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BIOMASS ENERGY CONVERSION IN HAWAII

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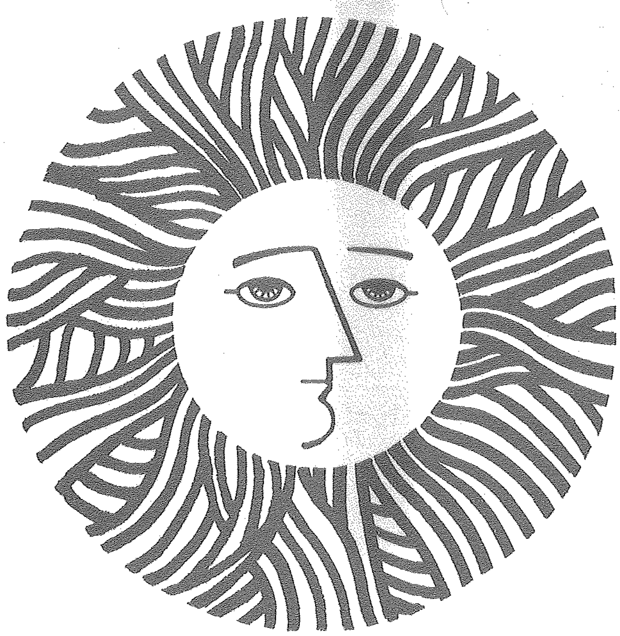

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Biomass Energy Conversion in Hawaii

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

BIOMASS ENERGY CONVERSION IN HAWAII

Ronald L. Ritschard
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SUMMARY

Organic wastes of many kinds, including municipal solid wastes, agricultural residues, and crops grown specifically for their energy-producing potential could all be burned to produce electricity in Hawaii. Molasses, however, is the only feedstock that is likely to be available for producing alcohol over the next decade or so, barring the collapse of the international sugar market. Current estimates suggest that if all the molasses Hawaii produces were used to make ethanol, gasohol could replace 7% to 10% of the state's gasoline consumption (at 1978 levels), or some 20 to 30 million gallons a year. Leafy trash, wood and other cellulosic material could be processed into ethanol or methanol, but with present technology their best use is in direct combustion as boiler fuels, replacing another significant fraction (about 10%) of imported liquid fuels.

Several things stand in the way of fully utilizing biomass as an energy source for Hawaii. Some agricultural wastes and sugar industry products and by-products are currently more valuable as human and animal food than as energy sources. Molasses, for example, is now used to manufacture beverage ethanol, industrial alcohol, and animal feed and sells for between $70 and $100 a ton. At today's prices, the ethanol that would be made from molasses is not competitive with gasoline. Gasohol use to date has been supported by government subsidies, which are expected to continue. Gasoline would have to cost about $1.70 a gallon to make gasohol attractive or even competitive. In addition, tree crops, which are one of the most promising biomass resources available in Hawaii within our 25-year time frame, require substantial land use. It would take a political decision to support the energy market for biomass or a drastic shift in present market values to redirect existing biomass resources entirely into an energy producing program. The technical problems that currently confront such a program are no greater than the economic and political barriers.

INTRODUCTION

Biomass is Hawaii´s most productive natural energy resource in terms of the electricity generated from it. Further, it is the only indigenous resource that can be converted to liquid fuels to replace imported petroleum fuels. Direct combustion of bagasse (a fibeous sugar cane residue), woodchips, and macademia nut shells generates approximately 12% of the electricity now consumed in the state.(1) Several studies have outlined a program of biomass energy use in Hawaii´s energy needs in the next two decades.(2,3,4,5)

Fuels can be derived from several biomass resources: wastes, which include all organic materials that accumulate at specific locations and whose disposal carries an associated cost, e.g. municipal solid wastes (MSW), lumber mill wastes, and sewage sludge; residues, which are plant materials left in the field or forest after agricultural crops or timber are harvested; and energy crops, i.e., those crops specifically cultivated for their fuel content. Some recently proposed energy crops for Hawaii are aquatic plants (to be cultivated in land-based systems), ocean kelp, corn, sugar cane, and various tree crops, such as eucalyptus and giant koa haole.

Technologies that convert biomass to energy and that are believed to have the greatest potential in Hawaii for the near-term (before the year 2000) include direct combustion of wood chips and wastes--such as bagasse, MSW and pineapple trash--and the production of liquid fuelss, especially ethanol from various feedstocks (cane juice, molasses, and pineapple). Biomass is the only renewable resource that will be suitable for conversion to liquid fuels before the turn of the century.

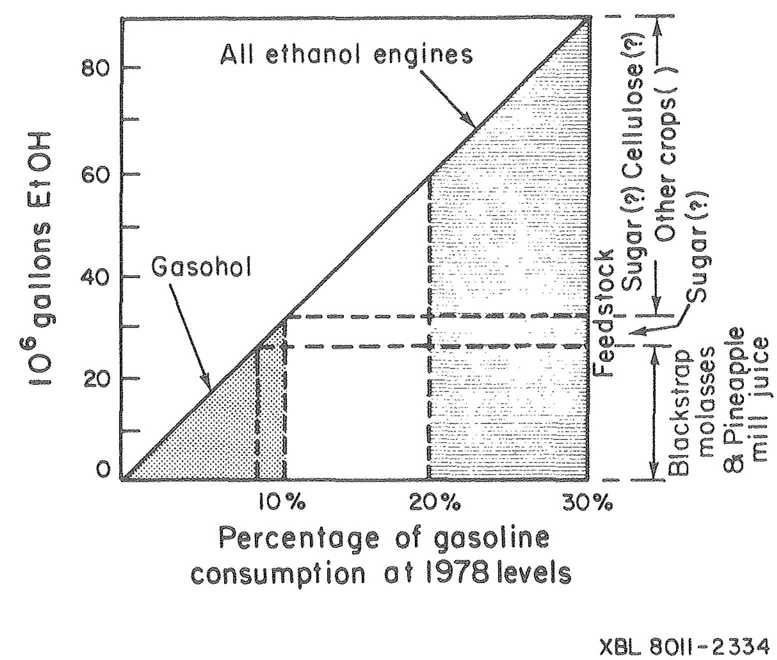
The most important consideration in the use of biomass for energy is its availability as a resource. For Hawaii, four major biomass resources appear most promising. These include the resources of the Hawaiian sugar industry (bagasse, cane juice, leafy trash, and molasses), tree crops, municipal solid wastes, and algae. Of these, only the sugar industry products and trees are now available in sufficient quantities to supply a significant amount of Hawaii´s future energy needs.

LIQUID FUELS FROM BIOMASS

The experience gained from the use of gasohol in the U.S. and other countries, combined with the existence of a strong Hawaiian sugar industry, make alcohol fuels a possible replacement for some of the 314 million gallons of gasoline consumed annually in the state. Gasohol is already used experimentally in at least 15 states on the Mainland and has been a major source of energy for transportation in Brazil since the 1930s. Further, the technology for production and use of gasohol is well known and proven in practice.

In the short-term, molasses is the best feedstock for production of ethanol in Hawaii. The sugar contained in molasses (55% by weight) is of low value because it cannot be economically crystallized and sold as food. Some mill juice from pineapple canneries is also available. There is enough molasses and pineapple juice to replace 8.4% of the state's gasoline consumption at 1978 levels (see Figure 1). If enough alcohol were produced to replace more than 10% of gasoline consumption, it could still be added to gasoline. Internal combustion engines designed for gasoline can run on a mixture containing up to 20% ethanol with only an engine tuneup. The use of mixtures containing more than 20% ethanol requires major engine modifications.

