 10.0% |
| Guatemala | 68 | 5,715 | 84 | 560 | 8.24 | 9.8% |
| Guyana | 53 | 3,520 | 66 | 247 | 4.66 | 7.0% |
| Haiti | 45 | 700 | 16 | 46 | 1.02 | 6.6% |
| Honduras | 31 | 2,300 | 74 | 210 | 6.77 | 9.1% |
| Jamaica | 41 | 2,350 | 57 | 205 | 5.00 | 8.7% |
| Panama | 37 | 2,100 | 57 | 170 | 4.59 | 8.1% |
| Peru | 47 | 7,000 | 149 | 730 | 15.53 | 10.4% |
| St. Kitts-Nevis | 3 | 298 | 99 | 32 | 10.67 | 10.7% |
| Asia | | | | | | |
| Bangladesh | 150 | 1,180 | 8 | 95 | 0.63 | 8.1% |
| Burma | 55 | 1,900 | 35 | 52 | 0.95 | 2.7% |
| Fiji | 60 | 4,070 | 68 | 480 | 8.00 | 11.8% |
| India | 3,000 | 165,000 | 55 | 6,920 | 2.31 | 4.2% |
| Indonesia | 286 | 20,929 | 73 | 1,827 | 6.39 | 8.7% |
| Pakistan | 360 | 14,000 | 39 | 1,280 | 3.56 | 9.1% |
| Philippines | 310 | 17,360 | 56 | 1,539 | 4.96 | 8.9% |
| Thailand | 620 | 24,500 | 40 | 2,465 | 3.98 | 10.1% |



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Table II.1 (cont.)

Cane and Sugar Production in A.I.D. Countries

| | Cane Area Harvested (000's HA) | Cane Production (000's MT) | Cane Yield (MT/ha) | Sugar Production (000's MT) | Sugar Yield (MT/HA) | Sugar Yield (As % Cane) |
|---|---|---|---|---|---|---|
| Africa | | | | | | |
| Cameroon | 24 | 900 | 38 | 75 | 3.13 | 8.3% |
| Chad | 3 | 220 | 73 | 20 | 6.67 | 9.1% |
| Ghana | 9 | 250 | 28 | 10 | 1.11 | 4.0% |
| Guinea | 4 | 250 | 63 | 25 | 6.25 | 10.0% |
| Ivory Coast | 35 | 2,600 | 74 | 175 | 5.00 | 6.7% |
| Kenya | 40 | 3,700 | 93 | 375 | 9.38 | 10.1% |
| Malawi | 17 | 1,500 | 88 | 170 | 10.00 | 11.3% |
| Mali | 5 | 270 | 54 | 5 | 1.00 | 1.9% |
| Mauritius | 80 | 6,000 | 75 | 615 | 7.69 | 10.3% |
| Senegal | 7 | 630 | 90 | 80 | 11.43 | 12.7% |
| Somalia | 7 | 450 | 64 | 50 | 7.14 | 11.1% |
| Sudan | 30 | 4,200 | 140 | 325 | 10.83 | 7.7% |
| Swaziland | 33 | 3,560 | 108 | 410 | 12.42 | 11.5% |
| Tanzania | 20 | 1,200 | 60 | 126 | 6.30 | 10.5% |
| Uganda | 8 | 180 | 23 | 10 | 1.25 | 5.6% |
| Zambia | 11 | 1,100 | 100 | 145 | 13.18 | 13.2% |
| Zimbabwe | 33 | 3,600 | 109 | 455 | 13.79 | 12.6% |
| Near Asia | | | | | | |
| Egypt | 85 | 6,670 | 78 | 720 | 8.47 | 10.8% |
| Morocco | 10 | 600 | 60 | 50 | 5.00 | 8.3% |

Source: For cane and sugar data, USDA, Foreign Agricultural Service. Data on Energy from UN, "Energy Balances and Electricity Profiles," 1982.

Table II.2

Potential for Cane Energy in A.I.D. Countries

| | Country Electricity Production (000's MWh) | Cane Electricity Potential* (000's MWh) | Cane Electricity Potential (As % Prod.) |
|---|---|---|---|
| Latin American/Caribbean | | | |
| Barbados | 300 | 129 | 43% |
| Belize | 53 | 150 | 283% |
| Bolivia | 1,450 | 375 | 26% |
| Costa Rica | 1,950 | 413 | 21% |
| Dominican Republic | 2,930 | 1,530 | 52% |
| El Salvador | 1,495 | 462 | 31% |
| Ecuador | 2,895 | 467 | 16% |
| Guatemala | 1,485 | 857 | 58% |
| Guyana | 455 | 528 | 116% |
| Haiti | 260 | 105 | 40% |
| Honduras | 800 | 345 | 43% |
| Jamaica | 2,400 | 353 | 15% |
| Panama | 2,390 | 315 | 13% |
| Peru | 9,150 | 1,050 | 11% |
| St. Kitts-Nevis | 27 | 45 | 166% |
| Asia | | | |
| Bangladesh | 2,355 | 177 | 8% |
| Burma | 1,311 | 285 | 22% |
| Fiji | 306 | 611 | 200% |
| India | 113,060 | 24,750 | 22% |
| Indonesia | 7,330 | 3,139 | 43% |
| Pakistan | 12,959 | 2,100 | 16% |
| Philippines | 16,713 | 2,604 | 16% |
| Thailand | 14,790 | 3,675 | 25% |



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Table II.2 (cont.)
Potential for Cane Energy in A.I.D. Countries

| | Country Electricity Production (000's MWh) | Cane Electricity Potential* (000's MWh) | Cane Electricity Potential (As % Prod.) |
|---|---|---|---|
| Africa | | | |
| Cameroon | 1,320 | 135 | 10% |
| Chad | 63 | 33 | 52% |
| Ghana | 4,500 | 38 | 1% |
| Guinea | 495 | 38 | 8% |
| Ivory Coast | 1,600 | 390 | 24% |
| Kenya | 1,500 | 555 | 37% |
| Malawi | 340 | 225 | 66% |
| Mali | 100 | 41 | 41% |
| Mauritius | 434 | 900 | 207% |
| Senegal | 465 | 95 | 20% |
| Somalia | 72 | 68 | 94% |
| Sudan | 864 | 630 | 73% |
| Swaziland | 168 | 534 | 318% |
| Tanzania | 700 | 180 | 26% |
| Uganda | 650 | 27 | 4% |
| Zambia | 8,400 | 165 | 2% |
| Zimbabwe | 4,700 | 540 | 11% |
| Near Asia | | | |
| Egypt | 14,800 | 2,295 | 16% |
| Morocco | 4,372 | 270 | 6% |

Source: For cane and sugar data, USDA, Foreign Agricultural Service. Data on Energy from UN, "Energy Balances and Electricity Profiles," 1982.

*Assumed 150 kWh/ton harvested cane.

Given the existence of commercially proven systems, the Cane Energy Utilization Symposium highlighted currently or near-term viable technologies for cane energy production, with an emphasis on cane trash utilization and electricity production through cogeneration. It brought together technical and policy specialists in the area of cane residue energy use to focus on critical technical issues and recent commercial experiences in the U.S., Caribbean, and Asia.

## Symposium Objectives and Organization

To disseminate information on and demonstrate the opportunities in cane energy production, A.I.D.'s Cane Energy Assessment Program co-sponsored the symposium and invited industry experts and representatives from interested A.I.D.-assisted countries. The symposium's goal was to:

1) foster exchange between international specialists in cane energy production,

2) to increase technical knowledge in the field, and

3) to establish priorities for future cane energy work.

The focus of the sessions was on the major technical opportunities and obstacles to cane residue (also known as "trash" or barbojo) utilization for the production of electricity. Besides electricity production for utility or private use, results were presented from recent research on methanol production and use as a transport fuel, with the possibility of the sugar industry or sugar lands supplying the feedstock.

Exchanges on the critical issues facing cane trash utilization occurred on several levels. Formal presentations were given by experts from the Dominican Republic, Philippines, Puerto Rican, and Hawaiian sugar industry and reseach communities. As seen in Chapter IV, these experts covered topics ranging from new cane residue harvesting and storage techniques to key rate issues for negotiating firm power contracts with the utilities. Prior to the formal sessions, experts visited commercial cogeneration operations at Hawaiian sugar mills and experimental cane or forest species trials.

Representatives from the sugar industry, sugar research institutes, and energy and industrial ministries from the Dominican Republic, Jamaica, the Philippines, Thailand and the U.S. participated in the symposium (see Participant List, Annex 1). Each of these countries have on-going cane energy programs, major sugar industries, and an interest to undertake new cane energy projects.

