

BIOMASS: AN ALTERNATIVE ENERGY SOURCE

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BIOMASS: AN ALTERNATIVE ENERGY SOURCE

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ABSTRACT

Biomass is organic matter in which solar energy has been stored in the form 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 into 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

Saleable forest products require 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. 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 into methane. When sufficiently dried it can be burned directly as a boiler fuel or it can be compacted and stored for later combustion. With suitable technology, it can be converted to liquid fuels, gaseous fuels, or a broad range of chemical feedstocks. There is strong evidence that dried and powdered biomass can be fired directly in the existing oil-burning power plants.

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. Among the latter are tropical grass species of Sorghum, 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. 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 other species are border subjects 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 feelings by landowners unable to cultivate more valuable food or forage crops. Weeds 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, i.e., 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 at this time.

US mainland (12,13,14,15) and in Puerto Rico (16).

When considering Puerto Rico's biomass resources, foremost among the island's plant resources are sugarcane (*Saccharum* spp.) and related tropical grasses. First as the "noble" canes (*Saccharum 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*) 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). These 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*), initially developed as 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 Rio Piedras have related mainly to quality wood products and timber from minimum tillage operations (19,720,271). 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 (29,20,21). 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 family 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).
Minimum Tillage Biomass One other group of plants deserves mention as a biomass energy resource for Puerto Rico. These are the "low tilt" 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 boundaries. 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, redroot pigweed, tansy, ragwort, lambsquarters, cattail, and reed canary grass. Examples in Puerto Rico include such herbaceous species as wild sugarcane (*S. spontaneus*), napier grass, and Johnson grass, and woody plants such as Albizia, Leucaena, and Calotropis.

-6- 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 2200 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 \$530,000 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]

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 six-month interval June through

September. Experimental sugarcane in Puerto Rico has produced over 36 dry tons/acre per year (2). This is roughly equal to what northern cattail would yield if it grew continuously throughout the year. 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 saturation 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 species' growth and saturation 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 temptation 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 704 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.

The text is marketed today as high-test molasses. The Puerto Rican 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, it had declined to an 88% dependency on foreign suppliers in 1979. A preliminary net energy balance was performed on Puerto Rican energy cane in January, 1980. 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. Ziemer, 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 Puerto Rican energy cane has an output/input ratio of 8.2/1. 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 Puerto Rican energy cane is 6.2/1. 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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-b- Period of Tissue Maturation Day MATTER (4) Period OF Tissue Expansion AGE OF SPECIES
 FIGURE 1. A schematic representation of the maturation profile of plant species. With the visible growth phase (Groove exponentially completed, the energy plaster will gain more dry matter by allowing a brief additional time interval to elapse before harvest.

DRY METER (29 8 -u- Sugarcane 'Paper Grass 16 30 30 « 30 AGE OF SPECIES (WEEKS)
 FIGURE 2. Relative saturation profiles for Sorghum TOA, paper grass and sugarcane over a time-course of one year. Representative of the short, intermediate and long 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
 Dry Matter Yield: 33 (Oven-Dry) Short Tons/Acre
 Total: 6600 Tons

Preliminary Cost Analysis per acre (\$/Year)

- A. Land Rental, at \$0.00/Acre: 10,000
2. Seedbed Preparation, at 15.00/Acre: 3,000
3. Water (800 Acre Feet at 15.00/Acre): 12,000
4. Water Application, at 48.00/Acre: 9,600

5. Seed (For Plant Crop Plus Two Ratoon Crops), 1/2 Ton/acre/year at 15.00/ton: 3,000
6. Fertilizer, at 180.00/Acre: 36,000
7. Pesticides, at 26.50/Acre: 3,300
8. Harvest, Including Equipment charges, Equipment Depreciation, And Labor: 20,000
9. Day Labor, 1 Man Year (2018 hrs at 3.00/hr): 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 fuel: 46,200
13. Subtotal: 152,766
14. Management: 10% of Subtotal: 15,275
15. Total Cost: 168,023

DOE contract no. DE-AS05-76E120071.

2/ Labor which is not included in other costs

Total Cost/Ton: $(168,023 \div 6600)$: 25.46

Total Cost Million BTUs: $(25.46 \div 15)$: 1.70