THE ECONOMICS OF BIOMASS ENERGY: A STUDY OF TWO AGRICULTURAL WASTES

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The progressive escalation of energy shortages in recent years has led to an intensified search for viable alternate sources of energy in virtually every part of the United States. This is especially true of Hawaii, whose economic and geographic characteristics have constrained its present source of supply to a single fossil fuel, namely, oil. This monopoly of oil is further enhanced by the crucial role of transportation in the economic life of the islands dominated by tourism, plantation agriculture, and military services. Viewed in this perspective, the need for exploring and exploiting alternate sources of energy in the Hawaiian islands becomes urgent and compelling.

Alternate energy sources such as geothermal, ocean thermal, solar, wind, and silviculture appear to be promising in Hawaii from a geographic, environmental, and renewable resource perspective. However, there are several technical and socio-economic uncertainties involved in their utilization. Their long run feasibility, nevertheless, is an important part of Hawaii's energy research and development efforts, but their immediate application on a commercial scale is of a limited nature. What is needed is a renewable energy source which combines both economic feasibility and technological viability. Biomass is gaining rapid recognition as such a source as is evidenced by the top priority accorded to biomass production of energy in the new Carter budget (11). Hawaii is richly

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endowed with two major biomass sources: "bagasse", the fibrous residue of sugarcane left after crushing and extraction of the juices; and, pineapple trash, a post-harvest residue of the plant in the field.

This paper is a first attempt to explore the economic potential and operational feasibility of bagasse and pineapple trash as important new sources of energy for Hawaii. The paper consists of two major sections, the first dealing with bagasse and the second with pineapple trash. Each section briefly describes the institutional setting of the particular crop; discusses the extent to which the use of bagasse and pineapple trash as energy sources has progressed and estimates their potential generating capacities; proposes specific strategies to expand their supply; and assesses their environmental impact in the context of energy generation.

BAGASSE

Institutional Setting

The Hawaiian Sugar Industry consists of 17 plantations which control or lease about 221,000 acres and an additional 17,500 acres controlled by independent growers (7). The industry is the third largest in Hawaii and its contribution to the State's economy is approximately $227 million per year (5). It plays an especially important role in the economies of the islands of Maui, Kauai, and Hawaii (Table 1). The energy needs of these three islands are

TABLE 1. SUGARCANE ACREAGE AND SUGAR PRODUCTION IN HAWAII, 1977

Island	Cane Acreage	Raw Sugar (tons)
Hawaii	93,084	373,527
Kauai	45,900	231,685
Maui	47,528	265,193
Oahu	34,217	163,334
TOTAL	220,729	1,033,739

Source: Reference 7

largely accounted for by the industrial, residential, and tourist sectors. These three islands will have the greatest potential for utilization of bagasse as a field source. Oahu, the other producing island, has 80 percent of the State's population and plantations that are very energy-intensive on account of high irrigation demands; thus the potential contribution of bagasse to the total energy needs of this island is minimal.

Although the industry is durable and profitable, there are some factors which are presently contributing to the uncertainties within the industry. Recent advances in corn-based sweetener have made significant inroads into the natural sugar market. The opportunity cost of prime agricultural lands is growing rapidly because of the demands of residential and industrial growth. Hawaiian sugar is also facing serious competition in the world market from other sugar producing countries. These uncertainties are major considerations in assessing the investment behavior and production practices for maximizing electricity generation from bagasse.

Bagasse as an Energy Source: Current Trends and Potential

Bagasse has been used by the island sugar industry as a field source since its inception 100 years ago. The industry today is an established medium of considerable size and adaptability that has extensive generating capacity.

Plantations on the leeward side of the islands, where irrigation requirements are minor, have always had an excess supply of bagasse. Since 1969, in response to EPA requirements, numerous plantations have enlarged their boiler capacity as a means of bagasse disposal. In doing so, they entered into contractual arrangements with the utilities to supply electricity at a fixed rate. On Hawaii, 157 million kwh supplied to the Hawaiian Electric Company (HECO) accounted for 30 percent of the island's electricity demand, net of the plantations' use. On Kauai, 28 percent of the island's demand, net of plantation needs, was met by plantation sales to the utilities (1). On the islands of Maui and Oahu, due to irrigation requirements, the plantations maintain a demand-supply equilibrium with respect to the utilities. Figure 1 shows current sugar plantation sales to the utilities, possible additions to plantations' sales through the use of drip irrigation and dryers, and the sales theoretically realizable on the island of Hawaii, Kauai, and Maui and for the State as a whole.