## The Sugarcane Industry: Problems and Options

A healthy sugarcane industry is vital to the rural economies of many A.I.D.-assisted countries in terms of employment, income, infrastructure, and agricultural sector contribution to the GDP. Sugarcane is grown in fifty-three of the A.I.D.-assisted countries. Most sugar is sold internally or under pre-arranged quotas; however more than 70 developing countries depend on sugar exports to earn foreign exchange (World Bank, 1987). Increasing competition from other sweetener products and continual price pressure on internal and trade markets for cane sugar has created severe financial problems and the need for rationalization (restructuring) in the cane industry.

## CANE ENERGY POTENTIAL AND EXPERIENCE

Although the world sugar market historically is characterized by highly cyclical price swings, many factors are converging to indicate that long term adjustments are required in many countries. The factors exacerbating the problem for rural areas dependent on cane include (World Bank, 1987):

- heavy price supports to the sugar industry provided by most countries to ensure stable markets that drain national budgets;
- excess supplies of about 5% in most countries resulting in a world-wide build-up of stocks equalling around 30-40% of supply that has depressed world prices far below production costs in most countries;
- the small, freely-traded international market for sugar (only 25 % of all sugar cane and beet production) that cannot absorb large production increases;
- increasing production of sugar from beets and high fructose corn syrup sweeteners;
- the emergence of a new, large reserve capability to bring sugar quickly to market created by Brazil's aggressive cane-to-fuel alcohol program;
- large sugar production increases from Europe;
- smaller quota markets in Europe and the U.S.; and
- the lack of short term alternatives of the requisite scale and level of net returns to replace sugar lands.

Despite the growing markets for sugar in the developing world, further economic difficulties within the cane industry are expected unless programs are developed to help them diversify and reduce costs.

The problems of the sugarcane industry in many countries creates serious challenges for local governments. Heavy dependence on the industry has created severe hardships in rural areas. With some preferential export markets to the U.S. and Europe contracting and world prices falling below sugar production costs, the industry is unlikely to regain financial health at current levels of production in countries that export a significant percentage of their sugar production.

The poor world market situation for sugar has only exacerbated rural development problems. Some countries have tried to diversify their agricultural base. While some lands have shifted out of sugar to fruit and other cash crops, many proposed alternatives have proven commercially unattractive for a variety of reasons (World Bank 1987, A.I.D./RONCO Philippines Report 1986). Often they require the introduction of crops with which rural farmers and the host country have little experience and that require a strong infrastructure, marketing network and financial support (see Allison paper, Vol. II). In most cases, few alternatives exist that can fully absorb the large land, sunk investment and employment involved in cane production as well as provide returns per unit of land that match sugar in good times. Although in the long term such diversification efforts are necessary, they will take time to develop.

Thus, the cane industry faces difficult choices. While some lands will shift out of cane to other products, there remains a need to cut production costs for sugar from cane to prevent further market deterioration and to find new opportunities to increase net revenues through diversification. Development of by-products offers the sugarcane industry good short and long term opportunities to reduce the effective production costs of sugar. In many locations, strong markets exist for energy products including electricity, liquid fuels and household fuels.

## Cane Residues for Energy: Opportunities and Benefits

In the search for new revenues and better methods for disposing of its wastes, the sugarcane industry in some countries has already turned to the use of its residues--bagasse and cane trash--to make new products. Some companies have invested in systems to produce baseload electricity or liquid fuel. Others produce paper, fertilizer or animal feeds.

The experience of the Hawaiian sugar industry provides a good example of successful residue use for baseload energy production. In response to a variety of economic and environmental incentives, in the late 1960's the Hawaiian sugar industry began increasing the efficiency of its electricity production so that it could sell baseload or firm power to the utility. The motivations included: 1) higher power requirements by the grid, 2) high baseload or firm power rates paid by the utility, 3) U.S. Environmental Protection Agency (EPA) restrictions against ocean dumping for waste disposal, and 4) new air quality restrictions by EPA. On Kauai, mills had been producing excess electricity since the mid 1950's. Like most mills in the world, those in Hawaii already used residues for on-site steam and power generation. However, by making a committment to supply baseload power, the mills were able to attract higher payments from the utilities than they were receiving from dumping surplus power. Currently, the industry provides over 10% of the total electricity in the state of Hawaii, with local production on the island of Kauai meeting 58% of the island's demand (Kinoshita, 1987). According to the islands' utilities, such energy has been not only reliable but also important in providing low cost power to the state.

Diversification of the sugar industry into energy products can offer the general advantages of:

- allowing farmers to work with known or similar agricultural systems;
- reducing the dependence of the sugarcane industry on sugar prices by adding product flexibility;
- allowing national electricity systems to defer investments in new capacity because private power generation based on indigenous, renewable resources is available;
- decreasing dependence on imported fuels;
- improving natural resource management through better waste utilization;
- providing new opportunities for private and public sector cooperation;



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- directly increasing rural agricultural and off-farm incomes and employment;
- indirectly stimulating new development through multiplier effects in the rural areas; and
- strengthening rural infrastructure.

Besides these general attributes, converting cane residues into energy products may offer important financial benefits to private investors as well as broader economic benefits to the region. On the financial side, potential benefits may include:

- steady, reliable revenues from power sales;
- higher returns to the cane operations by improving resource recovery and steamlining of systems;
- lower on-site energy costs due to more efficient energy use in the facility; and
- spreading the overall risk through by-product use (provided the primary product market is strong).

While electricity production will not save the industry, it can provide an additional revenue source that improves profitability and increases the competitiveness of sugar from cane against sugar from beets, high fructose syrups, and chemical sweeteners. Some macroeconomic benefits to the government and public include:

- increased employment and personal income opportunities in cane producing regions;
- reduction in the financial burden on governments to provide capital for new power generation capacity;
- a reduced future energy import bill, and net foreign exchange savings, where private renewable-based power defers public sector investment in systems which require more expensive, imported alternative fuels;
- new private sector initiatives with multiplier effects; and
- rural industry diversification.

Traditionally, the sugar industry has considered cane residues, the bagasse and air-dried tops and leaves (referred to as cane trash or barbojo) as wastes that were either burned for internal on-site use or disposed of in a variety of methods. In the past, the industry's goal has been to maximize sugar yields and minimize cane residue production. The addition of energy production, either electricity or liquid fuels, requires reconsideration of the balance between maximizing sugar and energy production to increase total net revenues. The addition of power sales or liquid fuel production, will modify the industry's business and operational goals. The sugar industries in Hawaii and, to a lesser extent, the Dominican Republic, Puerto Rico, the Philippines, Jamaica and Thailand are exploring the advantages of having high yielding trash varieties and suitable conversion equipment to maximize energy revenues.



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## A.I.D. Cane Energy Assessment Program

In 1982 the U.S. Agency for International Development (A.I.D.) Office of Energy began a program to evaluate crop substitution and market diversification opportunites for the sugarcane industry in A.I.D.-assisted countries. The Cane Energy Assessment Program provides technical support to identify viable options for private sector investments. In cases where conversion of residues into energy products, including fuel ethanol as well as electricity, makes technical and economic sense, the Assessment Program provides further support to define the opportunity and develop a plan of action. In cases where other products, such as animal feeds, look attractive, the Assessment Program will attempt to find other channels for support. In studies carried out to date, production of energy often has been the most attractive short-term possibility.

To achieve its objectives, the Cane Energy Assessment Program fields teams of specialists to evaluate alternatives and prepare recommendations on what steps a sugar industry in a particular region or country might take to strenghthen their economic position. The recommendations are formulated for government and private sector action. Specific services the program has provided to various countries include:

- consultations to assess the appropriateness of conducting detailed investigations;
- technical and economic analyses for specific cane energy options conducted by teams of specialists;
- project development assistance for missions and host countries that express interest in carrying out cane energy projects; and
- assistance in locating private sector participants in the project where investment prospects are favorable.

The Cane Energy Assesssment Program is also sponsoring applied research in areas that are critical for commercial success. This includes tests on new cane trash harvesting systems in Hawaii and research into improved cogeneration technologies in the United States. At present, the program has conducted detailed feasibility studies in Jamaica (1986), Honduras (1986), the Philippines (1986) and Thailand (1986), and currently is working with industry specialists in Puerto Rico, Hawaii, and Louisiana.

These feasibility studies have identified a significant, though often country-specific, potential for cane energy projects. In Honduras, the potential for fuel alcohol production was explored and found not to be attractive given current market conditions for sugar, molasses, and oil (A.I.D., April 1986). A broad study of using cane residues in the Philippines for a range of energy products (boiler fuel, steam and electricity, and animal feed) showed that several possibilities were attractive enough to merit more detailed feasibility studies (A.I.D., December 1986). Possible future projects included substitution of bagasse and cane trash for fuelwood that currently is being burned in cane mills on Negros Island where severe deforestation problems exist, electricity generation on Luzon where the highest electricity needs are projected, and production of animal feeds in conjunction with alcohol. In Thailand, a team completed a feasibility study of electricity generation in collaboration with the sugar industry (A.I.D., September 1986). Due to the keen interest of the Thai government and the sugar industry in the recommendations of this study, the Cane Energy Assessment Program is now helping the mission in Thailand

develop a trial year program. As a result of earlier studies by the program, a major project for building a cogeneration facility at the Monymusk Estate in Jamaica is under consideration by the government and private investors (see paper by Keppeler, Vol. II). The Biofuels Workshop provided an excellent opportunity to bring interested country representatives and industry experts together to discuss new research and field experiences in cane energy use.