FIGURE 1. -- Suggested Strategy for Use of Gasohol



The uncertainty surrounding a number of technical and economic parameters makes difficult the assessment of long-term opportunity for alcohol fuels in Hawaii. As soon as the cheaper feedstocks for ethanol production become totally committed, methanol may again emerge as a possible alternative fuel, especially if lignocellulosic wastes are the primary resource available. The thermochemical process that produces methanol from cellulosic waste seems, as of today, to be potentially competitive with the hydrolysis-fermentation that would be used to produce ethanol from the same raw material.

Sugar will not be an economical source of alcohol unless prices stabilize at levels much lower than those presently observed. The competitiveness of sugar, and of sugar cane in particular, could be enhanced if some potential improvements in planting and processing are realized. Among the most important are: changes in crop management practices that could increase the sugar content of sugar cane and shorten the harvesting cycle; genetic enhancement that would permit harvesting of more ratoon crops; and use of less energy-intensive dehydration technologies that would substantially reduce processing costs and improve overall process efficiency. The feasibility of sugar cane as an ethanol feedstock will essentially depend on more efficient harvesting and processing, since the expansion of sugar-bearing crops in Hawaii is constrained either by land availability or climate.

Alternative Materials and Fuels

Theoretically, any alcohol can be added to gasoline for use in internal combustion engines. For technical and economic reasons, the choice is usually narrowed down to the two simplest alcohols: methanol and ethanol. The State of Hawaii has the necessary feedstocks to produce either methanol or ethanol from biomass. The presence of a strong sugar industry and some technical advantages in ethanol production suggest that ethanol may be the most attractive alternative, at least in the near term.

Most large-scale methanol production relies on coal as the main feedstock in procedures such as the Koppers-Totzek Gasifier, and the Texaco Partial Oxidation Process (6). It is also possible to produce methanol from cellulosic biomass resources. Formerly, in fact, it was commonly made from wood. Whether wood and other cellulosic materials will be used as feedstock for alcohol fuel or as feedstock providing cellulose fiber for the paper industry, or for some other purpose, is not clear. This depends on a number of factors, such as the type of alcohol fuel chosen for Hawaii and on the price of alternative feedstocks for the production of such alcohols.

Ethanol can be synthesized from oil or natural gas. Or, it can be produced via fermentation from a variety of agricultural crops that contain sugar or starch. It can even be made from cellulosic material via hydrolysis followed by fermentation. The availability of cheap petroleum products after World War II caused most ethanol to be synthesized from petroleum-derived ethylene, discouraging the use of agricultural feedstocks. In light of the oil price increases that occurred during the 1970s, producing ethanol from agricultural feedstocks emerges again as a potential alternative, particularly in the case of ethanol produced by direct fermentation with very little pre-treatment from ethanol and molasses. In addition, ethanol can be blended with cheaper, low-octane unleaded gasoline.

Anhydrous ethanol is miscible with gasoline at all proportions, always resulting in a fuel with desirable properties. The chemically correct level of fuel-air mixture in mass proportions varies almost linearly between the limits of 1:15 for pure gasoline and 1:9 for pure ethanol (7). At the level of approximately 10% ethanol (exact level may vary with type of engine), fuel consumption reaches a minimum which is lower than that of either pure ethanol or pure gasoline. Indeed, the addition of ethanol to gasoline in proportions of 1:9 improves the octane number, thereby enhancing engine performance. Up to a level of 20%, ethanol-gasoline blends can be used directly in gasoline engines, requiring only a tune-up. At levels beyond 20%, engines require an increasing number of modifications, making those mixtures less practical and more expensive.

If enough ethanol were produced to dislocate more than 20% of gasoline consumption, the best strategy would probably be to follow the example of Brazil and convert part of the car fleet to engines that can run on 95% pure ethanol. Those engines have the advantage of requiring a cheaper and less energy-intensive fuel because they can burn hydrated ethanol, which costs less and requires less energy for its distillation than the anhydrous alcohol that must be used in blends with gasoline (7).

Materials and Processes for Producing Ethanol

Hawaii consumed 314 million gallons of gasoline in 1977. In order to use a 10% ethanol-gasoline blend, Hawaii would have to produce 31 million gallons of ethanol annually. Each of the ethanol feedstocks available to Hawaii -- sugar cane juice, molasses and bagasse, as well as some less likely candidates such as pineapples -- has its own technical and economic drawbacks and advantages.

Sugar Cane Juice

From a technical perspective, sugar cane is the most logical Hawaiian crop to use for ethanol production because the sugar contained in the juice extracted from the plants is easily converted to ethanol by fermentation. By fermenting simple sugars in ethanol, over 90% of the energy originally contained in the glucose is concentrated into half the weight of the final product in a very efficient reaction (92 grams for the mole of ethanol and 180 grams for the mole of glucose) (Table 1). This is equivalent to saying that, theoretically 13 pounds of sugar are necessary to produce a gallon of ethanol. In practice, the production of a gallon of ethanol requires about 14 pounds.

TABLE 1. -- Fermentation of Glucose to Ethanol

Glucose	Ethanol
$C_6H_{12}0_5$	$2C_2H_5OH + 2CO$
180g	92g
673 Kcal	655 Kcal
Energy in Ethanol / Energy in Glucose	= 0.97

The process for fermentation of sugar into ethanol is well known and has been practiced for years. Brazil produces all of its ethanol from sugar cane, using this alternative product to counteract fluctuations in the international price of sugar. Nevertheless, producing alcohol as an alternative to sugar is probably not cost-effective. If sugar cane is to be planted for the specific purpose of producing ethanol, a number of changes should be made both in harvesting and in processing procedures that would yield ethanol at a more competitive cost (8). In the production of sugar, the main objective is to produce the largest possible quantity of crystallized sugar from the cane juice; whereas in the production of ethanol, the objective is to use a minimum of energy to produce a liquid fuel. Furthermore, when producing sugar, one seeks to avoid operations that might inhibit the process of crystallization, whereas in the production of ethanol it is only necessary to assure that the fermentation is not disturbed by prior operation. A partial or even complete inversion (formation of glucose and fructose) of the sugar in the cane, and even an acid reaction of the solution, is acceptable in ethanol production. Growing sugar cane for sugar requires that harvest be preceded by a ripening period that varies from a few weeks to several months in order to increase the content of recoverable sucrose (9), whereas in the production of alcohols this ripening period becomes unnecessary because the reducing sugars are as important as sucrose in the fermentation process.

The two end products also require differences in the way the juice is treated during processing (8). Ethanol production is not altered by the presence of other soluble substances besides sugar, insofar as these substances do not interfere with fermentation. Some substances might even contribute to a faster fermentation and to an increase in the alcohol yield. Therefore, the sugar cane can be exposed to much higher temperatures during processing than would be permissible in sugar production. The solution to be fermented should be as sterile as possible to maintain the purity of the yeast and to permit recycling, which reduces operating costs and increases yields. Sterility of the solution is also a requirement for any continuous fermentation process. If the State of Hawaii chooses to use some of its sugar cane to produce alcohol, it will be certainly advantageous to investigate all of these possible improvements, which are likely to enhance the competitiveness of alcohol as a fuel.

Even though prices are likely to make sugar an uneconomical source of ethanol in Hawaii, the following calculations show the approximate amount of sugar and the land area required to produce enough ethanol to displace 10% of 1977 state consumption of gasoline. In addition, they help one to visualize what share of the yearly production and what portion of the planted area would have to be committed to the production of alcohol.

