BIOMASS: AN ALTERNATIVE ENERGY SOURCE

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AES-UPR and CEER-UPR Biomass Energy Program

Presented to the

CUARTO CONGRESO DE INVESTIGACION CIENTIFICA

Condado Beach Hotel, San Juan, P.R.
February 8, 1980

Contributed By

The UPR Center for Energy and Environment Research
Río Piedras, Puerto Rico

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TABLE OF CONTENTS

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ABSTRACT

Biomass is organic matter in which solar energy has been stored in the forms of fiber and fermentable solids. In this context plant materials are viewed as solar energy collectors in which photosynthesis is the decisive process for converting sunlight to usable energy forms. Although not very efficient, plants are the only form of solar collector that has ever worked at any appreciable level of magnitude, with any appreciable economy, for any appreciable period of time.

As renewable energy sources terrestrial plants are grouped into two categories: Woody (trees and other perennial forms) and herbaceous (primarily annual plants). Members of both groups can be managed as crop plants, and each group has numerous wild species that produce biomass without the aid of man. Whatever the species, the energy content of this biomass will be about 7500 BTUs per oven-dry pound. There are many ways of recovering this energy. The two most immediately practical recovery methods are direct combustion (for electrical power production) and fermentation to alcohol (for motor fuels and chemical feedstocks).

Biomass energy production as an agricultural commodity or a salable forest product requires land and water resources in addition to a warm growing season and suitable species. Puerto Rico is blessed with a year-round growing season and adequate sunlight for both woody and herbaceous plant forms, but land and water are limited. A very careful analysis of land-use potentials is needed to arrive at the correct trade-offs between food and energy crops in a small island urgently in need of both commodities.

Puerto Rico's outstanding biomass resource today is sugarcane and related tropical grasses. These plants make optimal use of the warm climate in producing both fiber and fermentable solids on a year-round basis. Puerto Rico's historical experience in producing cane, raw sugar, and molasses spans four centuries. More than at any time in Puerto Rico's past, sugarcane is needed today as a boiler fuel and a source of fermentation substrates for alcohol. Sugarcane molasses is also needed with mounting urgency to meet the demands of Puerto Rico's rum industry. Current and past research by CEER-UPR on biomass energy production is outlined in this presentation.

1/ Presented to the Cuarto Congreso de Investigación Científica, Condado Beach Hotel, February 8, 1980.

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INTRODUCTION: BIOMASS IN PERSPECTIVE

Biomass is solar energy stored in the conveniently manageable forms of plant tissues (cellulose, hemicellulose, lignin) and fermentable solids (sugars and starches). In its fresh or "green" state it can be converted anaerobically to methane (1). When sufficiently dried it can be burned directly as a boiler fuel or it can be compacted and stored for later combustion (2). With suitable technology it can be converted to liquid fuels, gaseous fuels, or a broad range of chemical feedstocks (3,4,5,6). There is strong evidence that dried and powdered biomass can be fired directly in the existing oil-burning power plants of electrical utilities (7).

Literally thousands of land plant species—both herbaceous and woody—are potential energy sources. They are both a renewable and a domestic resource. For nations blessed with a tropical climate such species can be managed on a year-round basis as agricultural or forest commodities. In this context a whole range of employment opportunities is opened for both skilled technicians and an unskilled labor force. An oven-dry short ton of biomass represents

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about 15 x 10^6 BTUs of stored energy. The direct incineration of one such ton, in a stoker furnace with high-pressure boiler having a 70 percent conversion efficiency, would displace about two barrels of residual fuel oil.

Some species also produce sugars and polyglucosides in sufficient quantities to justify extraction and sales as fermentation substrates. Alcohols produced from biomass fermentable solids have a growing demand in the motor fuel and chemical feedstock markets, not to mention alcoholic beverages 1/. Still other species store energy in the more highly-reduced form of natural hydrocarbons (8,9).