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# CHAPTER III

# CANE ENERGY FIELD TRIPS

## Introduction

Hawaii has been a pioneer in the area of commercial biofuel energy use and research. Its sugarcane industry is a particularly good showcase for demonstrating commercially successful electricity generation and sale to local public utilities. The industry is also a leader in experimenting with high production energy crops. Thus, field trips to Hawaiian sugar mills and to species trials organized by the Hawaii Natural Energy Institute were a major component of the Biofuels Workshop.

Field trips to four mills that produce baseload energy highlighted the variety of different technical and financial decisions undertaken by Hawaiian mills for cane energy production. Emphasis was given to the harvesting, storage, cogeneration, business and public utility aspects necessary for commercial viability. Besides electricity production, the Hawaiian sugar industry through the Hawaiian Sugar Planters' Association (HSPA) has been planting experimental cane and high-yielding fiber crops, such as short rotation trees and grasses, for future use by the mills. Field trips to both the mills and species trials allowed participants to interact with Hawaiian sugar industry specialists.

## Hawaiian Cane Energy Experience

Electricity and steam generation fueled by cane bagasse have been an important cost-saving and revenue generating operation for Hawaiian sugar mills. At present, over 10% of the total electricity generated in the islands is produced by the sugar industry. On the islands of Hawaii, Kauai, and Maui, the mills provided 33%, 58%, and 32%, respectively, of the total island electricity in 1986 (Table III.1). Over 48% of the 700 million kWh produced by mills throughout the islands in 1985 were sold to the public utilities.

In shifting from generation for on-site use, with some sale of surplus electricity, to the provision of firm or baseload power to the utilities, each mill has dealt with a variety of bagasse preparation and processing issues as well as complicated utility arrangements. While the Hawaiian sugar industry differs from other countries' industries, the experience of these mills is instructive. First, there are a variety of cane energy systems being used in different mills, thereby showing the broad conditions in which cane energy systems are viable. Second, the research on new cane energy varieties being undertaken in Hawaii by HSPA is at the frontier of species testing. The combination of an aggressive, industry-supported research institute (HSPA) with an industry committed to energy production provides important lessons for other countries.

Characteristics of the Hawaiian industry that make its experiences in cane energy use either replicable for other countries or unique to Hawaii were readily observed during the field visits. Factors that enhance the replicability of the Hawaii cane energy experience and research are:

TABLE III.1
GROSS ELECTRICAL GENERATION
In Hawaii by Source

| Island/Year | | Plantation Utility | Plantation Biomass | Plantation Total | Total | From Plantations |
|---|---|---|---|---|---|---|
| | | (----------$10^6$ kWh---------- | | | ) | (%) |
| 1981 Statewide Total | | 6,840[a] | 628 | 776 | 7,616 | 10.2 |
| 1982 Statewide Total | | 6,709[a] | 606 | 758 | 7,467 | 10.2 |
| Hawaii | 1982 | 358 | 235 | 260 | 618 | 42.1 |
| | 1983[b] | 382 | 244 | 262 | 644 | 40.7 |
| | 1984 | 380 | 248 | 265 | 646 | 41.1 |
| | 1985 | 431 | 193 | 211 | 643 | 32.9 |
| Kauai | 1982 | 103 | 150 | 215 | 318 | 67.6 |
| | 1983[b] | 124 | 144 | 211 | 335 | 63.0 |
| | 1984 | 170 | 133 | 191 | 361 | 53.0 |
| | 1985 | 150 | 144 | 208 | 358 | 58.1 |
| Maui | 1982 | 500 | 122 | 174 | 674 | 25.8 |
| | 1983[b] | 530 | 169 | 221 | 751 | 29.4 |
| | 1984 | 551 | 183 | 249 | 800 | 31.2 |
| | 1985 | 521 | 178 | 249 | 770 | 32.3 |
| Oahu | 1982 | 5,748 | 99 | 109 | 5,857 | 1.9 |
| | 1983 | 5,853 | 110 | 120 | 5,973 | 2.0 |
| | 1984 | 5,622 | 105 | 111 | 5,733 | 1.9 |
| | 1985 | 5,626 | 102 | 110 | 5,736 | 1.9 |

[a] Excludes generation on Lanai.
[b] Data for September 1983.

Sources: Kinoshita, C.M. Energy Inventory of Hawaiian Sugar Plantation - 1982, 1983, 1984, and 1985. Unpublished Data. Hawaiian Sugar Sugar Planters' Association. Experiment Station. Aiea, Hawaii.

- centralized cane processing facilities similar to those in other countries;
- opportunities throughout the industry to use cane residues more efficiently to produce energy; and
- highly variable climatic and geographical conditions in the cane producing regions of Hawaii, making Hawaii's experimentation with different energy species applicable to broad regions of the world.

The Hawaiian industry began producing electricity for sale because of the profit potential and the need to manage residues more effectively. The sugar industry's processing systems vary only slightly throughout the world, which greatly facilitates the transfer of innovations between countries. However, through comparison with their own systems, workshop participants identified some critical differences that would need to be addressed for successful cane energy use in their countries. Differences that set off the Hawaiian experience from some, though not all, countries include:

- heavy dependence on cane producers with large, plantation land holdings;
- high labor costs that have led to capital-intensive, highly mechanized cane and residue harvesting systems and biennial cropping that yields over 110 ton/hectare/year at harvest;
- existence of U.S. laws permitting and regulating private power generation and sales to utilities (PURPA); and
- reliable supply of residues for use by mills throughout the year.

Many developing countries have predominantly small cane producers, manual harvesting and seasonal operations. Different cane residue systems need to be developed to produce the same degree of reliability of fuel supply. The other key advantage in Hawaii is that power can be produced by private power generators and sold under a variety of contractual terms. Laws are already in place for systematizing contracts and providing formulas for setting fair returns for power sales. Although mills had begun selling electricity to the utility prior to the new regulations, these laws greatly increased the attractiveness of cane energy utility power sales.

While these differences between the Hawaiian and other cane industries are important, they do not reduce the attractiveness of cane energy for other locations. Indeed, a major emphasis of the Cane Energy Assessment Program is to develop systems matched to the constraints that exist in any particular country. The positive experience of the Hawaiian sugar industry with cane energy use provides one rationale for the program while making available a history of concrete experience upon which to draw.

## Sugar Mill Trips

Mill field trips included visits to the Hilo Coast Processing Company (HCPC), Hamakua Sugar Company's Haina Sugar Factory, and the Puna Sugar Mill with its operating power plant on the island of Hawaii, the Puunene Mill on Maui, and the Lihue Mill on Kauai. The relevant characteristics of these mills are outlined in Table III.2. System characteristics differed at each mill and are described by category below. The Puna Mill no longer produces sugar but continues to produce power because of the terms of its contract.

TABLE III.2
CANE AND ENERGY PRODUCTION CHARACTERISTICS OF FIELD TRIP MILLS (1985)

| Mill | Island | Annual Sugar Production | Power Plant Capacity Total | Power Plant Power Distribution Mill | Power Plant Power Distribution Utility | Electrical Generation Purchased | Electrical Generation Sold Firm | Electrical Generation Sold Stand by/ Unscheduled | Electrical Generation Used | Average 1987 Purchase Rate | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (96 DA sugar) | (MW) | (----- MW -----) | | (---------- $10^6$ kWh ----------) | | | (¢/kWh) | | |
| Hamakua Hina | Hawaii | 64,200 | 15.0[a] | 6.9 | +8.0 | 0.37 | 42.48 | 0 | 34.51 | NA | Contract; Pelletize |
| Hilo Coast Co. Processing | Hawaii | 108,500 | 23.9[b] | 5.0 | +16.0 | 0.85 | 87.56 | 0 | 34.20 | 3 | Provides 20% island energy; Rate affected by oil prices. |
| Puunene (Hawaiian Commercial & Sugar Co.) | Maui | 49,700 | 40 | 26.0[c] | +12[c] | 1.7[c] | 54.04[c] | 33.70[c] | 124.65[c] | NA | Attempted distillery; ethanol plans abandoned. |
| The Lihue Plantation Co. | Kauai | 82,600 | 27.1[d] | 5.5 | +12 | 0.06 | 69.91 | 1.86 | 35.59 | 5 | Leasing agreement with cogeneration equipment manufacturers. |

a With mill consolidation, expect capacity at Haina to expand to 25 MW.
b Includes 0.1 MW diesel.
c Electric generation numbers reflect combined total for HC & S Co.'s Puunene and Paia Mills.
d Includes 1.3 MW hydro power.

