CEER- 8-104 SYMPOSIUM PAPERS: FUELS AND FEEDSTOCKS FROM TROPICAL BIOMASS - THE UPR CENTER FOR ENERGY AND ENVIRONMENT RESEARCH

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'OPENING REMARKS: FUELS AND FOODSTOCKS FROM TROPICAL BIOMASS.'

Symposium on Alternative Domestic Energy Systems for Puerto Rico By Dr. Juan A. Bonnet, Jr, Director of the Center for Energy and Environment Research (CER).

November 24, 1980.

On behalf of the CER and our co-sponsors, the Chemical, the Electrical, and the Mechanical Institutes of the Puerto Rico Professional Society of Engineers and Surveyors, I extend a warm welcome to all of you. Good morning to all participants and to our visiting scientists.

Following the order in the program, our invited speakers are: Dr. Donald Kiass from the Institute of Gas Technology, Chicago, Illinois, Dr. Beverly J. Berger, Acting Director, DOE Division of Biomass Energy Systems, Washington, D.C, Mr. W. O. Young, Stern-Roger Engineering Corp., Denver, Colorado, Mr. F. Hasseris, Combustion Equipment Associates, Inc, New York, Dr. George Samuels, Agricultural Research Associates, Winter Park, Florida, Dr. H. Bungay, Rensselaer Polytechnic Institute, Troy, New York, Dr. J. R, Moreira, Institute of Physics, University of São Paulo, Brazil, Dr. David Jenkins, Battelle-Columbus Division, Columbus, Ohio.

We are delighted to have you with us at this important meeting. First of all, I must ask you to excuse Dr. Ismael Almodóvar, President of the University of Puerto Rico, for not being with us today as he had hoped to be. As many of you know, Dr. Almodóvar was the first director of this...

Center and one of the pioneers in promoting biomass research in Puerto Rico. Urgent business has taken him away from us today. However, allow me to welcome you on his behalf. It is our pleasure to welcome you and to benefit from this discussion of a fundamental and urgent problem affecting the welfare of Puerto Rico and all mankind. In the case of Puerto Rico, where we are still almost entirely dependent on imported petroleum as our basic energy source, the escalation of petroleum prices has nearly halted our previously successful efforts to expand our economy and improve the standard of living of the people of Puerto Rico.

Prior to 1973, the structure of the Puerto Rican economy and its energy sector was based on expectations of continued availability of cheap imported petroleum. These expectations were shattered with the quadrupling of oil prices by OPEC countries in December of 1973. The repercussions in our island economy were severe: double-digit inflation, the most severe recession in the post-World War II period, and a heavy burden on our balance of payments. The competitive position of Puerto Rican manufacturing suffered severely, particularly the petrochemical and refining industries.

The increase in the price of imported oil has continued. Between January 1974 and December 1978, the price of petroleum increased by twenty percent. During 1979, the revolution in Iran and a consequent drop in Iranian production of oil allowed OPEC to catch up in a turbulent and rising market, causing a doubling of crude oil prices. The economic crisis of our energy sector continues unabated with crude oil prices exceeding thirty dollars a barrel in 1980. This crisis is exacerbated by the continued turbulence and uncertainty of world oil markets, which are heavily affected by the political instability of the Middle East.

The crisis of increasing oil prices poses a challenge to Puerto Rico. The vital task for all of us is to achieve greater energy independence through the conservation of energy and the

The development of alternative energy sources is a challenge that none of us here this morning can avoid. No man of science can be indifferent to the problem. We, as scientists and engineers, are in the business of discovering and developing new technological options. In doing so, we create the opportunity to select from a variety of options such as biomass, in the continuing search for technologies to serve the public good and to minimize the negative impacts of the high cost of energy. Seminars like this one are needed to begin appraising the short and long-term impacts of the biomass option.

At the request of the Government of Puerto Rico, a major one-year study was conducted by the National Academy of Sciences to determine Puerto Rico's options for alternative energy.