TERRESTRIAL FORMS OF BIOMASS

Only a small fraction of the earth's land plants have been examined closely as potential energy-supplying commodities. Woody species used as fuel over thousands of years were mainly a gift of nature. Even in modern times forest species management has been primitive by agronomic standards and directed to conventional timber and wood products rather than fuels and feedstocks. A slightly larger number of herbaceous species have been studied as domestic energy resources. Among the latter are tropical grass species of Zea, Sorghum, Saccharum, and Pennisetum which were recognized for their high yields of fiber and fermentable solids long before the petroleum embargo of 1973. However, there is good reason to believe that woody plants once fully developed could supply greater quantities of energy than crops such as sugarcane. Indeed, the R & D emphasis of the US Fuels From Biomass program has been heavily slanted toward silviculture in recent years.

1/ For example, Puerto Rico's rum industry consumes about 40 million gallons of molasses each year, more than double the molasses output of the island's sugarcane industry.

A majority of terrestrial plants have never been cultivated for food, fiber or fuel (10,11). In warm climates wild grasses such as Sorghum halepense (Johnson grass), Arundo donax (Japanese cane), and Bambusa species are borderline cases where occasional use has been made of their high productivity of dry matter. In cooler climates, self-seeding herbaceous plants such as reed canary grass, cattail, wild oats, and orchard grass may be viewed with mixed feeling by landowners unable to cultivate more valuable food or forage crops. Species such as ragweed, redroot pigweed, and lambsquarters are recognized for their persistent growth habits while otherwise regarded as common pests. Nonetheless the fuel value of such species is rising dramatically as fossil energy forms become increasingly costly.

Evaluating the long-term energy potential of silviculture (forest) species is a more time-consuming task (12-16). Most of our information on wood production relates to wild forests or extremely marginal cultural management regimes. Moreover, conventional timber and wood products continue to command a more lucrative market than fuels and feedstocks, even with today's rapidly-escalating energy values. Wood conversion to fuels is essentially confined to lower-quality species, forest residues, and residues from conventional timber harvest and milling operations. However, two concepts are gaining acceptance as means of capitalizing on forest energy potentials: (a) Woody species must be removed from the purely wild state and "managed" as crop plants, ie, in forest "energy plantations", and (b), maximum yields can be obtained through coppicing (frequent recutting of shoots from established stumps). Both concepts are under investigation on the US mainland (12,13,14,15) and in Puerto Rico (16).

PUERTO RICO'S BIOMASS RESOURCES

1. Herbaceous Plants

Foremost among the Island's plant resources are sugarcane (*Saccharum* spp.) and related tropical grasses. First as the "noble" canes (*S. officinarum* selections) and later as interspecific *Saccharum* hybrids, sugarcane has been planted here for over 400 years (17, Chap. 1). The highest recorded yield was 36.4 oven-dry tons/acre year (about 105 green tons) obtained in 1979 (2). Wild *Saccharum* species (*S. spontaneum*, *S. sinense*, *S. robustum*) are presently found on the Island but all are post-Columbian imports (18). Other cultivated tropical grasses include sweet sorghum (*Sorghum vulgare*), napier grass (*Pennisetum purpureum*), and "Sordan" (a sweet sorghum x Sudan grass hybrid). The latter yield lower tonnages than sugarcane but produce exceptional growth for short periods of time. Several wild tropical grasses are also being studied as biomass resources. Johnson grass (*Sorghum halepense*) originally developed as a cattle forage and imported for this purpose, "escaped" on the Island and is widely regarded as a noxious weed by local farmers. Bamboo cane (also "Japanese cane") growing wild on the semi-arid south coast, is an *Arundo* species formerly used in the production of wind instruments.

2. Woody Plants

Puerto Rico's forest or silviculture species also have large biomass potentials; however, these potentials have never been defined in an "energy plantation" context where total dry matter (cellulose, hemicellulose, lignin) is the preferential product. Data gathered by the USDA Institute of Tropical Forestry in Río Piedras have related mainly to quality wood products and timber from minimum tillage operations (19,20,21). Hence, the production of silvicultural biomass as a renewable energy source offers a new and significant challenge for Puerto Rico's forest industry. In this context woody species would serve as a partial substitute for imported fossil fuels (valued at $1.20 billion in 1978) rather than a substitute for imported timber (valued at $0.25 billion in 1978). Among the most promising forest genera having large biomass potential in Puerto Rico are Eucalyptus, Cassia, Albizia, Leucaena, Casuarina, Syzygium, and Pinus (19,20,21).