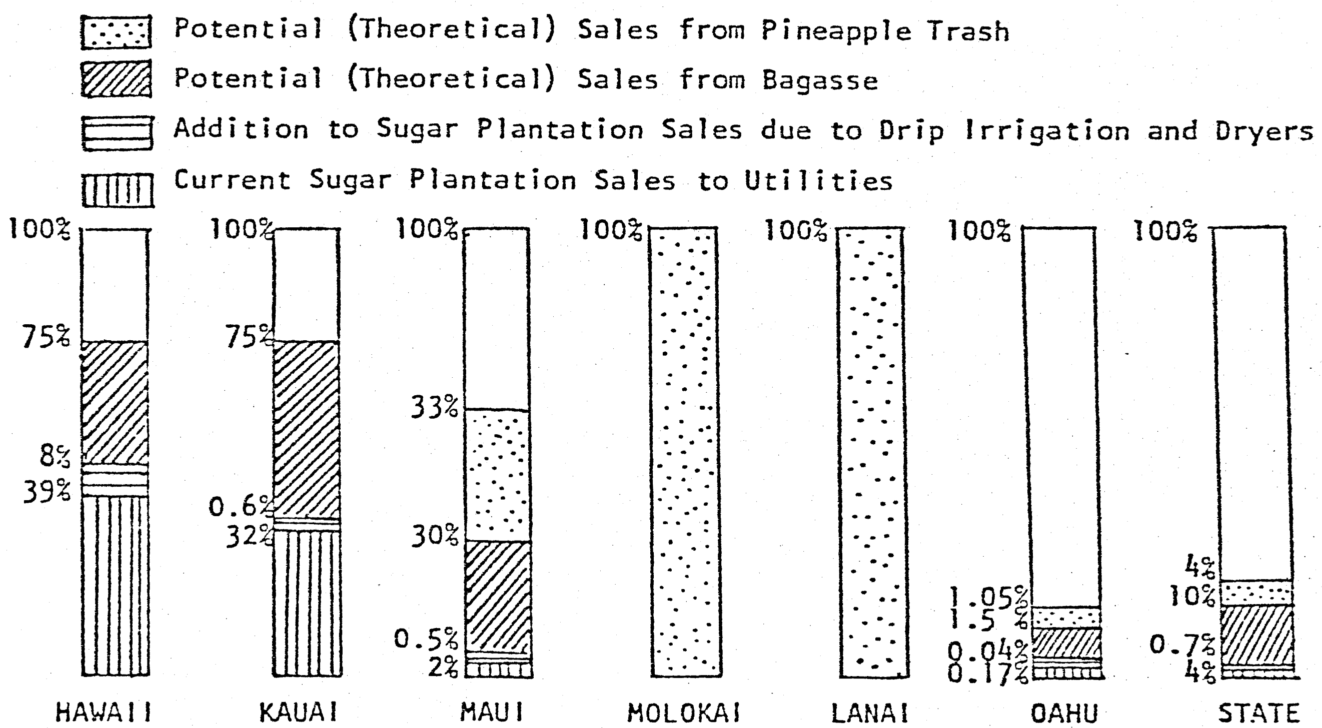

FIGURE 1. PRESENT (1978) AND POTENTIAL SUGAR AND PINEAPPLE PLANTATION SALES TO UTILITIES

The sugar industry has a long established, two-way distribution system with the utilities to supply a fixed amount. The contractual arrangements established by the plantations that presently supply electricity to the utilities on a fixed basis are adequate for use under expanded conditions. The utility agrees to purchase a fixed amount of electricity from the firm and pay the fixed cost for the generating capacity needed to produce this amount.

The rate is set by the utility's generating cost and price of oil, not including hydro-electric. The cost of expanding the transmission system would have to be subject to negotiations.

The sugar industry can become a significant supplier of electrical power to the island's utility grid through four basic strategies: (1) expansion of generating capacity, (2) expansion of the quantity of bagasse, (3) improvement in the quality of bagasse, and (4) reduction of the sugar industry's electrical consumption through conservation practices (6).

Environmental Impact

The environmental impact of bagasse as a fuel source compared to wind, hydro-electric, geothermal, and ocean thermal power is shown in Table 2 (3). The table ranks each source in terms of a variety of environmental quality indicators using an impact severity rating system ranging from 1 to 4. The

TABLE 2. EVALUATION OF ENVIRONMENTAL IMPACT OF ALTERNATE ENERGY SOURCES[a]

Impact	Severity Rating[b]					
	Bagasse	Pineapple Trash	Wind	Hydro-electric	Geo-Thermal	Ocean Thermal
Energy resource depletion	1	1	1	1	3	2
Area committed for conversion	1	1	3	3	3	3
Area committed for transmission	1	1	3	3	3	3
Water consumption	3	3	1	1	3	3
Use of air space	1	1	3	1	2	1
Air pollution	3	3	1	1	2	1
Water pollution	2	2	1	1	3	2
Construction activities	3	3	3	3	4	3
Heavy metals or toxic substances	1	1	1	1	2	1
Thermal discharge	3	3	1	1	3	2
Solid waste	2	2	1	1	2	1
Visual intrusion	2	2	3	2	3	1
Noise generation	2	2	2	1	2	1
Public health	1	1	1	1	2	2
Transportation hazard	1	1	1	1	1	2

[a] Source: Reference 2.
[b] Impact severity rating: 1 = negligible; 2 = slight; 3 = moderate; 4 = severe

The table shows that the environmental impact of bagasse is comparable to or less than that of other sources.