Sources: Kinoshita, C.M. 1986. Energy Inventory of Hawaiian Sugar Plantations - 1985. Unpublished data.
Hawaii Sugar Producers Association, Experiment Station. Aiea, Hawaii. December 23, 1986;
HSPA, 1986. Hawaiian Sugar Manual 1985/86. Hawaiian Sugar Planters' Association. Aiea, Hawaii.

° Cane Residue Preparation and Processing

Moisture Content

The mills use a variety of techniques to prepare the bagasse and trash to increase the per unit energy content and to extend the storage time of the feedstock. The HCPC and Hamakua mills partially dry their bagasse through flue gas dryers prior to burning to reduce its moisture content. With such drying, moisture contents, expressed on wet basis (m.c.w.b.), fell by about 10% from reportedly 47% to 37% m.c.w.b. To decrease the moisture of cane trash, it was reported by representatives from the Dominican Republic and Puerto Rico that trash is generally left in the fields for a week to drop its moisture from about 50-55% to about 35% m.c.w.b. Engineers at the mills reported a significant improvement in boiler stability due to partially drying the bagasse and other residues.

Densification

To test the techniques, the Hamakua Haina mill on Hawaii experimented with pelletizing part of its bagasse residues. It planned to use these pellets to extend the biofueling season at the mill. While technically feasible, it found the process costly due to problems in maintaining the integrity of the dies. Subsequently, it extended its milling season through consolidation and discontinued pelletization at its plant.

Contaminants

Along with field residues, contaminants such as stones and dirt will often be brought in during collection. To rid themselves of such contaminants, some mills use mechanical separators and washing plants prior to processing the cane. In the Dominican Republic, the representative of Central Romana reported that they raise the height of the windrowing equipment when collecting cane trash to leave behind most contaminants and sufficient field residues (50%) for nutrient recycling.

° Feedstock Supply

Because of the long cane harvesting season, cane residues supply a high percentage of the energy produced at the mills. In all four mills, the bagasse supply was adequate to provide over 70% of the boiler fuel needs (Table III.3).

° Fuel Mix

Due to the almost year round supply of sugarcane, bagasse and cane trash were the primary fuel sources for the mills (Table III.3). All mills use auxillary fuels. The mills visited all used oil and HCPC also used some coal.

TABLE III.3

Boiler Fuel Dependence in Selected Hawaiian Sugar Mills
(1985)

| Mill | Percentage of Total Boiler Fuels Use[a] | |
|---|---|---|
| | Bagasse (%) | Fossil Fuels (%) |
| Hamakua Sugar's Haina Mill | 96 | 4 |
| Hilo Coast Processing Co. | 97 | 3 |
| Puunene (HC & S. Co.) | 73 | 27 |
| The Lihue Plantation Co. | 89 | 11 |

[a] As percentage of total heat transferred to steam.

Source: Kinoshita, C. M. 1986. Energy Inventory of Hawaiian Sugar Plantations - 1985. Unpublished data. Hawaiian Sugar Planters' Association. Aiea, Hawaii. December 23, 1986.

° Power Reliability and Contribution

In all mills that were visited and in separate discussions with utility management, the power reliability from the mills was reported to be excellent. For instance, reliability at HCPC has been over 80%. Engineers at the mills felt that drying some or most of the bagasse with flue gas dryers was key to maintaining system reliability. The significant contribution of plantations' electricity production to the state can be seen in Table III.1. Excluding Oahu, at least 30% of total electricity in the islands comes from the mills.

° Financing Cogeneration Facilities

Like most sugar mills during the past decade, the Lihue mill on Maui was faced with equity and liquidity limits that constrained their capacity to raise funds to invest in more energy efficient boilers and new cogeneration facilities. In looking for alternative financing arrangements, the mill found that the cogeneration equipment manufacturer was willing to enter into a leasing arrangement with Lihue. Recent discussions by the Cane Energy Assessment Program with other power generation equipment firms suggests that such cogeneration financing might be available also to developing countries.



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° Utility Contracts

Rate Structure

Each company has separately negogiated its power contract with the island utility. Because new U.S. legislation affecting private power sales (PURPA) was not passed until the late 1970's, utility contracts differ among mills. One major difference is a variation in purchase rates (prices received for electricity sales to the utilities). In the case of HCPC, its twenty-year 1974 firm power contract was written prior to enactment of the Public Utility Regulatory Policies Act (PURPA). Rather than have a rate based on a wider variety of factors as would be required under PURPA, HCPC has a rate structure tied to oil prices. When oil prices recently fell, HCPC's payments for power dropped from a 5¢/kWh average purchase price during 1986 to a 3¢/kWh price in 1987. When oil prices were at their peak, HCPC received 6.5¢/kWh. In contrast, other mills currently have rates (4¢/kWh at Lihue) that are based on a broader combination of factors, such as projected utility production costs.

Risks

Due to the poor sugarcane market, the owners of the Puna Sugar Mill (AMFAC) decided to shut it down in 1985. Until that point the Puna mill had been producing electricity for the grid from bagasse. With the closure of the mill, the owners hoped to close down the cogeneration as well as sugar processing facilities. Because of a penalty clause in its 20-year firm power contract, the owner of the mill has found it cheaper to continue producing electricity from woodchips or other fuels than pay the penalty. This experience demonstrates a potential risk involved in entering into long-term power contracts with the utilities if a firm's sugar processing business is not competitive.

° Other Energy Products

In 1984-85, the Puunene mill on Maui began production of ethanol from molasses but found it not commercially viable. Like the Puna mill, this failure highlights the risk of entering a by-product business. Similarily, the HCPC operation looked into ethanol production but decided against it because of the lack of ethanol markets.

° Environmental Impacts

Waste Management

One motivation for increasing energy production from residues was the objection by the state of Hawaii to mills dumping excess residues in the ocean. Under pressure to decrease their pollution, the mills turned to electricity production. To minimize the negative environmental impacts of cane transport, the Hilo Coast Processing Company (HCPC) on Hawaii recently switched

transport systems to reduce their littering, and inadvertantly increased the amount of cane and residues coming into the mill.

Agronomic Impact

The HSPA has monitored impacts of complete above-ground residue removal on cane production in Hawaii. Cane production in general has not been affected. The A.I.D. Cane Energy Assessment Program will sponsor examination of the impact of residue removal in more detail.

These issues represent a sample of the major factors affecting cane trash use for electricity generation. By no means are they inclusive of all variables that must be considered. Each mill in Hawaii has evolved its own system and it is likely that mills in other locations will evolve different systems.

Species Trials

The HSPA began to explore the opportunities of growing high yielding energy crops on sugarlands in 1985. Species trials were planted in 1987 on five locations throughout the islands to test different cane, herbaceous (napier grass), and tree crops (see Osgood paper in Vol. II). Annex 2 provides a list of the species and site characteristics for the plots visited on the field trip.

Besides the HSPA sites, field trips to the BioEnergy Development Corporation's 1978 eucalyptus Plantations on the island of Hawaii were also made. Results from the plantings suggest the need for fertilizer applications, every 6 months, to maintain adequate growth rates. A mixture of eucalyptus with nitrogen-fixing trees can eliminate the need for synthetic fertilizer after the first year. Preliminary yields ranged from 4.7 to 21.3 green tons (gt) per acre (11.8 to 53.5 metric tons per hectare) per year (Whitesell 1986). The most promising species are E. saligna, E. grandis, E. robusta, and E. Urophylla on the big island sites (Annex 3). Cost date estimate establishment to be about $4-5/gt and harvesting $9/gt (down from $12-14/gt), for a total cost of $13-14/gt at 48-50% m.c.w.b.

# CHAPTER IV

# CANE TRASH COLLECTION, STORAGE AND USE PRESENTATIONS

## Introduction

The Cane Trash Utilization Symposium provided a forum for U.S. and international industry experts to discuss new approaches to cane residue collection, storage and use as well as to suggest areas for future work. The session consisted of formal presentations and informal discussions between workshop participants. The papers described on-going cane energy projects in the Caribbean and the Asia-Pacific region. Discussions following the papers and informal talks with participants during the Biofuels Conference identified technical priorities and country needs.

Interest in cane energy projects and research has been rapidly increasing over the past five years in the Caribbean and Asia-Pacific region. Drawing upon existing experience, participants presented papers covering a broad spectrum of issues related to the collection, storage and use of cane field residues. Specific topics included general cane energy use, field experiences from the Dominican Republic and Philippines, on-going research on trash harvesting systems and field equipment costs in Puerto Rico, and a proposed Jamaican cogeneration project. Summaries of the presentations given during the session and conference that dealt with cane energy use are given below. The papers[1] presented at the meetings are in Volume II.