In conformity with the National Academy of Sciences' recommendations for biomass research in Puerto Rico, we quote the following: "Of all the alternatives discussed, biomass cropping, based on the present sugarcane industry, has probably the largest potential. It could produce a significant fraction of the Island's electricity, with bagasse as fuel, by the year 2000. All in all, energy cropping may in the intermediate term be for Puerto Rico the most important renewable energy source. Given vigorous development, it might provide 10 percent or more of the Island's electricity by the year 2000. Ethanol produced as a byproduct could eliminate the Puerto Rican rum industry's dependence on imported molasses and also supplement gasoline supplies."

While we are in general agreement with this particular NAS recommendation, we welcome your observations and comments. Moreover, it is obvious that the research and analytical tools available to us in the basic and applied sciences cannot be effectively used without appropriate funding and seed money. In this matter, it is clear that meeting Puerto Rico's needs for alternative energy sources can make a substantial contribution to the solution of the energy crisis.

The same problem is faced by many other oil-dependent areas of the world. I quote the NAS report again: "Puerto Rico, in dealing with its own energy problems, should seize the opportunity to become an international energy laboratory, seeking and testing solutions especially appropriate for oil-dependent tropical and subtropical regions of the world. The Island's geographical position and its established energy research and development facilities enhance this potential, which should be brought to the attention of agencies and institutions looking to invest in accelerating development overseas. Hopefully, this Symposium will further develop and clarify the 'state of the art' in different aspects of biomass utilization as an alternative energy resource. The Center for Energy and Environment Research is open to your ideas and will endorse and support any promising avenues towards the mitigation or solution of the energy crisis that we are all facing. Welcome again on behalf of the University of Puerto Rico and its Center for Energy and Environment Research. Thank you very much.

2 ENERGY FROM BIOMASS AND WASTES: AN OVERVIEW

Presented To The Symposium FUELS AND FEEDSTOCKS FROM TROPICAL BIOMASS

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Contributed By: THE INSTITUTE OF GAS TECHNOLOGY, Chicago, Illinois

ENERGY FROM BIOMASS AND WASTES: AN OVERVIEW

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ENERGY FROM BIOMASS AND WASTES: AN OVERVIEW

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ABSTRACT

ENERGY from biomass and wastes already contributes about 850,000 barrels of oil equivalent per day.

U.S. primary consumption: Recent changes in federal funding of energy projects are expected to stimulate the commercialization of additional biomass energy systems, particularly those processes that utilize biomass and wastes for the manufacture of ethanol fuel. However, although research and development on biomass production and conversion is progressing at a rapid rate, commercialization of non-ethanol and non-combustion based processes has been minimal. Commercial plants in the United States currently include one municipal solid waste gasification plant, one manure gasification plant which was recently shut down, and eight landfill methane recovery systems. The present address of the Institute of Gas Technology is 3424 South State Street, ITT Center, Chicago.

Energy from Biomass and Wastes: An Overview

Introduction

Few realize that the present contribution of energy from biomass and wastes to U.S. primary energy consumption is equivalent to about 850,000 barrels of oil per day (1.8 quads per year) or slightly more than 2% of total consumption. Recent projections by the Office of Technology Assessment indicate that by the year 2000, the biomass energy contribution could be as high as 12 to 17 quads, which is about 11 to 15% of projected energy consumption, assuming that it will be about 95 quads (excluding biomass) in 1995. Thus, energy from biomass and wastes is already a major commercial energy resource for the United States and is expected to exhibit substantial growth. Recent research and commercialization efforts in the United States are briefly reviewed in this paper to provide an overview of the state of the technology. Because of the multitude of projects now in progress, this review is necessarily selective and not all projects are discussed. However, each major category of activity is summarized by using certain projects as examples.