Sugar Required = 31 million gal ethanol x 13 lb sugar/gal ethanol
= 201,500 tons of sugar
Area Required = 201,500 tons sugar x 10 ton cane/ton sugar
x 1 acre/93 ton sugar cane = 21,700 acres, or 9000 ha

Considering that sugar cane is a biennial crop in Hawaii, the necessary area would be 18,000 hectares (ha) (43,000 acres). This does not imply that such an area would be required in addition to what is already planted. If production of ethanol became economical, the alcohol would be likely to produced with sugar cane from existing plantations. The sugar required would amount to 20% of current production, whereas the required area is about 10% of the area currently planted, that is, 20% of the area harvested annually. In 1978, about 46,000 ha (113,600 acres) of sugar cane were harvested in Hawaii, while the total planted area was about 92,000 ha (227,000 acres) because sugar cane grows in a two-year cycle in Hawaii.

Because of land and water constraints there is limited possibility for substantial increase in sugar cane production. Only 4% of Hawaii's land is potentially arable, and most of that is already taken with sugar cane and pineapple plantations. According to estimates made by the Hawaiian Sugar Planters Association, a maximum of 10,000 to 20,000 additional hectares could be made available for growing sugar cane. Such a small increase would be barely sufficient to accommodate the 18,000 hectares necessary to produce enough ethanol to displace 10% of the state's gasoline consumption. More than 600,000 ha (1.5 million acres) of the state land is classified as grazing lands, and it is unsuited for the plantation of sugar cane because of shallow soils, steep slopes, and insufficient water availability. Indeed, water availability appears as the most limiting factor to the the expansion of sugar cane plantation in areas with the appropriate slope and soil depth. While on one side of the islands the level of moisture is very high, the dry side can receive as little as 50 cm of rain per year (10). In principle, water could be transported from the wet side to the dry side of the islands, but the cost of doing this would represent a substantial increase in the current cost of alcohol.

Molasses

Blackstrap molasses is a by-product of sugar cane processing. After the juice is extracted from sugar cane and clarified, sugar is concentrated and crystallized by evaporating the juice, and the sugar so obtained is removed by centrifugation. The process is carried on until the formation of sucrose crystals becomes uneconomical. The remaining liquid phase is molasses, a dark syrup containing non-crystallizable sucrose and fermentable sugars (11). The molasses contains 55% sugar by weight, and sucrose accounts for 35% to 40% of that. The remaining is invert sugar, the equimolar mixture of fructose and glucose. The sucrose lost in molasses represents the highest loss in the processing of sugar cane, and has therefore been the object of a number of studies aiming at recovering the sugar in a economical way (12).

Producing ethanol by fermentation is one of the ways to use the sugar contained in molasses. Before fermentation begins, the solution is diluted to give a sugar concentration of 10% to 15%. Acid is added to reduce the pH of molasses from 5.3 to somewhere between 4.0 and 5.0. Fermentation begins with the injection of yeast enzymes and continues for 28 to 72 hours (averaging 45 hours), producing alcohol concentrations of 8% to 10% (12). After fermentation is completed, the liquid goes to a centrifuge where the yeast is extracted to be recycled. The liquid from the centrifuge goes through a heat exchanger and into the still. The still residue, known as stillage, can be concentrated and dried; about 6.4 pounds of stillage are produced for each gallon of ethanol extracted. The azeotropic mixture of ethanol and water is usually broken down by adding benzene. However, cheaper processes are being devised using materials such as cellulose, corn starch, and shelled corn, with substantial savings in the energy needed to obtain the anhydrous alcohol (13).

The quantity of molasses produced in processing sugar cane is about 20% - 50% that of sugar by weight. Traditionally, molasses is used in the manufacture of both beverage and industrial alcohol, and as animal feed. It sells for $70 to $100 per ton (1980$). If molasses were reserved as the main feedstock for production of alcohol fuels in Hawaii, the markets for beverage ethanol feedstock and for animal feed would have to otherwise supplied.

The potential supply of alcohol from molasses can be theoretically estimated on the basis of 24 pounds of molasses for each gallon of ethanol (12). In practice, the requirements have been higher, in the neighborhood of 29 pounds per gallon. In 1978, Hawaii produced 310,000 tons of molasses, which would yield about 26 million gallons of ethanol, enough to displace 8% of the state's gasoline consumption in 1978. Therefore, in order to achieve a uniform 10% alcohol-gasoline blend throughout the state, it would be necessary to find a complementary feedstock to displace the remaining 2% of gasoline consumption. Since the production of molasses is tied to that of sugar, there is little possibility of increased availability of molasses in Hawaii.

Bagasse

Approximately 94% of the bagasse generated in the processing of sugar cane is used in the sugar mills as boiler fuel (14). Considering Hawaii's dependence on imported oil, it is important to investigate the possibility of using that fraction of bagasse that is not used as fuel to produce ethanol via hydrolysis. Even though it is valid in principle, the idea of converting bagasse into alcohol fuels is unlikely to be cost-effective in the foreseeable future. The production of ethanol from bagasse would possibly employ one of the following: strong acid hydrolysis; weak acid hydrolysis; or enzymatic hydrolysis (each of these technologies are summarized in a recent publication) (15). At present, these processes suffer from problems such as low concentration of alcohol in the fermented solution leading to high distillation costs, generation of substances that are both toxic and an obstacle to fermentation, contamination hazards, and the high cost of enzymes. Cellulose is a stable polymer; breaking it down to glucose may require long reaction hours which translate into high equipment capital costs.

Pineapple

Pineapple would be a good feedstock for the production of liquid fuels, considering that it is a native crop in Hawaii and has substantial sugar content (16% by weight). A recent article supports the use of pineapple as a feedstock for the production of ethanol (16). The soil and temperature requirements are similar to those of sugar cane; pineapple has lower water requirements and is well adapted to the islands of Molokai and Lanai where rainfall may be as low as 60 cm. Containing sucrose and invert sugars in concentrations up to 16%, pineapple would have a lower ethanol yield per acre but would make more efficient use of irrigation water than sugar cane (see Table 2) (16). As with sugar, the major obstacle to utilization of pineapple as a feedstock for production of fuel is the high value ($300/ton) that it has as food.

Methanol from Wood

Whereas this analysis is concerned primarily with the use of ethanol as a fuel in the state of Hawaii, there is, in principle, the possibility of producing another alcohol, methanol, from wood. Differences in the nature of the resources required, economics, and end-use characteristics do not permit a comparison of the two alcohols in the context of the liquid fuels market in Hawaii.

While the production of ethanol is based primarily on the fermentation of sugar and has been practiced for years, producing methanol from wood is based on pyrolysis followed by catalytic conversion.

These processes are well understood, but no commercial-scale plants are in operation. The preliminary cost estimates that have been made are naturally surrounded with uncertainty. In fact, even cost estimates for the production of ethanol are constantly revised, although fermentation is a rather simple and well-known process compared to the processes that produce methanol.

TABLE 2. -- Comparative Yields of Pineapple and Sugar Cane

Crop	Yield (ton/acre)	Ethanol Production (liter/ha-month)	Water Requirement (cm/month)
Sugar cane	93	921	180
Pineapple	20*	482	83

*20 ton/acre is the yield of the fruit, not the whole plant.
Source: (16)

As for end use, the two alcohols differ in that while ethanol is already being used as a fuel, methanol is used primarily as a feedstock for the petrochemical industry in the manufacture of formaldehyde, and achieves a very high market value as such. Industrial methanol is now produced from natural gas by a simple partial oxidation process at a lower cost than could be achieved by (hypothetical) plants producing methanol from wood.