Areas least suited to biomass production are the non-irrigable zones of the Island's semi-arid south coast. Even here, species of the Euphorbiaceae and Asclepiadaceae families appear to have important potential as sources of plant hydrocarbons. In all, some 65 species from ten families have been identified as potential hydrocarbon-bearing plants for Puerto Rico (22).

3. Minimum Tillage Biomass

One other group of plants deserves mention as a biomass energy resource for Puerto Rico. These are the "low till" species whose importance stems not from their high yields but rather from their ability to produce some biomass under marginal conditions unsuited to conventional agriculture. Members of this group tend to cross conventional taxonomic and ecological boundries. A common characteristic is that they propagate solely in the wild, or are agricultural selections sufficiently close to the wild state that no special care from man is needed for survival. They are usually self-seeding and often have specialized features such as long tap roots or an ability to fix nitrogen, or anatomical features designed to conserve moisture or to resist extreme temperatures and natural enemies. Typical examples in temperate climates include ragweed, red-root pigweed, tansy, ragwort, lambsquarters, cattail, and reed canary grass. Examples in Puerto Rico include such herbaceous species as wild sugarcanes (S. spontaneum), napier grass, and Johnson grass, and woody plants such as Albizia, Leucaena, and Calotropis.

In some cases minimum tillage may include a low level of agriculture where seedbed preparation and one or two irrigations are provided to aid species establishment. At the other extreme no tillage of any form is ever given aside from such operations as are needed to prevent plant takeover of a given property. A good example of this is found in Puerto Rico's autopista and road right-of-ways where wild plants are periodically cut back as a part of normal highway maintenance and beautification. The cut materials are ordinarily left on the roadside or trucked to the nearest municipal dump. The author estimates that about 1200 acres are thus occupied in autopista borders and dividers alone. With an average annual yield of four oven-dry tons per acre, the discarded material would represent some 12,000 barrels of fuel oil, worth about $330,000 at this writing (Feb., 1980). This conservatively represents less than one percent of the wild biomass refuse that at some future date could be trucked to a biomass-fueled incinerator for the production of electrical power.

BIOMASS AS AN AGRICULTURAL COMMODITY

1. Climate Considerations

Under suitable circumstances a case can be made for biomass energy planting as an agricultural commodity in most of the earth's croplands traditionally planted in food and fiber commodities. But to obtain the maximum biomass yield possible on a per annum basis two factors are needed: (a) A climate sufficiently warm to sustain plant growth throughout the year, and (b), available plant species capable of continuous growth throughout the year. Both factors are unattainable in all regions of the US mainland. Each is happily present in Puerto Rico and most other tropical areas of the world.

In addition to warm temperatures there is an obvious need for soil, water, and light resources to sustain plant growth. None of these is quite so limiting for plant growth as temperature, especially minimum night temperature. Even in Puerto Rico the "winter" growth of sugarcane slackens to less than 20 percent of the summer growth rates (2). An example of a very good biomass yield in temperate climate conditions is the 10-12 dry tons/acre of cattail (Typha spp.) obtained by Pratt and Andrews (23) in Minnesota. This yield was produced in the 4-month interval June through September. Experimental sugarcane in Puerto Rico has produced over 36 dry tons/acre year (2). This is roughly equal to what northern cattail would yield if it grew continuously throughout the year.

2. Botanical Considerations

It is generally recognized that both woody and herbaceous species have characteristic yield potentials for biomass. However, for economical production, the energy planter must give careful attention to his crop's growth and maturation profile. This profile is particularly important for herbaceous species such as sugarcane and other tropical grasses. For such plants a miscalculation of harvest date by as little as two weeks can defeat the grower's best intentions.