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[1] Presentations with papers are asterisked(*)

General Cane and Biofuel Energy Use

## The A.I.D. Biofuel Energy Program

Dr. James Sullivan, Director
U.S. Agency for International Development
Office of Energy, Washington, D.C.

Investment in the power sector represents a critical component to economic growth and improved rural welfare in all developing countries. The bill for power development is enormous in these countries, with 30 percent of development funds or more not infrequently going into power sector expansion. Demand, particularly in rural areas, usually far outstrips supply. Most A.I.D.-assisted countries are setting targets of at least 6.5% annual growth in their electricity supply. Yet if funding constraints on expansion were removed, they could easily face any where from 10 to 12 percent growth in demand.

To keep up with these projections and compensate for a loss of private commercial financing, donor agencies have invested heavily in the power sector over the past decade. Given recent debt constraints on developing country governments, public lending for power generation is much constrained and donor agencies are trying to absorb some of this slack. The World Bank has estimated that needed investment in power generation in developing countries will be $US 50-60 billion per year. In 1986, the World Bank expects to invest some $US 2.6 billion; other donors provide roughly an additional $2 billion this including investment in power generation from all donor agencies approach approximately $US 4.5 or 5 billion. With such a strong demand but heavy financial constraint on public power institutions, private power generation can make an important contribution to these countries. A.I.D.'s has been exploring the possibilities of private power generation from key industries in many developing countries.

With shrinking markets for agricultural commodities such as sugar, the diversification of the sugarcane industry into power generation for commercial sale benefits the industry, national energy agencies, and the country as a whole. For the private investor, the use of cane residues for power generation helps alleviate the pollution disposal problem from unused residues, while also generating revenues for the industry. From the public welfare perspective, private power production reduces the pressure on the public utility and often improves rural welfare by providing new jobs.

A.I.D.'s Cane Energy Assesment Program was created to explore the possibility of diversifying the sugarcane industry, with special emphasis on energy by-products. The program provides services and specialists in A.I.D.-assisted countries to interested industries. It conducts pre-feasibility studies, provides expertise on technical assistance, and identifies potential U.S. and host country private firms for cane energy use and investment. A primary objective of the progam is to identify private sector firms to implement and to provide financing for cane energy projects. The program coordinates its cane energy projects with other donor agencies, such as the World Bank, and with private firms.

A proposed project in Jamaica, for example, would integrate a major World Bank rehabilitation of the Monymusk Estate sugar facilities with installation of new private sector funded cogeneration capabilities. The cogenerating systems, perhaps privately owned in a joint venture, would export electricity to the mill and utility. This cane power could defer expansion by the public utility and reduce the government's debt financing needs.

If successful, private power generation from sustainable energy sources such as cane residues could help the profitability of an industry, expand the national power supply, promote rural development, and improve waste removal problems. With initiatives in Jamaica, research in Puerto Rico, cooperation with major U.S. research institutes, and potential projects in Thailand, A.I.D.'s Cane Energy Assessment Program plans to identify viable options for the cane industry.

## Cane Trash Utilization Issues

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Before we go into specific technical areas of cane energy use, it is useful to begin these papers by laying out an agenda of those aspects of cane energy utilization that will determine the success or failure of cane energy systems in many countries. These fall into the categories of resource production and preparation, energy conversion, agricultural research, and economic and institutional feasibility.

### A. Resource Production and Preparation

The first issue that potential users face is: What is a reliable estimation of the sustainable resource base? The second is: What new technologies are appropriate to collect and store the field residues. In order to determine the actual supply, data must be gathered on how much is available, when it is available, and what is the variation and condition, moisture content and contaminants, of the residues. In order to answer these basic resource supply questions, information regarding the technical and economic feasbility of new harvesting and storage technologies is needed. Historically, the cane industry relied upon conventional agricultural harvesting machinery. Currently, several countries (e.g., the Philippines and the Dominican Republic) and the Cane Energy Assessment Program are exploring better collection and storage technologies to improve residue preparation and production systems. For instance, Brazil has developed a new chemical spray that reportedly decreases the moisture content of bagasse. We need to know if this process really decreases the water content, how it compares technically and economically to alternative bagasse drying processes, and what are its environmental effects. The comparative technical, economic and social (e.g., labor versus capital intensive) advantages and constraints of most collection and storage systems also still need to be clarified.

B. Energy Conversion

At present, most conversion technologies used in electricity production from cane residues are off-the-shelf systems. While these cogeneration systems are far superior in efficiency to most boiler systems that exist in mills throughout the world, research into more efficient and cheaper coversion systems could provide economic incentives to the adoption of cane energy. Current research on gasifier/gas turbine systems (by Princeton University and some U.S. private power equipment manufacturers, discussed later by Larson et. al.) suggests that these hold the potential of being substantially cheaper and more efficient than present commercial conversion systems.

C. Agricultural Research

Two key areas for agricultural research are: 1) identifying high-yielding energy crops; 2) estimating the environmental impacts of cane residue use. Hawaii's research is at the frontier of species trials. To date only limited information exists on the long term environmental impacts and pollution effects of cane energy use. The Dominican Republic believes that no serious nutrient deficiency problems result from its cane trash operations because they only remove trash from fields that are going to be replanted and leave 50 percent of the trash in the field. However, these operations need to be monitored by agronomists to gather conclusive data. Finally, no one has explored the possibility of using the ash from boilers for other by-products. Such use may remove a waste disposal problem as well as add revenue to the industry.

D. Economic Feasibility

Many assessments have focused on the financial costs only neglecting the economic impacts of cane energy projects. These analyses have focused on costs of production of such systems under static conditions. As a result little information exists on broader economic impacts and how costs might affect system choice. The development of computer models that incorporate technology and cost optimization may provide important information to the industry and potential investors. Such models could illustrate, the optimal economic combination of harvesting, storage and conversion technologies as well as the economic effects of changes in product mix, technologies, and rate structures.

E. Institutional

If cane energy systems are to gain acceptance they will require new institutional arrangements and legal instruments, particularly to structure the necessary cogeneration between producers and national utility authorities.

## Multi-Purpose Cane/Biomass in Development Strategy*

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Almost everywhere, the traditional sugar business is a bad business to be in, both in the short-run and in the long-run, whether one is producing for export or producing for local consumption. However, its raw material - the cane plant - offers many advantages for subtropical, developing countries and should not be discarded. Presented in the paper is the outline of a new, multiproduct industry based on cane, which produces energy, sugar and/or molasses and should be profitable on a life-cycle basis. The first steps toward introduction of this new industry are being planned in Puerto Rico.

# Resource Production

## Energy Crops in Hawaii*

Dr. Robert Osgood
Hawaiian Sugar Planters' Association

In 1985, the Hawaiian Sugar Planters' Association (HSPA) initiated programs to develop high-fiber sugarcane for biomass energy and to compare woody crops with herbaceous crops for dry-matter yield over a five-year period.

The motivation to develop energy sugarcanes and to evaluate woody biomass comes from the likelihood of higher oil prices and the need to supply electrical power under long-term contracts to utility companies.

In the 1960's, Hawaiian sugar mills began producing power for sale to the public utilities from its surplus bagasse. The total biomass-based power sold by Hawaiian mills exceeded 600 x $10^6$ kWh in 1985. HSPA's energy crops program is designed to identify sugarcane and woody biomass crops with high dry-matter yield potential that can thereby reduce unit costs of energy production. The HSPA estimates that at the present price of oil ($20 bbl), the breakeven production point for a sugarcane energy farm (no sugar produced) is 26 dry tons per acre per year.

The funding for the HSPA energy crops program is from three sources--the HSPA member companies, a state legislative appropriation, and a grant from the Hawaii Department of Planning and Economic Development, Alternative Energy Branch. Funds have been sought but not received from the Department of Energy through the Hawaii Natural Energy Institute (HNEI) and from a cooperative agreement with A.I.D. Cane/Energy Assessment Program.



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Energy sugarcane program

The energy sugarcane program is designed to develop a high-tonnage sugarcane through breeding and selection procedures. The initial breeding and selection work has already been accomplished and yield evaluations are now in progress at seven sites.

Woody and Herbaceous crop biomass comparative trials

Trials were established in five Hawaii locations to determine the dry-matter yield of woody and grass biomass crops over a five-year period. Each site is approximately 5 hectares and consists of a large plot (0.6 ha) trial including three tree species replicated three times and a one-acre plot of either sugarcane or napiergrass. In addition, a series of small plot (0.01 ha) trials with eight tree species replicated four times were established at each site.

The Eucalyptus species were the most productive of the tree crops at nine months after planting the sites. The harvest date for the trees is planned at five years. After planting of the tree crops, a major cost at all sites was weed control. Irrigation costs were high at the two dry land sites.