Finally, there is the issue of allocation of the wood available in the state. Even though Hawaii's geographic location favors the growth of a variety of trees, it is not certain that the wood from those trees would be available for methanol production. Competing for the same resource are both energy and non-energy applications. Furthermore, most wood in Hawaii has its greatest value at standing trees, i.e., as natural ecosystem. Today, wood is used as a supplementary fuel in some new sugar factories in Hawaii. Most of those factories would be interested in purchasing more wood for use as a boiler fuel, both for the generation of steam process and electricity. Since all sugar refineries are already equipped with boilers capable of burning biomass material, it seems that any additional wood available for the energy market would be used as boiler fuel. In that application, incidentally, wood resources would be making their best contribution to dislocating imported liquid fuels, because whenever the supply of bagasse is short, boilers have to burn fuel oil. Among non-energy applications, the paper and pulp industry can be expected to bid for the additional wood made available.

Before methanol can be considered a viable alternative for the liquid fuels market in Hawaii, several questions remain to be answered. They include:

* At what price level is wood competitive with natural gas for the production of methanol?

* At what price level is methanol competitive with gasoline and, eventually, with ethanol?

* Given the several alternative uses of wood resources, how much could be expected to be available for production of methanol in Hawaii?

At this point it seems unlikely that, in the absence of interventions in the market, methanol will be used as a fuel to any significant extent in Hawaii over the next ten years.

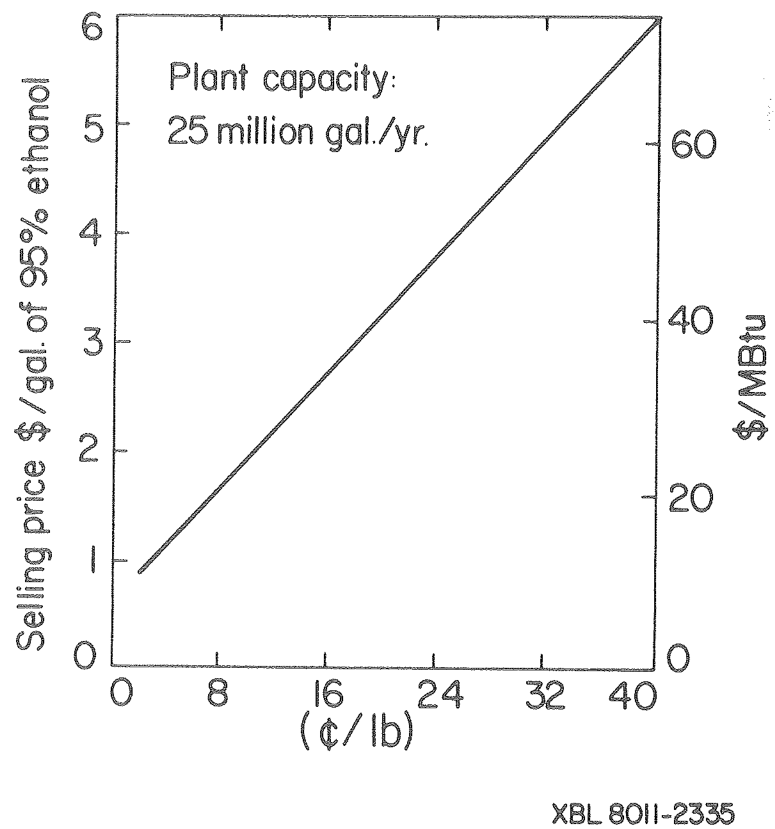
Costs

Even though fermentation of crops to produce ethanol has been known and practiced for centuries, there is relatively limited experience regarding the large-scale production of ethanol from agricultural feedstocks other than sugar cane. For many years Brazil has been producing all of its ethanol from sugar cane, and in many parts of the world liquor distilleries use blackstrap molasses to make beverage alcohol. However, most alcohol for industrial application today is synthesized from petroleum or natural gas. In the US, more than 90% of the 300 million gallons of ethanol consumed annually are produced from ethylene. The recent interest in alcohols, especially ethanol, as an alternative or additive to gasoline calls for increased use of agricultural feedstocks for the large-scale production of ethanol. A variety of materials can be used, ranging from sugar-bearing crops such as sugar cane, sugar beets and pineapple; starch-bearing crops such as corn and a number of grains; to any kind of agricultural waste containing cellulose, such as straw and wood chips. For each alcohol distillery, the use of one of the possible feedstocks will be determined by geographic location and seasonal price variations. In the Midwest, for instance, most ethanol will probably be produced from corn or cornstalks, whereas in Louisiana or Hawaii, some sugar cane-based feedstock is more likely to be used in the immediate future.

The diversity of materials used to produce ethanol makes it difficult to estimate costs. Different feedstocks require changes in the initial segments of the process, and the price of any given agricultural input can fluctuate substantially from one season to another. A study prepared by the MITRE Corporation reviewed cost data provided by 28 ethanol distilleries in an attempt to identify major patterns of cost composition and to test for the sensitivity of total cost to variations in the main components (17). The general conclusions indicate that in most cases, capital costs represented 10% to 20% of total production costs, except when wood or wheat straw were used as feedstock. In the latter case, capital costs represented a share of 30% due to the processing required prior to fermentation.

Feedstock costs consistently accounted for more than 50% of total production cost, except in the case of wood or wheat straw. Since in Hawaii most ethanol is likely to be produced from sugar crops, it can be expected that about half the total cost will be due to feedstock. This estimate is also compatible with the cost breakdown obtained for the production of ethanol from sugar cane in Brazil (18). The linear relationship shown on Figure 2 was derived in a recent article for the estimation of the effect of variation in the price of sugar on that of ethanol (19). The dependence between the two variables is definitely sensitive to the assumptions made about plant characteristics such as plant capacity, capacity factor, discount rate, and basic feedstock, some of which are specified for the curve shown on Figure 2.

FIGURE 2. — Effect of Sugar on Ethanol Price



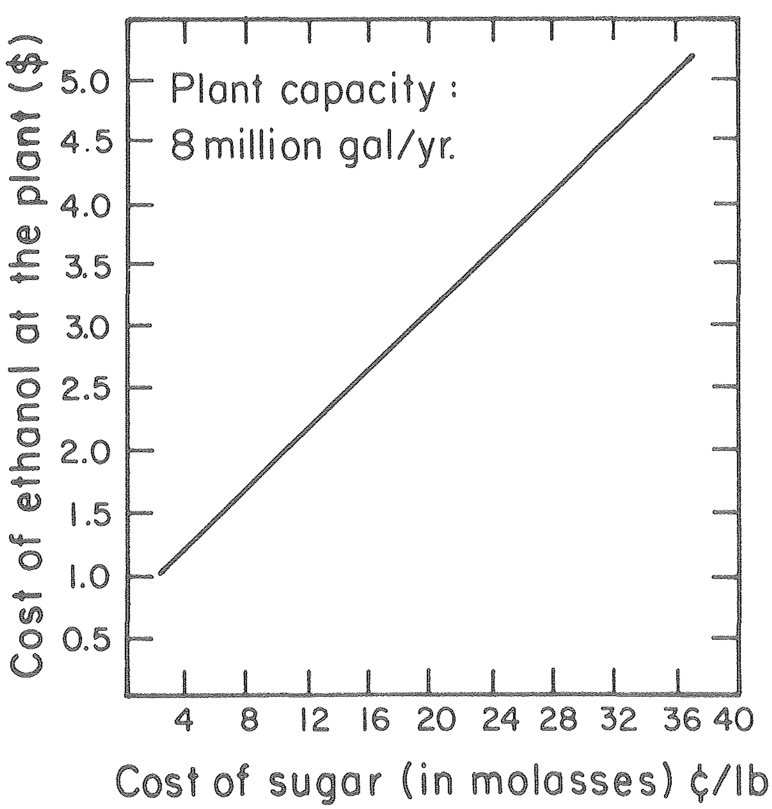
Source: (19)

The curve indicates that for variations in sugar prices in the range of 11¢ to 14¢ per pound, which is well below current prices, the price of alcohol would fluctuate in the range of $2.00 to $2.50 per gallon, which is well above current gasoline prices. Furthermore, the curve on Figure 2 is derived for 95% (V/V) ethanol; if used in mixture with gasoline, the alcohol would have to be anhydrous, requiring further processing, which would certainly increase the price of the product. To make alcohol competitive with gasoline today, the price of sugar would have to be as low as 4¢ per pound, or alternatively, the price of gasoline would have to increase sharply in relation to ethanol prices.