A given specie's growth and maturation profile can be plotted as an S-shaped curve (Figure 1). Typically, the early-juvenile plant will experience a relatively long period of tissue expansion, followed by a short period of tissue maturation. The plant's visual size increases markedly during the expansion phase, but little dry matter is accumulated and in fact these tissues consist mainly of water. The maturation phase involves little outward change in plant size but dry matter increases drastically (Figure 1). For the energy planter this dry matter is his principal salable product. He must resist the tentation to harvest his crop when growth has appeared to cease, for by waiting just a little longer his yields might be increased several fold, and without committing any additional production inputs.

While the S-configuration is characteristic of most growth profiles, the magnitude of this profile will vary enormously among species over a time-course of one year (Figure 2). Hence it is necessary to categorize available species in accordance with the time interval needed to maximize biomass yield. As illustrated by Figure 2, a "short rotation" species such as Sordan 70A will maximize its dry matter yield within about 10 weeks after seeding. This is an excellent energy crop for tropical regions where a given site is available for energy cropping only 10 or 12 weeks (as for example between the harvest of one food crop and the planting of another food crop). If a longer time-frame is available for energy cropping, say 4 to 6 months, a superior species would be napier grass or some other "intermediate rotation" plant that maximizes dry matter yield somewhat later than Sordan 70A. If a full year is available neither Sordan 70A nor napier grass would be sown. In this instance the energy planter would turn to sugarcane or some other "long-rotation" species whose finest yield attributes are expressed a year or more after seeding (Figure 2).

As described above, the concept of tailoring crop selection to the correct maturation profile is almost an over simplification. Yet, it is a botany-oriented concept not readily grasped by non-botanists or others unfamiliar with the principals of energy planting. A persistent error by authors evaluating biomass potentials for the United States is an assumption that biomass energy planting is essentially comparable to planting conventional food and forage crops. Hence, workers in Florida (24) still recommend that sugarcane be harvested several times per annum; similarly, in a recent testimonial (25), it was recommended that sugarcane yields be increased with varieties suited to two harvests per year. While such programs are based on good intentions, they are contrary to the botanical capabilities of sugarcane and impose unnecessary constraints on the energy planter.

3. Production Costs and Energy Balances

The "energy plantation" concept for biomass production has received widespread attention since the mid 1970's. Cost figures for energy plantation operations are, at this time, mainly projections based on conventional agricultural operations. Baseline data for sugar crop management for energy have been gathered since 1975 (5), but these also are heavily reliant on figures supplied by the cane sugar industry. Meaningful production cost data for herbaceous plants as a whole may require several decades of research by literally hundreds of contractors. Baseline cost data for silviculture species has also been published in limited quantity (15). Many years will be needed to compile production costs for the world's forest species managed as energy crops.

Production costs for sugarcane managed for energy in Puerto Rico are fairly well known, owing largely to production research sponsored here first by ERDA and later by the DOE Fuels From Biomass Systems Branch (2). Because of the emphasis given to energy products (boiler fuel and molasses) rather than sucrose the term "energy cane" has been adopted by the CEER-UPR biomass energy program.

Preliminary cost analyses for energy cane production were performed in 1979, on the basis of first-ratoon yields from three varieties planted at two row spacings (Table 1). These figures pertain to a family-owned, 200 acre operation yielding 33 oven-dry tons of biomass per acre year. The most expensive equipment items (a whole-cane harvester and low-bed truck) would be hired from the PR Sugar Corporation together with the equipment operators. In an energy cane industry such items would probably be family owned—in which case the operation and maintenance costs would be appreciably lower. Both water and fertilizer charges are conservative; actual data showed them to be lower in the ecological zone where baseline data were gathered. Total costs, including delivery to the milling site, amount to $25.46 per oven-dry ton, or about $1.70 per million BTUs. By way of reference, Puerto Rico is presently paying about $4.30 per million BTUs in the form of residual fuel oil.

In an energy cane scenario about 68 percent of this dry matter would be burned as boiler fuel. The remainder would be extracted as fermentable solids during the cane dewatering process and later sold as constituents of high-test molasses. The fermentable solids from one acre of energy cane (ie, with a yield of 33 dry tons/acre year) would be valued at around $1,800 if marketed today as high-test molasses. The PR rum industry is the logical first buyer of this byproduct since rum is one of the island's leading sources of revenue. Domestic molasses is also in extremely short supply. Although Puerto Rico was one of the world's major exporters of molasses in 1934 (26), she had declined to an 88% dependency on foreign suppliers in 1979 (25).