PINEAPPLE TRASH

Institutional Setting

Hawaii's pineapple industry consists of 6 plantations (16 farms) encompassing 47,000 acres of land that is generally unsuitable for other uses. These plantations are owned by three Hawaii-based companies with significant overseas operations.

The industry is the fourth largest in Hawaii and its annual contribution to the State's economy is about $162 million. The plantations are located on four islands--Oahu, Maui, Molokai, and Lanai (Table 3) (4, 5).

TABLE 3. PINEAPPLE INDUSTRY: ACREAGE AND EMPLOYMENT, 1977

Island	Pineapple Acreage	Employment (Direct)
Oahu	15,500	3,120
Maui	11,100	650
Molokai	4,800	510
Lanai	15,900	875
TOTAL	47,300	5,155

The plantations play an especially significant role in the economies of Maui, Molokai, and Lanai. The energy needs of these islands are rapidly growing due to the burgeoning residential, commercial, and tourist sectors (3). And they hold out the greatest potential for the utilization of pineapple trash as a fuel source. The potential for its use on Oahu, the State's major population center, is quite limited.

The 75 year old pineapple industry's importance in Hawaii's economy has registered a decline in recent years as evidenced by its falling share in the world market, and a consequent reduction in acreage, production, and employment.

However, there are strong indications of a reversal in this trend. According to a recent report, about 3,000 acres of former pineapple land on Molokai are scheduled for reconversion to pineapple production later this year, with an eventual expansion of up to 9,000 acres. This would boost immediate pineapple acreage to 50,000 acres and 56,000 acres by 1981-82 (12).

Several factors have contributed to the revitalization of the pineapple industry: technological innovations, higher prices, and increased demand for products. The outlook for the industry in Hawaii thus appears quite favorable, a fact that has special relevance in any assessment of the potential for pineapple biomass as an energy source.

Pineapple Trash as an Energy Source: Current Trends and Potential

Pineapple plant material is currently used for two purposes: the production of livestock feed, and the replenishment of the pineapple fields with essential nutrients through post-harvest, open-field burning. In both instances, it is the embodied energy in pineapple trash that is being utilized. No serious effort has been made until very recently to explore its considerable potential as a direct energy source. This section will briefly examine the use of trash as a livestock feed and nutrient source and compare it with its potential as a rich source of biomass energy, the first such attempt.

Biomass as Feed

Since the early thirties there have been a number of studies evaluating pineapple bran and pineapple plant material as livestock feed. In Hawaii, during the last decade, the demand for pineapple green chop and pineapple bran has remained stable due to a declining trend in the livestock industry. The energy recovery from the plant material in terms of crude oil equivalent, when used as livestock feed, is very low. The nutritional content of and energy recovery from pineapple green chop (plant material) and pineapple bran are given below (Table 4).

TABLE 4. NUTRITIONAL CONTENT AND ENERGY RECOVERY OF PINEAPPLE PLANT MATERIAL AND BRAN USED AS LIVESTOCK FEED

Feed Type	Energy Content	Crude Oil Equivalent (per ton)	Market Value
Pineapple Green Chop	42 K Cal/lb	0.058 bbl	$16/ton
Pineapple Bran	535 K Cal/lb	0.732 bbl	$90/ton

As is evident from the above table, the market value of pineapple bran is more than five times that of green chop and they both compete with the use of pineapple trash as a direct energy source. The current demand for pineapple green chop and pineapple bran is estimated at 52,000 tons and 18,000 tons, respectively.

Biomass as Nutrient Source

One acre of land in pineapple cultivation yields about 100 tons of vegetative matter. A third of the total pineapple acreage in the State is recycled each year. After reducing the moisture content through open drying, the plant residue or trash is burnt in the open fields. This, theoretically, burns off the nitrogen and sulphur, but returns 100 percent of other major and secondary plant nutrients back into the soil--potassium, phosphorus, calcium, magnesium, and other trace elements (10). The relatively low cost of replenishing the soil, to the extent of nutrient loss due to field removal of trash, from alternate inorganic sources puts a very low value on such use. What is more, it clearly indicates an extreme inefficiency in energy conservation practices in the field.