At this date, molasses seems to be the source able to provide ethanol at the lowest cost in Hawaii. A recent study analyzes in detail the alternative processes for producing ethanol from molasses (20). The results indicate that a continuous fermentation plant could produce ethanol at a cost of $1.60 per gallon, assuming the price of molasses is $71.76 per ton, which translates into a price of about 7¢ per pound of sugar (50% sugar in molasses by weight). The resulting cost of ethanol takes into account the processing of stillage and assumes that the potassium recovered in that operation will be sold at 18¢ per pound. The study provides information relating the cost of ethanol to the price of molasses. The data have been converted into the same units as those in Figure 2, and are shown on Figure 3. The comparison of the curves in the two figures should take into account that whereas Figure 2 shows the <u>selling price</u> of ethanol, Figure 3 shows the cost of ethanol at the plant, which does not include marketing costs. The higher <u>costs</u> in Figure 3 can in part be attributed to plant size (8 million gallons per year), which is approximately one-third of the capacity assumed in Figure 2. As mentioned before, the cost of ethanol has been shown to be rather sensitive to plant capacity.

In general, the two studies confirm each other's findings regarding the effect of sugar prices on the cost of ethanol. In either case, ethanol from sugar is not competitive with gasoline at current prices, implying that the large-scale utilization of ethanol as a fuel in the near future would require some form of subsidy.

FIGURE 3. -- Effect of Sugar on Ethanol Cost



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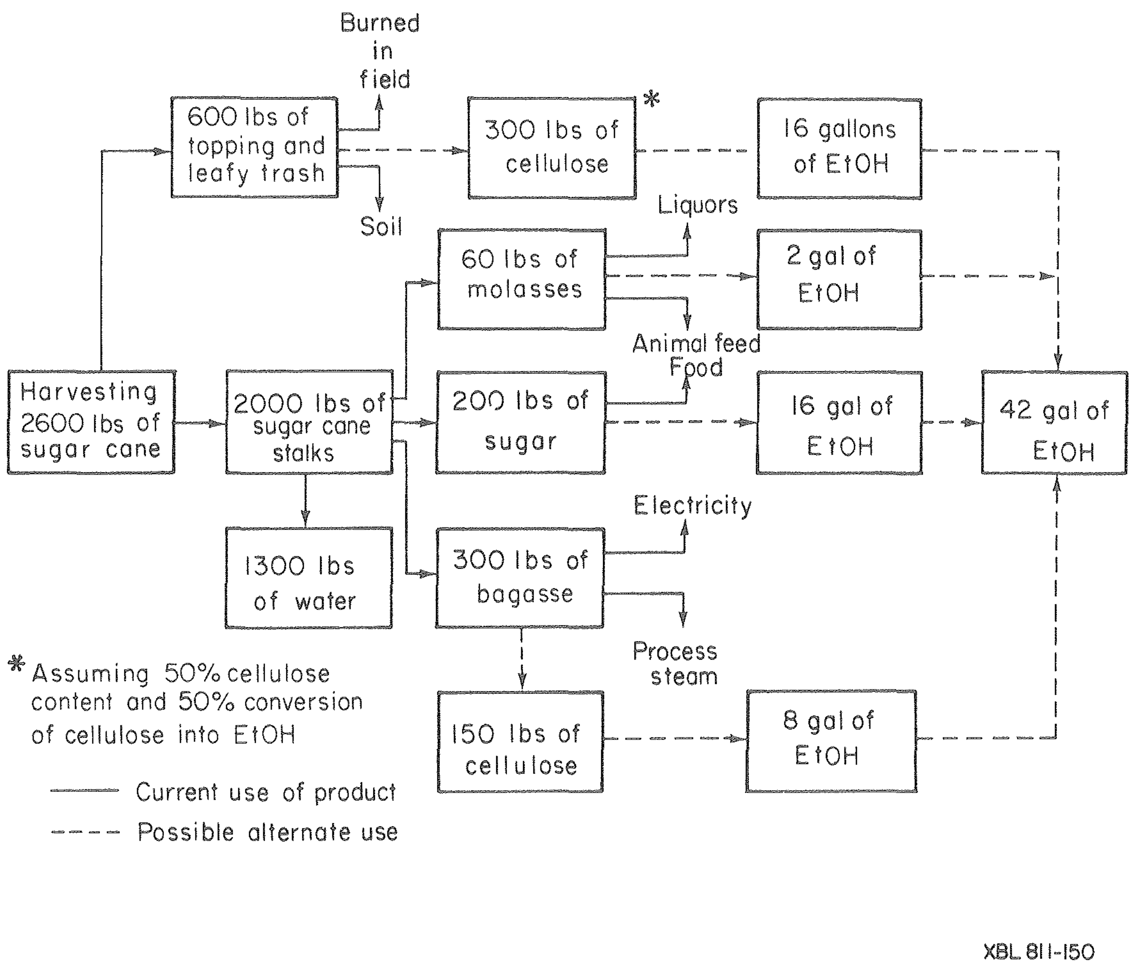
Allocation of Biomass Resources for Ethanol Production

A Strategy for use of the state's resources should seek to allocate all available biomass feedstock where it can be most valuable. (Note that "most valuable" is to be a political decision and not a market decision.) In theory, every part of a sugar cane plant could be converted into ethanol for use as liquid fuels, yielding about 42 gallons of ethanol for every ton of sugar cane stalks harvested, not accounting for the energy use in the conversion (Figure 4).

Nevertheless, the conversion of all the indicated materials into ethanol is not necessarily the best strategy for Hawaii. For example, the leafy trash and bagasse in every ton of sugar cane harvested can be combined to produce as much ethanol as the molasses and the sugar extracted in the same operation would yield. Both bagasse and leaves can be more valuable as boiler fuel for the generation of electricity and process steam. In 1978, 12% of the electric power generated in Hawaii came from bagasse-fueled stations; if more leafy trash were recovered in harvest (currently some of it is dumped on the field) it could also be valuable as boiler fuel. When burned directly, totally dry bagasse and leafy trash could theoretically yield as much as 8000 Btu/lb. If the material is instead converted to ethanol, the second law of thermodynamics guarantees that some of the energy will be degraded to non-usable forms; the energy content of the alcohol produced will necessarily be less than the maximum energy that could be extracted from the dry bagasse and leafy trash. Of course, the liquid fuel (ethanol) is usually a more convenient source of energy. In everyday practice, bagasse is burned at 50% moisture content by weight, which reduces its heating value about 4500 Btu/lb. Devising an optimal strategy for use of bagasse would require comparison of the amount of energy required to dry further and upgrade the heating value of bagasse and leaves as a direct fuel, to the amount of energy required to convert those materials to ethanol.