A preliminary net energy balance was performed on PR energy cane in January, 1980 (27). The energy balance is of decisive importance to all candidate species for biomass production, since an appreciably greater amount of energy must be recovered from the crop than that expended in its production and processing. Authors vary considerably in their derivations of a net energy balance owing in part to the difficulty in selecting and defining the parameters used in their respective models (28). Zeimetz (29), for example, divided the energy content (higher heating value) of dry harvested material per acre by energy input per acre. The output/input ratio ranged from 3.3/1 for Missouri corn to 10.7/1 for South Dakota alfalfa. By equal treatment PR energy cane has an output/input ratio of 8.2/1 (27) 1/. A more meaningful energy balance is the ratio of usable steam recovered per acre to the energy expended per acre. By this standard the output/input ratio for PR energy cane is 6.2/1 (27).

1/ Assuming that the extractable solids (about 640 pounds per dry ton) are removed during the dewatering process and are not credited to boiler fuel.

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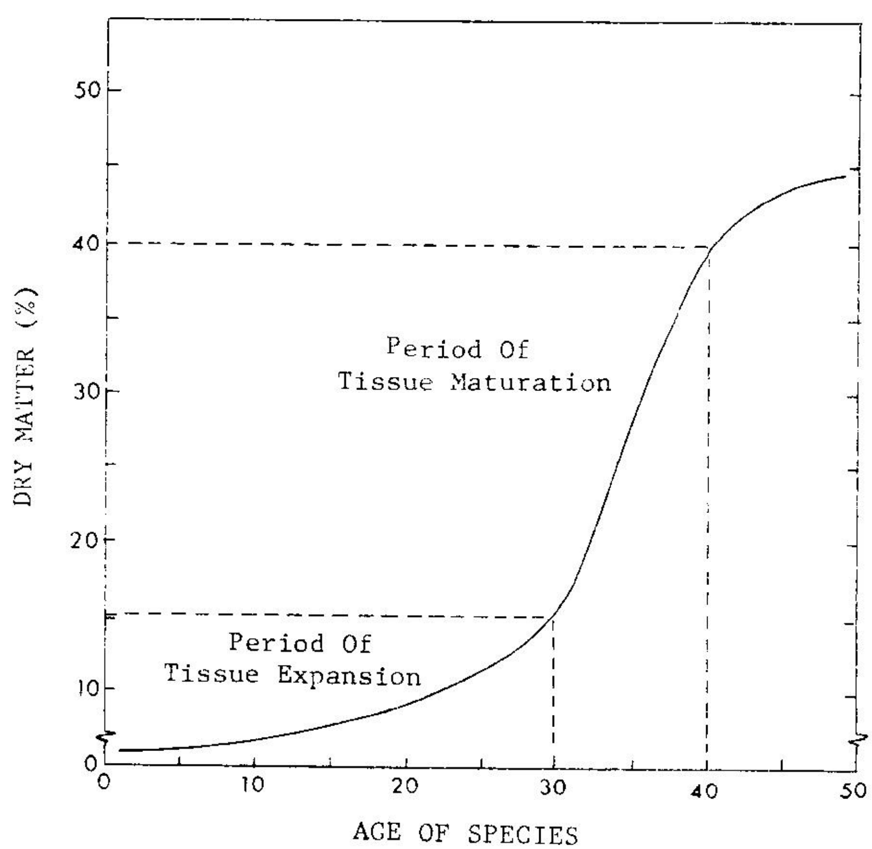

FIGURE 1. A schematic representation of the maturation profile of plant species. With the visible growth phase (tissue expansion) essentially completed, the energy planter will gain much more dry matter by allowing a brief additional time interval to elapse before harvest.