Prerequisites for successful energy farming are high recoverable dry-matter production at low production cost, proximity to the energy conversion site, and a high net energy ratio. HSPA's research efforts should produce important biomass crop data for countries throughout the tropics.

## Collection and Storage of Cane Field Residues

### Harvest and Preparation Technology*

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Biofuels derived from the residues of agricultural crops show promise of being technically and economically viable. Sugarcane is one of the leading candidate crops because of its ability to produce large tonnages as well as its importance in the agriculture of many tropical regions. The use of cane fiber in the form of bagasse for energy is already an established technology. The exploitation of field crop residues in addition to bagasse offers attractive possibilities for further development of sugarcane as a biomass fuels crop as well as a sugar crop.

Recent studies have given some data on the energy quantities and properties of crop residues available in association with millable cane. However, few large scale commercial operations have yet to be carried out for recovering and utilizing these crop residues. Standard forage harvesting machinery has been used with success on a

commercial scale at Central Romana in the Dominican Republic, using forage choppers to pick up cane trash which has been raked into windrows following hand harvest of unburnt cane. In Puerto Rico, balers have been used on an experimental scale to make large round bales from raked trash.

Pilot-scale field trials are recommended to obtain performance and cost data for the proposed harvest systems under a variety of specific operation conditions. Strategies for recovering cane trash include separation of tops and leaves from millable cane in the field using either hand harvest or machine harvest, or alternatively harvesting and transporting the entire plant for delivery to the mill. Whether the biomass is to be used for direct combustion or destined for other conversion processes, a wide range of options should be evaluated.

## Densification of Biomass

Francis S. Morgan, President
Hamakua Sugar Company

Strong economic incentives exist for private power producers to provide firm or baseload power for the utilities. A pre-requisite for baseload energy production, however, is a year-round supply of fuel. For cane energy producers, this often presents problems due to the length of the cane cropping season. Typically, sugar mills in Hawaii that produce power for the utility grid rely on auxillary fuel, usually fuel oil, during the off-season. Such fuel is more expensive than cane residues, and lowers net returns to the industry. One solution to this cane energy supply contraint that replaces fossil fuel dependency is densification.

Hamakua Haina sugar mill on the island of Hawaii decided to explore the technical and economic feasibility of pelletizing bagasse. Its purpose was to extend its cane residue supply and thereby lower net fuel costs. At present, the factory burns a mixture of partially dried bagasse (75%) with wet field bagasse (23-4%) and some pellets (1-2%). Flue gas driers reduce the moisture of field bagasse from 47% mcwb to about 35% mcwb. Bagasse that went into pellets was dried down to 10% mcwb. By mixing in some pellets, the boiler efficiencies reportedly increased from 72 to 80%.

During the experimentation with densification, Hamakua Haina has modified the pelletizer to handle cane residues. Although the pelletization proved technically feasible, and provided energy efficiency benefits, only a small percentage of bagasse has been pelletized due to the lack of surplus bagasse. Because of the characteristics of the bagasse, the dies on the pelletizer required frequent replacement, which increased total costs. For these reasons, the Hamakua Haina mill has temporarily suspended its densification efforts.



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## Field Experiences from the Dominican Republic, Philippines and Puerto Rico

### Field Experience in the Collection and Transport of Cane Trash (Barbojo) at Central Romana*

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Collecting and transporting cane trash (barbojo) has been done by the Central Romana Corporation in the Dominican Republic for over five years. Its familiarity and success with cane trash collection makes it exemplary among the sugar industry throughout the world. Considering its size of operation, over 64,000 hectares in cane, Central Romana is probably one of the largest cane trash users in the world.

Extensive field experience with trash collection provides solid data on such cane trash characteristics as moisture, average yields, and energy values. Typically, anywhere from 25 to 30% of the total cane tonnage is barbojo, with this number varying depending on cane variety and prevailing growing conditions. Average moisture content is 50%, at cutting, but this can fall to about 30% (sometimes 20%) with a week of sunny days. To preserve nutrients and retain moisture, trash is removed only from fields being replanted except for some fields close to the factory. The average oven-dried calorific value of barbojo is 4,180 Kcal/Kg (7540 BTU/lb), or 2,850 kcal/kg for sun-dried (30% moisture) trash. Low density causes high transportation costs. Various densification systems have been tried to lower unit costs although none are currently in operation.

Several cane trash collection and storage systems tried at Central Romana include chopping, baling, and briquetting. Technical and economic data on these systems and specific equipment configurations are presented in the paper. Average cost per tonne of harvested barbojo in 1987 is estimated to be RD$23.30/gt (U.S. $7.10/gt) using conventional foraging equipment. The main operational problem encountered is the relatively weak construction of the forage harvester. This problem is understandable since the equipment was not designed for cane trash collection. As always, selection of actual collection systems depends on many site-specific factors. Due to the success at Central Romana, the Dominican government is planning a large barbojo recovery program to produce fuel for a 30 MW plant. The Central Romana field experience has proven the technical and economic feasibility of cane trash collection and transport.

## Trash for Fuel: A Luisita Project*

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In 1983-84, two sister companies in the Philippines, Central Azucarera de Tarlac (CAT) and Hacienda Luisita (HL), began field experiments to use cane trash for fuel. The incentives for exploring trash for fuel came from high bunker fuel costs and a limited bagasse fuel supply. Both mechanical and manual harvesting methods were tested. Over 160,000 bales of trash were produced, with over 80% being used as fuel. The experiment encountered no significant problems in baling trash, except cutting green cane lowered output from the mechanical harvesters compared to the normal practice of cutting burned cane. Harvesters averaged 20 tons of cane per hour (TCH) for fresh cane, and 30 TCH for burnt cane. However, the trash operation was discountinued due to lack of adequate facilities for mechanical feeding of the boilers.

Given the extremely favorable economics of trash fuel use, CAT is expecting to recover 50,000 tons or 80% of its estimated trash available for a new 1987-88 project. On just fuel costs, it expects to save ₱12.3M or U.S. $600,000 per year. A breakdown of total estimated costs and benefits is provided in the paper. Besides imported fuel savings, it expects additional labor income to workers of about ₱6.5 M/yr (U.S. $300,000/yr) and to increase company revenues by ₱20.5 M/yr (U.S. $1,000,000/yr). Thus, the project provides strong private sector as well as public welfare incentives.

## Intensive Cane Energy Production for Energy, Sugar, Food and Fiber*

William Allison
Puerto Rico Office of Energy

Over the past fifteen years, the sugarcane industry in Puerto Rico has been on a steady decline. With one of the lowest sugar production levels in the world--26,000 hectares in cane and 87,000 tons sugar produced per year--the island is slowly going out of the sugarcane business. Abandoned cane lands have reverted to forests and pasture, and alternative crops such as vegetables and rice have been tried, but with very limited success.

The government decided in 1985 to try to bring back cane in Puerto Rico and committed $US 600,000 to a demonstration project that would look at food, feed, fiber, fuel and fertilizer possibilities from cane. Puerto Rico's Department of Agriculture is managing the project on 250 acres with a focus on finding optimal techniques for cane trash collection and storage.

So far, field experience with different cane trash harvesting has shown that some minor technical problems exist in collection of the trash for high production cane varieties. Conventional forage harvesting equipment has difficulty harvesting such cane. With 108

tons of wet material per acre in the field, the systems were only able to effectively harvest 65 tons with the use of conventional cane harvesting machines. Different trash recovery systems were tested to remove the tops and leaves from the field. These systems used side-delivery rakes to form windrows and conventional round bale hay balers to compact the material. Several mechanical problems during collection with the equipment included belts slipping on the baler and the pickup-feeder baler tines being too fragile to effectively feed the trash into the baler.

Having tested conventional systems designed for other crops, the project is presently seeking equipment manufacturers willing to redesign existing baling and harvesting systems to meet cane trash removal needs. Over the next year, such systems will be tested and their applicability to different situations and countries determined.

To date, the energy conversion results show that high ratios of stalk to leaves are more compatible with existing harvesting, processing and combustion systems. Of the three cane varieties tested, the most dependable variety had an average production of stalk and leaves of 93 wet tons stalk (86%) and 15 wet tons of leaves and tops (14%) per acre. This ratio of stalk to trash gave the least problems with harvesting, processing, or burning when using conventional processing and combustion equipment. Some varieties of sugarcane (green basis) contain as high as 45% tops and leaves, while others have less than 15 percent. The lower the content of tops and leaves the more suitable the cane (raw material) for harvesting, processing, and recovery of major products. This is especially true when conventional or existing systems of harvesting and processing are used. Conventional sugarcane processing factories are not constructed to effectively process cane with a low ratio of stalks to leaves.

## Power Generation

### Electricity - End Use for Biofuel*

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The process of converting biofuel into electricity is well established, and therefore the most economical use of Kauai's biofuel.