Funding

Over the last several months, changes in the federal funding of energy projects have occurred that directly affect biomass energy development. The Energy Security Act (Public Law

The law (96-294), which established the Synthetic Fuels Corporation (SFC), was signed on June 30, 1980, by President Carter. This government-backed SEC could allocate up to $88 billion by 1992 to reach production goals of 500,000 barrels of oil or its equivalent per day by 1987, and 2 million barrels/day by 1992. Title II of this act is known as the Biomass Energy and Alcohol Fuels Act of 1980. On October 1, 1980, it allocated $1.27 billion for biomass energy projects, $15 million for demonstration, education, and technical assistance, and $12 million for research and development. This latter figure does not include the U.S. Department of Energy's research programs on biomass and waste, which are summarized in Tables 1 and 2.

The $1.27 billion in Title II for biomass energy was distributed over two years beginning on October 1, 1980, as follows: $525 million to the USDA for loans, loan guarantees, price guarantees, and purchase agreements for biomass energy plants with an annual production capacity of less than 15 million gallons of alcohol or its equivalent; $525 million to the USDOE for loan guarantees, price guarantees, and purchase agreements for biomass energy plants with an annual production capacity of at least 5 million gallons of alcohol or its equivalent; and $220 million to the USDOE for loans, loan guarantees, price support loans, and price guarantees for municipal waste-to-energy projects.

Another funding source for biomass energy projects was the Alternative Fuels Production Program, created in November 1979 by Public Law 96-126. Ninety-nine feasibility study and cooperative agreement awards totaling about $200 million were made by the USDOE out of 971 proposals on July 9, 1980. Tables 3 and 4 present details of the awards made on projects related to biomass and waste. Interestingly, about one-third of the awards made on a dollar basis were for biomass and waste projects, which accounted for about two-thirds of the total number of awards. Another source of funding for biomass energy projects is still being explored.

The funding for which biomass energy projects are eligible is provided by the Supplemental Appropriations and Rescission Act of 1980 (Public Law 96-304), which President Carter signed in July 1980. This act provides $100 million for feasibility studies and $200 million for cooperative agreements. The awards are expected to be announced near the end of this year. Three billion dollars are also provided by Public Law 93-304 to stimulate domestic commercial production of alternative fuels via purchase commitments, price guarantees, and loan guarantees. Overall, Federal support of biomass energy projects has increased substantially and is expected to have a significant impact on commercialization.

In terms of biomass production, much of the research currently in progress on the selection and growth of suitable biomass species for energy applications is limited to laboratory studies and small-scale test plots. There are no commercial, fully-integrated biomass production, harvesting, and conversion systems of any significant scale in which biomass is grown specifically for energy applications yet operational in the United States. Most of the test programs on biomass growth for energy have only recently been initiated. This is an important factor to keep in mind because low-cost biomass is needed to make biomass fuels competitive. For example, at a cost of $15.00 per dry ton of biomass, the energy cost contained in the biomass is about $1.00 to $1.25 per million BTU.

In terms of tree growth, intensively managed growth and short rotation tree production methods are being evaluated for energy applications in all sections of the country. It is expected that valuable data will be generated for the selection of suitable high-yield species as these tests progress. Some of the species of particular interest are red alder, black cottonwood, Douglas fir, and ponderosa pine in the Northwest; Eucalyptus, mesquite, Chinese tallow, and the leucaena in the West and Southwest; sycamore, eastern cottonwood, black locust, catalpa, sugar maple, poplar, and conifers in the East.

The Midwest is home to sycamore, sweetgum, European black alder, and loblolly pine; the Southwest has sycamore, poplar, and sugar maple. Generally, tree growth on test plots is studied in terms of soil type and the requirements for planting density, irrigation, fertilization, weed control, disease control, and nutrients. Harvesting methods are also important, especially in the case of coppice growth for short-rotation hardwoods. Although tree species native to the region are usually included in the experimental design, non-native and hybrid species are often tested too. Considering the large number of new plots now under test, it is estimated that the results will start to be publicized in volume in the early 1980s. Real cost data for short-rotation hardwoods, the preferred tree production method for energy applications, should result from this work.