The strategy for using biomass resources will have to be reassessed periodically in the light of price variations in the energy market. The final solution will depend on the relative prices of gasoline and boiler fuel, as well as on the form and quantity of energy available to dry the bagasse before burning. The value of bagasse for non-fuel applications, such as paper and pulp, would also have to be accounted for in establishing a general strategy.

FIGURE 4. -- Complete Conversion of Sugar Cane into Ethanol



Environmental Impacts

The use of ethanol as fuel is environmentally benign insofar as it decreases the level of most emissions from internal combustion engines. The production of ethanol, however, generates substantial quantities of stillage that can be a damaging water pollutant.

In general, the level of emissions from engines running on pure ethanol would be less than the equivalent emission from gasoline engines. Lead emissions are totally eliminated because no lead-based additives are needed to improve the octane number; carbon monoxide emissions are slightly lower because ethanol can be used with air in leaner mixtures than gasoline. The major difference is that NO_x emissions are sharply reduced, especially if hydrated ethanol is used. Emissions of hydrocarbons may be somewhat increased, but that is still a controversial point.

The major potential environmental hazard posed by the large scale use of ethanol results from stillage discharges. In Brazil, where all ethanol is produced from sugar cane, an average of thirteen gallons of stillage are generated for each gallon of ethanol produced. The stillage has very high biological oxygen demand (BOD) and can be very harmful if directly released into waterways. Aquatic life had been all but destroyed where this has been the practice.

The solution to the stillage problem exists in the form of processes that extract the solid contents of the stillage which can then be used as fertilizer or cattle food.

DIRECT COMBUSTION OF BIOMASS

Sugar Industry Products

Hawaii's sugar industry controls or leases 5% of the total state land area, over 200,000 acres of land. In 1979, land used by sugar companies totaled 247,973 acres, while land used by independent producers totaled 11,433 acres for a combined total of 259,906 acres. Of that total, 218,773 acres were planted to cane (22). The harvested sugar cane is processed in mills located along the coastlines of the four sugar islands (Hawaii, Kauai, Maui, and Oahu). In 1979, the sugar industry harvested about 9.6 million tons of sugar cane and produced over 1 million tons of raw sugar and over 325,000 tons of molasses (Table 3). In the process, 2.9 million tons of bagasse, and about 2 million wet tons of cane trash were obtained and about 276,000 dry tons of leafy trash were dumped in land fills. (Table 4). Each ton of bagasse, containing about 50% moisture (as processed), has an oil-equivalent heating value of approximately one barrel of residual fuel oil, while 1.48 tons of leafy trash (about 60% moisture) are equivalent to one barrel of fuel oil.

TABLE 3. -- Sugar Production in Hawaii - 1979

Island	Total Cane Acreage (In thousands)	Harvested Cane Acreage (In thousands)	Raw Sugar Tonnage (In thousands)	Molasses Tonnage (In thousands)
Hawaii	91.2	39.4	388.3	116.5
Kauai	45.8	23.2	232.4	70.7
Maui	47.7	21.8	252.8	79.4
Oahu	33.6	17.0	186.2	59.2
Total	218.8	100.6	1059.7	325.8

Source: (22)

TABLE 4. -- Bagasse Production/Consumption - 1979

Island	Bagasse Production (Thousands of wet tons)	Bagasse Consumption (Thousands of wet tons)
Hawaii	1242.5	1164.9
Kauai	628.5	577.3
Maui	551.0	537.2
Oahu	484.4	430.5

Source: (14)

Bagasse has been used by the local sugar industry as a fuel source since the industry's inception 100 years ago (3). Currently, about 94% of the bagasse generated in sugar cane processing is used in the sugar mills as a supplemental fuel (6). In 1969, federal environmental regulations eliminated ocean disposal of cane waste. Many sugar mills then enlarged their boiler capacities to dispose of bagasse they weren't already burning to provide steam for processing sugar cane. In doing so, some mills entered into contractual arrangements with the utilities to supply excess electricity at a fixed rate. As a boiler fuel, bagasse directly displaces petroleum fuel. After supplying its own needs, the sugar industry now sells to utilities about 200,000 MWh per year, an amount equivalent to about 25 MW.

In dry form, bagasse can have a heating value as high as 8500 Btu per pound; however, it is usually burned at a moisture content that ranges between 48% to 50%, and at a rate of 65 tons per hour, yielding a heat value of approximately 4500 Btu/lb. The bagasse is burned in cogeneration plants to produce process steam as well as electricity. In 1977, nearly 3 million tons of bagasse were burned in sugar mill boilers, which is equivalent to about 3.8 million barrels of oil (5).

Islands with extensive sugar production have the highest potential for using the fuel capabilities of bagasse. Sugar mills on the windward side of the islands, where irrigation requirements are minor and energy requirements for sugar production are therefore less, have always had an excess supply of bagasse. In 1977, for example, about 28% of Kauai's electricity demand and about 40% of the Island of Hawaii's electricity requirements were met by plantation sales of electrical power to the utilities. On the other sugar islands of Maui and Oahu, the increased energy requirements for irrigation leave little excess electrical energy available for sale to the utilities.

A significant amount of bagasse (96,200 wet tons) is discarded each year by the sugar mills (Table 5). The primary measure of the fuel quality of bagasse is its moisture content, since reducing the moisture content substantially increases the heating value. Improving the heating value, however, requires investing energy in the drying process, unless a system using waste heat is employed. In 1978, the Waialua Sugar Company on the Island of Oahu installed a dryer that uses stack exhaust to dry the bagasse, reducing the moisture content to about 35%. The process is expected to increase the heat value of the bagasse by about 17%.

Recently, the C. Brewer Company has developed a method for converting bagasse to an animal feed that is reported to have the nutritional equivalent of alfalfa. About two tons of bagasse is needed to produce each ton of animal feed (23). This feed has been used to supplement the diet of cattle on the Island of Hawaii and was found to be superior to alfalfa. Because bagasse would probably command a better price as an alfalfa substitute than as a boiler fuel, this high value use of bagasse may compete with its role in displacing petroleum in Hawaii's energy future.

Sugar companies are interested in increasing electrical generation through the use of bagasse and cane trash (24). About 370,000 dry tons of cane trash (the leafy portion of the sugar cane plant) were harvested in 1978, of which 93,000 tons were used for boiler fuel and the remainder (277,000 tons) disposed of in landfills. (Table 5). Some of what is harvested is used as supplemental fuel in boilers, but most of it is dumped in landfills or otherwise discarded according to the relative economics of the alternatives. Cane trash is not widely used as a fuel because of its high moisture level, its low energy yield, and the necessity to remove soil and gravel before burning.

TABLE 5. -- Bagasse and Cane Trash Disposed by Sugar Industry, 1979

Island	Bagasse (Thousands of wet tons)	Leafy Trash (Thousands of dry tons)
Hawaii	55.0	115.6
Kauai	32.3	76.0
Maui	7.9	65.6
Oahu	12.2	18.7
Total	96.2	275.9

Source: (14)

Burning the leafy trash before harvest reduces the fibrous matter, which in turn reduces the cost of transporting the sugar-containing material to the mill. Proposed harvesting processes would use machinery that would dispense with pre-harvest burning, thereby recovering all the leafy trash. If the prevailing prices of oil and costs associated with the new harvesting techniques rises high enough, recovering all leafy trash for use as fuel may become feasible. If so, the leafy trash produced would represent an additional 11 trillion Btu, or the equivalent of about 1.8 million barrels of oil each year. Such new harvesting methods have been proven in the management of plantations with twelve-month cycles, but they have not been successful when applied to Hawaii's biennial sugar cane crop. The issue of field burning prior to harvest versus harvesting unburned cane, however, is a difficult one that has not been resolved.