In the near term, biofuel use for electrical generation is the highest end-use priority for Kauai. The increasing importance of biofuels to Kauai is shown in its rapid change to biofuel dependency over the past decade. In 1978, Kauai Electric (KE) depended upon fossil fuels to provide 89% of its electric generation, with the remaining 11% coming primarily from bagasse-based electricity from Kauai's sugar mills. By 1982, only 45% of KE's electric generation was based on fossil fuel use and 55% came from the plantations. While this percentage from non-fossil fuels has been slowly decreasing to 39% in 1986, biofuel use is still vital to Kauai.

Due to increasing electricity demand and a limited capability within the sugar industry to expand its biofuel energy production, the percentage of biofuel use in Kauai may continue to fall. If no alternative energy projects come on line, by 1996 KE predicts the contribution from non-fossil fuel to be down to 28 percent. If new hydro-electric and wind farms projects materialize, by 1993 the non-fossil fuel contribution on Kauai could go up to 60 percent. Although this leaves Kauai 40% dependent on oil, the recent history and expected future of Kauai is still bright for biofuels.

## New Prospects for Cogeneration in the Cane Sugar Industry*

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Using advanced cogeneration technologies fired with cane residues, the cane-sugar industry could produce about as much electricity as is now provided by electric utilities using oil or about 1/5 of the total generated by utilities in cane-producing developing countries. Such a major role for cane-sugar producers in power generation is technically feasible, despite the fact that, at present, all the bagasse, the fibrous residue of cane milling, is typically burned as fuel for the factory.

Bagasse is currently used in small steam-turbine cogeneration systems to meet the modest steam, mechanical power, and electricity demands of sugar factories. However, the present balance between energy supply and on-site demand reflects traditional sugar-factory designs intended to insure that the factory is energy self-sufficient and disposes fully of its bagasse "waste". If more energy-efficient power generating equipment were used, considerable amounts of power could be produced for export to the utility grid. Even more power could be produced for export by (a) installing steam-conserving process technologies (e.g., condensate juice heaters and falling film evaporators), and (b) utilizing the barbojo to extend the residue supply into the non-milling season.

Larger, more energy-efficient steam-turbine cogeneration systems have recently been installed in a number of factories and are being considered seriously for others. Advanced gas turbine cogeneration systems show important technical and economic advantages over such steam turbine systems. Advanced gas turbines offer the advantages of higher thermodynamic efficiency and lower unit capital costs. In addition, in contrast to the case with steam-turbines, scale economies are weaker for the gas turbines. Thus, the economics of gas turbine power generation are typically favorable at scales of just a few megawatts.

* The research described here is being supported by the A.I.D. Office of Energy, Washington, D.C. A detailed report by the same authors is forthcoming: "Steam-Injected Gas Turbine Cogeneration for the Cane Sugar Industry."



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To date, gas turbines have required high quality oil or natural gas for fuel. However operation of gas turbines on gas derived from coal has been successfully demonstrated in California, and lower-cost, energy-efficient aircraft-derivative gas turbines fired with gasified coal are now being developed in the U.S., where demonstration plants are planned for startup in the early 1990s. Operating gas turbines with gasified biomass should be easier than operating with gasified coal, because there would be no significant sulfur emissions to contend with. One major U.S. manufacturer has already begun development of gas-turbine systems fired with gasified biomass.

Gasifer/gas-turbine systems would be financially attractive to sugar producers, generating a higher internal rate of return than an investment in a steam-turbine system. With a gas turbine system, the amount of electricity available for export at an efficient factory would be over twice that for a steam turbine. At a sale price of 6¢ per kWh, up to $25 of revenue would be generated per tonne of cane with the gas turbine. Sugar revenues would be comparable for a sugar price of $0.25 per kg ($0.11/lb).

Utilities also may benefit from these new systems because they can defer investment into more expensive alternatives. As an illustration, cane-power with this advanced system in Jamaica could be produced more cheaply than power from what has previously been identified as one of the least-cost generating operations there (a 61 MW steam-electric plant firing imported coal).

Some engineering development and a pilot demonstration are needed to bring the gas turbine technology to commercial readiness. However, how rapidly the technology is commercialized will probably depend less on technical constraints and more on how quickly institutional thinking patterns change in the sugar and electric utility industries.

## Integrated Cane Energy Project

### Jamaican Cane/Energy Project: Production of Electricity from Sugarcane Wastes*

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Important technical, financial and socio-economic feasibility factors have been considered in the recent study of a proposed, high performance, steam-electric generation installation at the Monymusk Factory in Jamaica. These include equipment design changes, new business management objectives, and utility-private sector agreements. The opportunity to add new revenues from energy sales by adding cogeneration exists at Monymusk since this facility currently is undergoing major renovation. Such additions would allow Jamaica to maintain, in part, the country's capability to supply its favorably-priced domestic and Commonwealth demand for sugar and molasses, while also meeting some of its electricity expansion needs through private sector investment.

The proposed power generation station, to be added in 1990 to the rehabilitated Monymusk Factory, would more efficiently use the renewable, biofuel resources (bagasse and barbojo) that are available as waste products of the sugarcane production and processing operations. Increased power generation capacity would come from the installation of new equipment designed to operate at higher temperatures and pressures (900°F and 900 psig) than is currently installed.

The financial benefits of cogeneration to the existing operations and private investors would come from sharply reduced expenditures for purchased power and a new, more stable source of revenues through firm power sales to the utility. It is estimated that substantial socio-economic benefits to the country will be derived through displacing imported energy with home-grown energy, strengthening private sector investment, diversifying the sugar industry, increasing rural income, employment and skill levels, and shifting government investment in electricity expansion to the private sector.

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# ANNEX II

# SPECIES TRIALS

HSPA Biomass Trials
Mountain View, Hawaii

## Species Planted

Acacia mangium
Acacia mernsii
Casuarina equisetifolia
Eucalyptus grandis*
Eucalyptus robusta
Eucalyptus saligna*
Eucalyptus urophylla*
Leucaena leucocephala 'K 636'
Saccharum spp. hybrid 'H68-1158'

## Spacing

| | |
|---|---|
| Small plots | 1 x 1 meter |
| Large plots | 2 x 2 meters |

## Date Planted

June 5, 1986

## Fertilizer to Date

### Large Plots

| | |
|---|---|
| N | 34 g/tree |
| $P_2O_5$ | 34 g/tree |
| $K_2O$ | 34 g/tree |

## No. Applications

(3) Planting, 6 months, 10 months

## Irrigation

Rainfed

*Large-plot plantings.



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Experiment: Spacing Study (83D006)

Field: F698

Treatments: 6
Replicates: 4

Trees Required: 2760
Date Planted: Sept. 20 & Oct. 3, 1983

Spacing & Plot Size: Varies
Area Required: 1.7 ha (4.2 ac.)

Species: Euc. grandis (Lot 166-2)

| Treatment | Spacing | Sq.m/Tree | Plot Size | Number of Trees | Trees/ha | Number of meas. trees |
|---|---|---|---|---|---|---|
| 1 | 1/2 x 3m | 1.5 | 312 sq.m | 208 (26 x 8) | 6667 | 24 (6 x 4) |
| 2 | 1m x 3m | 3 | 432 sq.m | 144 (18 x 8) | 3333 | 24 (6 x 4) |
| 3 | 2m x 3m | 6 | 576 sq.m | 96 (12 x 8) | 1667 | 24 (6 x 4) |
| 4 | 3m x 3m | 9 | 729 sq.m | 81 ( 9 x 9) | 1111 | 25 (5 x 5) |
| 5 | 4m x 3m | 12 | 972 sq.m | 81 ( 9 x 9) | 833 | 25 (5 x 5) |
| 6 | 5m x 3m | 15 | 1200 sq.m | 80 ( 8 x 10) | 667 | 24 (6 x 4) |

## Spacing Trials

Seven spacing trials were established on BioEnergy lands during the period 1979-84. Two at the Ka'u site were severely damaged by winds and were terminated. Information from additional spacing studies established by the USDA Forest Service on the Waiakea and Kalopa Forest Reserves, both on State lands on the Big Island and on Lihue Plantation Co. land on Kauai, will be integrated with that from the Bioenergy trials.

The remaining five BioEnergy trials, including one schedule to be harvested at Akaka, were remeasured during the current year. Data are being processed for a manuscript which is still in the first draft state. A technical review draft will be completed by May 15, 1987. The second manuscript originally scheduled for this task has been postponed until next year by mutual agreement between Department of Energy and the USDA Forest Service.