Non-Woody Herbaceous Plants: Considerable work is in progress to screen and select non-woody herbaceous plants as candidates for biomass energy farms. Some of the projects are aimed at the screening of plants that are mainly unexploited in the continental United States; others are concentrating on cash crops such as sugarcane and sweet sorghum; while others emphasize tropical grasses. A comprehensive screening program generated a list of 280 promising species from which up to 20 species were recommended for field experiments in each region of the country. The four highest yielding species recommended for further tests in each region are listed in Table 5.7. Since many of the plants in the original list of 280 species had not been grown for commercial use, the production costs were estimated as shown in Table 6 for the various classes of herbaceous species and used in conjunction with yield and other data to develop the recommendations in Table 5. Based on the results of small-scale test plots using cultivars and higher-than-normal planting densities (Table 7), sweet sorghum has apparently been selected as a prime energy candidate for expanded field.

Tests in North Dakota, Kansas, Nebraska, Illinois, Iowa, and Ohio showed that sweet sorghum and its sugar yields were increased by 40 to 100% by narrow inter-row spacing. For example, when the rows were 1.5 ft. apart instead of 3 ft. apart, the yields nearly doubled in the Belle Glade, Florida test plot. In greenhouse, small-plot, and field-scale tests conducted to screen tropical grasses, three categories emerged based on the time required to maximize dry matter yields: short-rotation species (2-3 months), intermediate-rotation species (4-6 months), and long-rotation species (12-18 months). A sorghum-sudan grass hybrid (Sordan 70A), the forage grass Napier grass, and sugarcane were outstanding candidates in these categories, respectively. Minimum tillage grasses that produce moderate yields with little attention were wild Saccharum clones and Johnson grass in a fourth category. The maximum yield observed to date is 27.5 dry tons/ac-yr for sugarcane propagated at narrow row centers over a time of 12 months. The estimated maximum yield is of the order of 50 dry tons/ac-yr using new generations of sugarcane and the propagation of ratoon (regrowth) plants for several years after a given crop is planted. Overall, the work in progress on the evaluation of non-woody herbaceous biomass shows that a broad range of plant species may ultimately be prime energy crops.

Aquatic biomass, particularly micro- and macroalgae, are more efficient at converting incident solar radiation to chemical energy than most other biomass species. For this reason, and the fact that most aquatic plants do not have commercial markets, experimental work has been performed for the last several years to evaluate several species as energy crops. Recent reports for freshwater macrophytes grown in cultural units show yields for common duckweed, water hyacinth, and Hydrilla verticillata of 34, 35.3 and 6.1 dry tons/ac-yr. For the first time, a single clone of the red seaweed, Gracilaria tikvahiae, was grown continuously in controlled conditions.

Culture can last over a year without replacement, projecting dry matter yields of 31 tons per acre per year. Large-scale experiments will be carried out with hyacinth and the red seaweed in units up to one-quarter acre in size to demonstrate mass culture systems and allow for realistic cost-benefit analyses.

In related experimental work, it has been shown that freshwater green algae such as Chlorella vulgaris can be grown on bicarbonate carbon alone. This interesting observation suggests that this method could be used to maximize algal yield because, normally, the transport of carbon dioxide from the atmosphere cannot keep pace with algal assimilation of carbon dioxide.

The experimental results support the conclusion that for both freshwater and marine microalgae, bicarbonate is a suitable carbon source, provided the pH is controlled. Carbon utilization under these conditions is virtually 100%. In studies on marine biomass production, most of the work has been concentrated on the giant brown kelp, Macrocystis pyrifera.

One of the key results to date is that nutrient-rich seawater from more than 1,000 ft. deep is superior to enriched surface water in supporting kelp growth. A larger scale test farm to confirm this with upwelled deep water was constructed off the Southern California Coast in late November and early December 1978. However, due to unanticipated operational difficulties, the program has been delayed.