In the future, cane trash, which is a high moisture product, may also be used as a feedstock for the production of ethanol. This process first requires the hydrolysis of the cellulosic materials by either acid or enzymes, followed by the fermentation of the resulting sugars to ethanol. The authors feed that combustion of cane trash is a more cost-effective use of this resource because it would displace imported oil directly with little preprocessing.

In summary, there is a great potential for increasing electricity production from bagasse and cane trash. the sugar industry could become a larger supplier of power to the utility grid by: 1) developing strains of sugar cane with a higher fibrous content; 2) changing harvesting and cleaning methods; 3) lowering the moisture content of the bagasse; 4) increasing the electrical generation efficiency of boilers at existing processing plants and using the waste heat more fully; 5) providing a method for bagasse storage in order to increase the electrical generation schedule from the existing nine-month period to a year; and 6) pelletizing the bagasse for better storage and for possible shipment to other power plant sites.

An incentive that has been suggested would involve a subsidy for sugar growers who have committed, or will commit, to crops and investment in biomass utilization for energy production. Another incentive should result from the new federal rules that say that electric utilities must purchase energy made available from non-fossil fuel producers at a rate that reflects the cost the utility would avoid by not using its regular sources. Historically, sugar companies that provided power to Hawaii's utilities complained that the utility was not willing to pay the appropriate rate. The state Public Utilities Commission is determining rules and regulations to incorporate the avoided cost concept into its rate setting formula.

Tree Crops

There are many possible sources of wood products in Hawaii. The most important are several species of eucalyptus, the giant koa haole tree, and ohia (a native hardwood). At present, wood chips and other wood wastes are burned in some sugar mill boilers to produce process steam and electricity. Wood chips from eucalyptus mixed with bagasse are being used as fuel on the islands of Hawaii and Maui. For example, at the sugar mill in Pepeekeo, Hawaii, 750 tons of eucalyptus wood chips were burned in 1978. These wood chips were used as a substitute for oil, which must be burned when the bagasse supply is insufficient.

Eucalyptus and giant koa haole are currently the most promising species for energy crops in Hawaii. Eucalyptus grows well on the marginal agricultural uplands that are most likely to be available for its cultivation. Eucalyptus prefers wet regions and can reach harvestable size in five to eight years. After harvesting, eucalyptus, like most hardwoods, coppices from the stump, allowing several additional harvests without replanting (three to four crops from a single planting). The trees can be grown, harvested, shipped and burned using existing technology.

Wood chips from eucalyptus have an alternate market: paper pulp. A private firm is currently harvesting eucalyptus species on the Island of Hawaii, chipping them and selling the chips to Japan for pulping. Tree farms supplying several markets such as fuel, paper pulp, and perhaps alcohol feedstock, could become part of a major timber industry in the Islands.

The value of wood chips as an export commodity for use in foreign paper industries (especially in Japan) is substantially higher at the present time than their value for energy purposes. Wood chips produced at eucalyptus farms have been estimated to cost about $28/dry ton, while sale of chips for paper pulp generated a return of $41/dry ton in 1977 (25).

In Hawaii, there are almost two million acres of forest land, of which nearly half (947,800 acres) is commercial forest land. Of this amount, more than 49,000 acres are now planted in eucalyptus and other tree species (Table 6). Ownership of the commercial forest land is split about evenly between private land owners and the state. Over half of the state's commercial forests are of native species (koa and ohia), and the vast majority of these trees are unused and of low commercial quality. Sixty percent of the possible commercial forest land is located on the Big Island of Hawaii. This island, which has the greatest potential to supply wood, has only 6400 acres of mature eucalyptus, 500 acres of which are currently being harvested each year. The primary market at present is wood chips for the paper pulping industry.

TABLE 6. -- Forest Acreage by Islands

Island	Total Forest 1970 (Acres)	Commercial Forest 1970 (Acres)	Planted Forest 1978 (Acres)
Hawaii	1,152,500	569,400	22,793
Maui	239,800	67,500	10,677
Lanai	43,900	4,500	512
Molokai	78,100	34,000	2,854
Oahu	205,300	126,500	7,224
Kauai	219,900	145,900	5,268
State Total	1,986,400*	947,800	49,326

*Islands of Kahoolawe (15,800 acres) and Niihau (31,100 acres) are included

Source: (25)

Eucalyptus were first planted in Hawaii for fuel wood in the 1880s, and plantings have continued to the present. Research on the intensive culture of eucalyptus for biomass production was initiated in 1978. BioEnergy Development Corporation, a subsidiary of C. Brewer and Company, is developing an experimental energy plantation on the Big Island in a program funded by the US Department of Energy and the C. Brewer Company (21). The project will involve planting 850 acres of marginal sugar-producing land (about 2000 trees per acre) in several varieties of eucalyptus during the next five years. The schedule calls for planting 50 acres the first year and 200 acres during each of the subsequent four years. The purpose of the program is to assess the economic and technical feasibility of using eucalyptus trees for energy farming in Hawaii. After the five to seven year growing time, the trees will be harvested, chipped and then burned at the power plants of the Hilo Coast Processing Company (Hamekua Coast) and Ka´u Sugar Company (southern part of the island) to generate electricity.

A program of developing eucalyptus tree farms for energy is being carried out by the Division of Forestry, Department of Land and Natural Resources. The Department estimates that the state´s cultivated commercial forest lands could be expanded as much as 400,000 acres if a national emergency regarding energy development were declared (26, 27). A more plausible estimate would be half that amount (200,000 acres), which would require that "incentives" increase significantly and some subsidies be provided. Current funding will permit planting about 500 acres per year.

Capital costs for an intensive tree farm of giant koa haole in Hawaii have been estimated at $2500 per acre. This includes equipment, land and other required facilities (28). It should be noted, however that this estimate is for an intensively cultured irrigated agricultural operation requiring rock-free, level land to accommodate particular harvesting technology. The costs were calculated for a 1000 acre irrigated energy tree farm on Molokai using leucaena, the giant koa haole. It was estimated that the farm could be economically feasible on Molokai, based on the current price of diesel oil burned for electricity. The target for the Molokai study was the production of 12 million KWh of electricity annually.

Direct combustion of wood chips to produce process heat or electricity would draw on existing technology. Wood-fueled boilers represent a well-developed technology; many such plants exist on the Mainland. Electricity from wood combustion would be most economically generated by 20-25 MW facilities that consume between 400 and 500 dry tons per day. Such a base- or intermediate load plant was recently suggested for the Island of Hawaii (29). The specific capital costs required for such a plant were estimated as $1500/KW. Assuming a potential eucalyptus yield of 10 bone-dry tons/acre-year and an average energy value of 17 million Btu/dry ton, a 200,000-acre wood resource could support about 320 MW of electricity. It does, however, require at least 25 years for such a farm area to build up to the maximum rate of production, so it would be well into the latter part of our study time period (beyond the year 2000) before such an output could be expected.

Energy conversion processes other than direct burning are in the developmental stages, but in the future, they may provide other energy products, such as chemical feedstocks for gasoline. The processes include pyrolysis of wood to gas or oil, acid or enzymatic hydrolysis followed by fermentation to yield ethanol, and thermogasification to produce gaseous fuels and methanol.

An option within the present state of the art involves the production of methanol, which can be converted catalytically to high octane gasoline, or used to extend it. It was suggested in a recent unpublished report that as much as 250 million gallons of gasoline per year could be produced from wood via the thermogasification/methanol synthesis process (27). This level of production would require the development of 400,000 acres of tree crops and a conversion process at the commercialization stage. The authors doubt that either of these conditions will be met during the time period of this study. (A further discussion of the wood to methanol/gasoline technology is found in the section on liquid fuels from biomass.)