The selection of optimum spacing for Eucalyptus plantations for energy production in Hawaii has been difficult. Maximum biomass production in 6 years is the goal, but the constraint is a minimum 15 cm d.b.h. for the average stand diameter. The 15-cm value is based on the high cost penalty for havesting small trees with current harvest systems. Early spacing tests (Akaka Falls-1979) and Amauulu-1981) were inadequately fertilized and have not met the 15.0 cm d.b.h. constraint in 6 years at any spacing. Newer studies (Kamae D6 and Pepeekeo D7) are only 3 years old, but they have been refertilized and trends are starting to develop. In projecting d.b.h. curves ahead on two selected spacings, it appears that the optimum spacing is between 1 m by 3 m (3 $m^2$/tree) and 2 m by 3 m (6 $m^2$/tree). The 3 $m^2$/tree spacing will probably not reach 15 cm d.b.h. until 6.5 years, and the 6 $m^2$/tree spacing will reach 15 cm d.b.h. by age 4.2. Curve projections are subject to error but is appears that the target is probably bracketed. It will take several more years of fertilization and measurement to confirm or deny these projections.



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Experiment: Fertilizer Study (83F010)

Field: F69B

Treatments: 16
Replicates: 4

Spacing: 2m x 1.8m
Plot size: 230.4 sq.m

Trees per Plot: 64 (8 x 8)
Trees per Meas. Plot: 16 (4x 4)

Trees Required: 4096
Area Required: 1.5 ha (3.8 ac.)

Date Planted: Oct. 10 & 11, 1983
Date Fertilzed: Nove. 10, 1983; April 2 and 4 , 1984

Species: Euc. grandis (Lot 166-2)

| | Grams/Tree | | |
|---|---|---|---|
| Treatment | N | $P_2O_5$ | $K_2O$ |
| 1 | 20 | 30 | 10 |
| 2 | 40 | 30 | 10 |
| 3 | 20 | 30 | 30 |
| 4 | 40 | 30 | 30 |
| 5 | 20 | 70 | 10 |
| 6 | 40 | 70 | 10 |
| 7 | 20 | 70 | 30 |
| 8 | 40 | 70 | 30 |
| 9 | 10 | 50 | 20 |
| 10 | 50 | 50 | 20 |
| 11 | 30 | 10 | 20 |
| 12 | 30 | 90 | 20 |
| 13 | 30 | 50 | 0 |
| 14 | 30 | 50 | 40 |
| 15 | 30 | 50 | 20 |
| 16 | 0 | 0 | 0 |

N = Urea

P = Triple Sugar Phosphate

K = Muriate of Potash



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## Fertilizer Studies

Experience for soil fertility management of tree plantations along the Hamakua coast comes a primarily from a few nutrient studies with eucalypts and macadamia. In sugarcane culture P is incorporated before planting while N and K are applied frequently during the 18- to 36-month rotation. Initial expectations in Bioenergy's plantations were that 114 g of NPK fertilizer (14-14-14) per tree at time of extablishment and at 6 months would provide nutrient supplements adequate to keep the tree seedlings ahead of the weedy competition during the first year. Research explored questions of types of fertilizers, rates, and frequency of applications. Nutrient status was monitored by sampling and mineral nutrient analysis of foliage. Six fertilizer experiments were remeasured during the year. Results of research to date show that initial applications of P and K are adequate on most sites but to reach target yields, additional semi-annual applications of N will probably be required. There is no evidence that higher rates of N can be used over longer periods as a less costly alternative. Liming of Hamakua soils does not appear to be necessary for best growth of eucalypts. The following discussion reviews field evidence for these conclusions.

One of the first fertilization studies established in the Bioenergy program was the nitrogen-phosphorus trial at Akaka Falls in 1979. Its purpose was to assess response of Eucalyptus saligna to nitrogen and phosphorus fertilizer, as well as to develop fertilization guidelines based on foliar nutrient status. Two manuscripts ready for publication provided results and conclusions of this study. "Six-year growth of Eucalyptus saligna plantings as affected by nitrogen and phosphorus fertilizer" deals primarily with growth response. "Early growth and nutrient status of Eucalyptus saligna as affected by nitrogen and phosphorus fertilizations" relates growth response to percent nutrient content of foliage as well as to DRIS indices based on foliar nutrient ratios. Results of the Akaka Falls study clearly show the importance of nitrogen as the primary nutrient element to be supplied, and the secondary role of phosphorus in first year establishment and growth. Nitrogen fertilization greatly increased first year growth, proportional to the rate applied. Phosphorus also promoted a modest growth response the first year but its effect disappeared in subsequent years. Nitrogen at the lowest application rate (23 g) doubled tre height and diameter over the control, while the two highest rates tripled these values over the 6-year period. Periodic response to N fertilization, however, dropped markedly during the third year and was no longer statistically significant during the fifth and sixth year.

Survival was also affected by N fertilization, as survival for trees receiving not N fertilizer was 61 percent compared to 92 to 94 percent for N-fertilized trees. Correlations of height growth to N nutrient status show that foliar concentrations of N are more closely related to future growth while the N DRIS index is better correlated with past growth. Since its advantage over the foliar nutrient content method is small and there is a large difference in data requirements and complexity, the DRIS index is not recommended at this time as a tool for fertility management of eucalyptus energy plantations.

## Bioenergy Development Corporation

| | |
|---|---|
| Experiment: | Species Trial (84S010) |
| Field: | F69B |
| Spacing: | 2m x 2m |
| Plot size: | 3 x 3 trees |
| Measured Trees: | 3 x 3 trees |
| Treatments: | 10 |
| Replicates: | 4 |
| Date Installed: | 1/30/84 |

| Treatment | Species | Seed Lot No. |
|---|---|---|
| 1 | Eucalyptus globulus | 068-4 |
| 2 | E. tereticornis | 176-19 |
| 3 | E. Alba | 231-20 |
| 4 | E. urophylla | 201-3 |
| 5 | E. camaldulensis | 178-6 |
| 6 | Acacia mangium | 230-31 |
| 7 | A. auriculiformis | 184-52 |
| 8 | Copaifera langsdorfii | 167-29 |
| 9 | E. saligna | 148-1 |
| 10 | E. grandis | 171-2 |

Notes: Fertilized with DC-153 on 1/30/84 (4 ounces/tree).

## Selection and Propagation Of Superior Phenotypes

No work was done on selection and propagation of superior phenotypes in our existing plantations during the current year because we cannot be sure of obtaining coppicing after harvesting. Sprouting of Eucalyptus saligna has been unpredicatable and extremely variable even when the trees were felled by chainsaw and there was minimal damage to the stump. Where mechanical harvesting was done many of the stumps were damaged during felling and by the tires of the feller-buncher and the skidder. Therefore, we are awaiting the results of our studies on coppicing before we do any further selection, to be sure that any superior phenotypes we identify have maximum opportunity to sprout.

Growth of the hybrid Eucalyptus clones we obtained from Brazil in 1984 continues to be promising. These are clones selected for fast growth, high yield, good coppicing ability, and disease resistance by Aracruz Cellulose Company in Espiritu Santo, Brazil. Through the good offices of Dr. Charles Hodges of the USDA Forest Service, Aracruz donated to us for trial cuttings of ten clones, which were rooted in our mist house and outplanted in 1985. Growth after 2 years at our Pepeekeo site is shown below.

| Clone number | Height m | Dbh cm | Survival pct |
|---|---|---|---|
| 21 | 10.52 | 7.1 | 100 |
| 999 | 10.19 | 6.7 | 100 |
| 1501 | 10.05 | 6.4 | 100 |
| 2277 | 10.02 | 6.4 | 97 |
| 1248 | 10.01 | 6.3 | 100 |
| 1139 | 9.86 | 6.4 | 89 |
| 1486 | 9.63 | 5.8 | 100 |
| 14 | 9.34 | 6.0 | 100 |
| 2185 | 7.96 | 5.2 | 100 |
| 19 | 7.71 | 4.9 | 97 |

At our Kamae site, which is poorly drained and has less favorable growing conditions than at Pepeekeo, the best three clones after 18 months are 1248, 2277, and 999, with average heights and dbh's of 5.29 m and 3.6 cm, 4.98 m and 3.1 cm, and 4.72 m and 2.7 cm respectively.

One advantage of these clones, which are progagated vegetatively using rooted cuttings, is that they produce a more uniform stand than do plants raised from seed. For exmaple, the ranges from smallest to largest height and dbh in the least variable 9-tree plot for each of the best five clones at Pepeekeo are shown below. Figure E-1 is a photograph of clone 999.

| Clone Number | Height Range | Dbh Range |
|---|---|---|
| 21 | 10.0 - 11.6 | 6.0 - 8.7 |
| 999 | 9.8 - 11.6 | 6.2 - 8.1 |
| 1501 | 9.8 - 11.8 | 5.6 - 9.1 |
| 2277 | 9.1 - 10.9 | 4.4 - 7.2 |
| 1248 | 10.7 - 11.7 | 6.9 - 8.3 |

If the best of these clones continue to perform well in Hawaii, and coppice as well as they do in Brazil so that we can propagate them vegetatively, they could save us several generations of tree selection and improvement work.

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