An interesting observation made after the loss of the protective curtain and 103 adult transplants on the farm due to storms was that after strong upwelling occurred locally in the spring of 1979, juvenile plants began to develop on the solid structures of the test farm from spores liberated by the adult transplants. This growth is now being monitored.

In regards to conversion combustion, direct wood burning for the production of steam and electric power by the forest products industries and for heating in residential wood stoves provided 1.8 quads of energy in the private sector in 1977. Some of the...

The recently announced plans in the final stages of design and construction include a $13 million wood-waste cogeneration plant by the Simpson Paper Company in Anderson, California. This plant is designed to generate 4 MW of electric power and 68,000 lb/hr of steam with an overall thermal efficiency of 64-65%. The plant, designed around a wood-waste fueled combustor and an indirectly fired turbine, is expected to have a 3-year payback and projected to save $1.6 million to $2.2 million per year in fuel at today's prices.

Larger wood-powered systems in the 40 to 50 MW range, the designs for which were recently completed, seem to have been placed on hold. One of the largest plants, a 50MW cogeneration plant for steam and electric production in Westbrook, Maine, has been designed, but the project has not yet been continued. In this proposed plant, wood harvested within a 50-mile radius of the site will supply the fuel at the rate of 1,000 oven-dry tons equivalent/day. Under average conditions, about 258,000 lb/hr of steam and 20 MW of power will be sold. The total investment and operating costs for the plant are estimated to be $64.5 million and $12.8 million/year, with wood priced around $25.00/ton.

Raw Municipal Solid Waste (MSW) and Refuse Derived Fuel (RDF) combustion is the second major source of energy generation by combustion. Commercial resource recovery coupled with energy recovery continues to grow as a substitute for waste disposal only, although it is not without problems. The 200-ton/day Ames, Iowa Plant for recovery and sale of iron, aluminum, and RDF, one of the first commercial plants of its type, is still operating since it started in 1975. In contrast, the $25 million, 1,000-ton/day, Chicago, Illinois plant for recovery of ferrous metal and RDF for co-combustion with coal has only operated intermittently for a variety of reasons since it was dedicated in 1976. Also, the $43 million, 1,500-ton/day plant in Saugus, Massachusetts for direct combustion of raw MSW and steam production processed its one millionth ton of refuse in March.

1979; the plant was started in October 1976. This is perhaps the best record of any of the plants in operation in the U.S.A. Currently, there are 23 operating plants in the United States for the production of steam or electric power via combustion of MSW or RDF. Additionally, 12 more plants are under construction, and 21 are in the advanced planning stage. The total design capacities for processing refuse in these plants is 15,163 tons/day (operating), 13,146 tons/day (under construction), and 23,506 tons/day (advanced planning). The corresponding equivalent barrels of oil assuming 100% utilization of the refuse heating value and a heating value of 9 X 106 Btu/ton of refuse, are 23,528, 20,399 and 35,770 bbl/day, or a total of about 80,000 bbl/day. This does not include the energy conserved by recycling the iron, aluminum, and glass because of the displacement of virgin materials. Obviously, it would be quite beneficial to operate these refuse processing plants near their design capacities.

Gasification Research, development, and demonstration activities on the production of low, medium, and high-Btu gas (500, 500-900, and 900 Btu/SCF) by anaerobic digestion and thermochemical gasification processes have continued to advance, especially at the PDU and pilot scales. Commercial utilization of the resulting information is, however, proceeding at a slow rate in the United States. Small-scale gasification units and package systems are commercially available and have been placed in operation for some processes, but few large-scale systems are in the construction or operational stages. For anaerobic digestion, small-scale farm digesters for manure and methane-recovery systems from landfills comprise the thrust of new commercialization ventures. For thermochemical gasification, most of the new commercialization ventures are concentrated on small-scale air-blown gasifiers for production of low-Btu gas. Only one large-scale pyrolysis plant is currently in operation in the U.S.A. for low-Btu gas manufacture. The highlights of