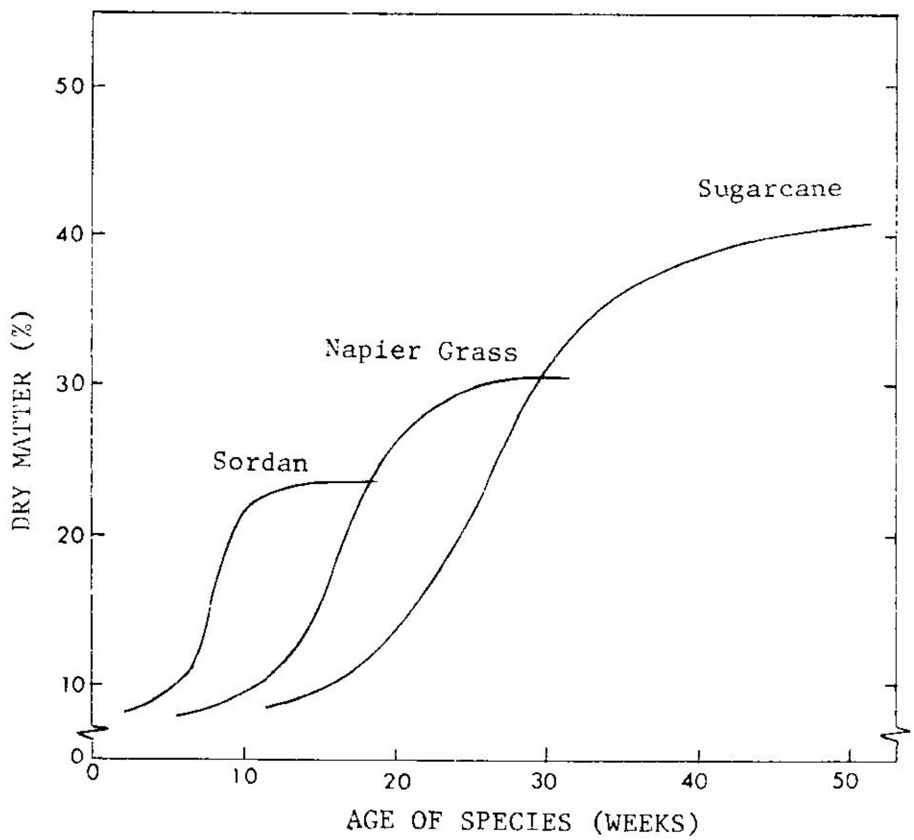

FIGURE 2. Relative maturation profiles for Sordan 70A, napier grass, and sugarcane over a time-course of one year. These plants are representative of the short-, intermediate-, and long-rotation cropping categories, respectively.

TABLE 1. Dry Matter Production Costs for First-Ratoon Sugarcane Managed as an Energy Crop 1/

Land Area: 200 Acres
Production Interval: 12 Months
DM Yield" 33 (Oven-Dry) Short Tons/Acre; Total 6600 Tons

Preliminary Cost Analysis

Item	Cost ($/Year)
1. Land Rental, at 50.00/Acre	10,000
2. Seedbed Preparation, at 15.00/Acre	3,000
3. Water (800 Acre Feet at 15.00/ft)	12,000
4. Water Application, at 48.00/Acre Year	9,600
5. Seed (For Plant Crop Plus Two Ratoon Crops), 1 Ton/Acre Year at 15.00/Ton	3,000
6. Fertilizer, at 180.00/Acre	36,000
7. Pesticides, at 26.50/Acre	5,300
8. Harvest, Including Equipment Charges, Equipment Depreciation, And Labor	20,000
9. Day Labor, 1 Man Year (2016 hrs at 3.00/hr) 2/	6,048
10. Cultivation, at 5.00/Acre	1,000
11. Land Preparation & Maintenance (Pre-& Post-Harvest)	600
12. Delivery, at 7.00/Ton/20 Miles of Haul	46,200
13. Subtotal:	152,746
14. Management: 10% of Subtotal	15,275
15. Total Cost:	168,023

1/ DOE contract no. DE-AS05-78ET20071.

2/ Labor which is not included in other costs

Total Cost/Ton: (168,023 ÷ 6600): 25.46
Total Cost/Million BTUs: (25.46 ÷ 15): 1.70