The fate of any wood conversion process depends upon the cost of conventional energy sources, especially the replacement cost of oil, and the competing economic uses, e.g., trees for lumber and paper. We estimate that a successful wood biomass program can meet a maximum of 10% of the state's total electrical requirements in the next two decades.

Municipal Solid Wastes

Nowhere in Hawaii is municipal refuse being burned now to generate electricity. The City and County of Honolulu, however, is incinerating about 500 tons/day of refuge for disposal without power generation. Most of the municipal solid wastes (MSW) that Hawaii could recover for energy and other resources are on the island of Oahu. At this time, energy recovery from MSW is close to economical only on the Island of Oahu. The Honolulu Program of Waste Energy Recovery (HPOWER) is currently negotiating contracts with two companies to convert Oahu's municipal refuse into electrical power. Two plant-size options are being considered: 1200 tons/day and 1800/tons/day. The 1800 tons/day plant would use essentially all the MSW available on Oahu. On the other islands, the municipal refuse is limited and not concentrated in large population centers (Table 7).

TABLE 7. -- Municipal Refuse Available in Hawaii, 1978.

County	Municipal Refuse Generated (Tons/Year)	Approximate (Tons/Day)	Estimated Combustible Fraction (Percent)
Honolulu	657,022	1800	83
Hawaii	63,145	173	71
Maui	48,190	134	73
Kauai	26,645	73	70
Total	795,700		

Source: (24).

Direct burning of refuse to produce steam with heat recovery is the only currently available conversion process that meets the economic constraints set by the City and County of Honolulu for this project. Two combustion technologies are being considered: waterwall incineration and refuse-derived fuels (RDF). The waterwall incinerator burns refuse either as received or after it has been pre-processed into a uniform fuel product. The REF process removes combustible materials from shredded raw refuse and either burns them alone in a specially designed boiler or as a supplemental fuel with bagasse, gas or coal.

Although there are other possible conversion processes, such as pyrolysis and anaerobic digestion, combustion is the most likely solid waste energy conversion technology to be implemented in Hawaii. It has been estimated that 35 MW of electric power capacity based on MSW combustion could be constructed on Oahu by the mid-1980s; 70 MW by the year 2000 (5). Potential capacity (for the year 2000) is about 10 MW on all other islands combined. Co-combustion of refuse and bagasse is of interest for the islands of Maui and Hawaii. The amount of bagasse is large enough to guarantee the feedstocks required for an economical, commercial size plant.

Other Biomass Resources

Other biomass resources that have energy producing potential are macadamia nut shells, pineapple wastes and hay. Currently, about 94 million pounds of shells are produced annually on the Island of Hawaii (24). The macadamia nut industry already burns some shells, and they have been burned in sugar mill boilers as well. But because of their high heating value (9200 Btu per dry pound) macadamia nut shells can damage the boiler traveling grate and are therefore not often used. The amount of land planted in macadamia orchards is increasing on the Island of Hawaii. Installing boiler equipment designed to withstand the high temperatures caused by macadamia shell combustion would enable full use of this biomass resource. It is, however, an extremely small contribution.

Pineapple wastes can also be a source of energy. Much of the plant is routinely left in the field after harvestering, but this trash could be recovered and burned in the same manner as bagasse. The results of the recently completed Molokai Pineapple Waste Study, sponsored by the State of Hawaii, Maui County, and various private interests including the Molokai Electric Company and two pineapple companies, are encouraging (30). The study concluded that enough pineapple field trash is available in Molokai to continuously fuel a 1.5 MW power plant, and that the material is harvestable with current production line equipment. It is anticipated that after burning, the ash from the pineapple crop trash will be redistributed over the fields to replenish the materials taken from the soil. It has been estimated that the pineapple trash on Molokai could supply up to 25% of the island's electricity needs (5). Pineapple wastes from the Dole Plantation on Lanai and others on Maui could also be burned for energy.

There is a proposal on the Island of Molokai to use hay as a feedstock for combustion and as a replacement for diesel fuel. The hay will be available from the Molokai Ranch. Some 18,000 tons of hay could provide about 10 million KWh of electrical power annually. Molokai Electric plans to begin burning a combination of pineapple wastes and hay, which will supply 50% to 60% of its energy needs (31).

Environmental Impacts of Direct Combustion Systems

The primary environmental problems of combusting biomass resources such as wood chips, bagasse and MSW vary with the type of combustion process and the feedstock employed. Residuals include: air pollutants (particulates and gaseous emissions); water effluents such as chlorides, total suspended soils, and phosphates; and a significant amount of ash that may require land disposal.

Particulates are the most significant air pollutant from direct incineration systems. Emission rates vary widely depending upon the moisture and ash content of the fuel, unit design and combustion parameters. Gaseous emissions (SO_2 and NO_x) are not viewed as significant environmental problems, since the feedstocks in question are typically low in sulfur and combustion usually occurs at temperatures at which little NO_x is formed. Trace elements such as beryllium, cadmium, mercury, copper and lead may be a problem when considering municipal refuse as an energy source.

Water pollution may result from the runoff of topsoil from chemically fertilized fields and from the sugar cane washing process. In addition, developing managed forests to produce wood chips as an energy feedstock will also require the use of chemical fertilizers that will run off from the topsoil during harvesting or processing. Landfill areas are required for unburnable cane waste and the ash residues from

MSW and wood combustion. A potential exists for water pollution problems if hazardous materials are leached from these landfills.

Finally, the transportation of crops (sugar cane and tree crops) or wastes (bagasse and MSW) to conversion facilities can result in various environmental impacts including noise, vehicle emissions and roadway disruption.

ALGAE

Algae have been described as a significant biomass resource in Hawaii, in part because they have a higher photosynthetic efficiency than most land-based plants and are capable of producing methane through the process of anaerobic digestion. The species available in Hawaii include both large attached marine kelp grown, harvested, and processed either in onshore or offshore facilities, and unicellular algae grown in terrestrial ponds. Although some kelp and other algae are endemic and grow in island waters, Hawaii has no history of intensive cultivation of algae. There has been little success to date in using algae as an energy crop in the United States or elsewhere. Many technical problems, especially in algae production and harvesting, have not been overcome within economic constraints.

A 1977 Stanford University Hawaii Biomass Study proposed a 23 square mile Sargassum plantation off the southwest coast of Molokai (2). Sargassum, an indigenous kelp species, can be used to produce methane gas. The capital cost of the plantation was estimated at that time as $98 million and was expected to replace 1.2 trillion Btu/year, about one-third of the energy sold as pipeline gas in Hawaii in 1975 and 0.5% of the total state petroleum demand in 1978 (19).

Much R&D would be required to determine the potential of energy conversion from aquatic feedstocks like kelp and other algae. R&D to date suggests the situation is not encouraging for the near future. There is a need for technical development of cultivation and harvesting methods. Suitable varieties of algae must be investigated and their growth requirements evaluated. The anaerobic digestion process, which is generally considered the most appropriate for conversion of aquatic feedstocks to fuel, must be proven feasible, especially for high salt substrates. Further, the process can become economical only if by-products such as food, livestock supplement and chemicals are marketable as well. Due to the technological advancements required and the high costs of the system, energy from aquatic biomass (kelp and other algae) will not be a viable energy source in Hawaii for the foreseeable future and will not be included in the energy supply scenarios for the Hawaii Integrated Energy Assessment.

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