Biomass as a Source of Energy

Out of the 47,000 acres of land currently under pineapple cultivation in Hawaii, approximately 4,000 acres remain out of pineapple production. At 100 tons per acre of wet material (80 percent moisture content) and with an annual recycling of a third of the acreage, the biomass material yield from pineapple amounts to 1.43 million tons per year. After making allowance for the supply of green chop to the livestock industry, approximately 277,000 tons of field-dried pineapple trash (20-30 percent moisure content) is available for fuel use in biomass boilers. This material is presently being burned in the field, as pointed out in the above section. The energy content of pineapple trash is equal to 386,773 barrels of #2 diesel fuel oil currently used by Hawaii's utility companies to generate electric power. Based on the above information, we conclude that pineapple biomass can contribute 138,000 megawatts, approximately 4 percent of the energy requirements of the state of Hawaii. In terms of individual islands, when the full potential is realized, the pineapple industry could meet 100 percent of the energy needs of the islands of Lanai and Molokai and 33 percent of the needs of Maui. Its contribution to Oahu's energy needs would be quite insignificant (Figure 1).

A comparative perspective of energy recovery and market value from alternate uses of pineapple trash is furnished below (Table 5).

TABLE 5. ENERGY RECOVERY FROM ALTERNATE USES OF PINEAPPLE TRASH

Use	Energy Recovery (bbl/acre)	Market Value (per acre)
Feed	3.635	$1,008
Field burning	0.303	177
Fuel	24.130	408

As is evident from this table, energy recovery from the use of pineapple trash as a fuel source is significantly higher than from other uses. The use of trash for uses with considerably lower rates of energy recovery thus constitutes a social cost of alarming proportions, especially in light of the State's virtual dependence on costly and uncertain outside energy sources.

It has been estimated in some major studies that biomass conversion might yield fuels costing less than $11.60/bbl (8). In Hawaii, estimates of capital cost for conversion of pineapple trash to energy seem to vary in accordance with the intended scale of utilization. It seems reasonable to project a typical cost of $13-20/bbl (per day) in 1976 dollars (8). There seems to be considerable promise for improvement in the cost, efficiency, and diversity of conversion systems.

The pineapple industry could increase the amount of pineapple trash by: (1) planting varieties which are vigorous vegetative growers, (2) retaining existing varieties, but increasing the use of potassic fertilizers, (3) extension of drip irrigation to increase the yield for forage and fuel use, and (4) growing pineapple on lands leased from the State Forestry Department and homestead lands for which there are no immediate competitors (9).

Environmental Impact

Field burning of pineapple residues is similar to burning sugarcane and other crop residues. Evaluation of relative contribution by burning to air pollution indicated concentration of photochemically active hydrocarbons to be negligible at a mile-and-a-half from the burning site (13). The effect on visibility, however, was found to be a significant aesthetic factor. Pineapple trash burning in boilers limits this pollution to moderate levels (Table 2) (3).

CONCLUSIONS

It is clear from the above discussion that the economic potential of bagasse and pineapple trash as alternate energy sources for Hawaii is very promising. The principal conclusions from our study are:

1. Hawaiian Sugar Industry currently generates about 75 percent of its energy needs from processing bagasse.

2. Bagasse could meet a significant part of the energy needs of the islands of Hawaii, Kauai, and Maui when its full potential is realized. However its impact on Oahu, the State's major city and population center, is minimal.

3. Pineapple industry has the potential to meet about 4 percent of the energy needs of Hawaii by supplying in excess of 138,000 megawatt hours to the State's utility grid, over and above its own use.

4. Maui County (consisting of the islands of Maui, Molokai, and Lanai), currently getting 30 percent of its energy needs from bagasse, is likely to obtain another 40 percent of its energy from stack burning of pineapple trash—a combined total of 70 percent.

5. The capital requirements of large-scale bagasse and trash use are minor compared to those of other energy sources.

6. The environmental impact of both bagasse and trash vis-a-vis other potential energy sources is insignificant.

7. The realization of the theoretical potential of both bagasse and trash as alternate energy sources would, in the final analysis, depend on a number of technical, economic, and institutional factors identified and discussed in the paper.

The strategies developed in this paper to exploit sugarcane and pineapple biomass as direct energy sources are predicated on the premise of deploying soft technologies using renewable energy flows, and thus on energy income, and not depletable energy capital. Our paper clearly demonstrates that a *prima facie* case exists, on the basis of economic rationality and technological viability, for the use of biomass as an alternate energy source for the state of Hawaii. And for this reason, the case for its efficient and expeditious development is both clear and compelling.

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