The efforts presented in this section focus on Anaerobic Digestion. Basic research on the anaerobic digestion of biomass has led to a better understanding of the mechanism and kinetics of the biological gasification process. However, improvements in digestion efficiencies, in terms of methane yield and volatile solids reduction, have been slow to evolve from this knowledge. The plateau of about 50% volatile solids destruction efficiency and 50-60% energy recovery efficiencies, as previously pointed out, seems to be holding. Typical methane yields and volatile solids reductions observed under standard high-rate conditions are shown in Table 8.7. Longer detention times will increase the values of these parameters, such as a methane yield of 4.79 SCF VS added and a volatile solids destruction efficiency of 53.9% for giant brown kelp at a detention time of 18 days instead of the corresponding values of 3.87 and 43.7 at 12 days under standard high rate conditions. However, improvements might be desirable in the reverse direction, i.e., at shorter detention times. Digestion system configurations that have shown advantages over standard high-rate digestion are two-phase, fed-batch, and plug-flow digestion. Considerable laboratory work is in progress to evaluate feedstock suitability and to develop pre- and post-digestion treatments that improve biodegradability.

Innovative designs in which thermochemical and biological gasification are combined and in which anaerobic digestion is used to generate in-plant fuel from fermentation alcohol residuals are under development. Demonstration projects are in progress with waste feeds, but none has yet been started with biomass. The only large-scale, commercial digestion plant for methane production in the U.S.A. uses cattle manure feedstock, but it has been shut down due to operating difficulties. Methane recovery from sanitary landfills in the form of medium- or high-Btu gas is now commercial technology, as shown by the listing of eight commercial systems in Table 9.

Several new methane recovery systems, notably those in New York and Chicago, are expected to be operated on a commercial basis in the near future. Thermochemical Gasification involves extensive research and pilot studies that are in progress to develop thermal processes for biomass conversion to fuel gas and synthesis gas. Basic studies of the effects of various catalysts and operating conditions are underway in the laboratory and Process Development Unit (PDU) scale on steam and steam-air gasification, and on hydromethanation. Other work on the rapid pyrolysis of biomass is being conducted in the laboratory and PDU scale.

The largest commercial pyrolysis plant in the United States, currently in operation with Municipal Solid Waste (MSW), is located in Baltimore, Maryland. This $24 million plant was originally based on Monsanto's Landgard design. It is sized to process 1,000 tons per day of shredded MSW in a refractory-lined inclined rotary kiln. A portion of the waste is combusted with air to supply the heat needed for pyrolysis. The pyrolysis gas has a heating value of about 120 BTU/SCF and is combusted onsite to generate steam.

When the plant was first started in January 1975, considerable operating and emissions problems were encountered. The City of Baltimore took over the plant, made several major modifications, and returned it to service in May 1979. About 520 tons per day of refuse is now processed in the plant, and the steam is sold to generate revenues of about $120,000-$140,000 per month. Further plant modifications are in progress to permit operation at higher throughput rates.

Commercialization of other developed pyrolysis processes such as the Andco-Torrax slagging process for non-sorted MSW, and the Purox process which uses partial oxidation with oxygen in a three-zoned shaft furnace for pyrolysis of coarsely shredded MSW under slagging conditions, have not yet occurred in the United States. Several large-scale Andco-Torrax plants have been placed in operation in Europe, and construction of a 100-ton per day plant is underway at Disney World. Recent steam gasification studies with... (text continues)

"Studies on cellulose have shown that gas-phase steam cracking reactions dominate the chemistry of biomass gasification. High heating rates and short residence times with gas phase temperatures exceeding 650°C were found to produce hydrocarbon-rich gases containing commercially interesting amounts of ethylene and propylene. Studies on the gasification of wood in the presence of steam and hydrogen showed that steam gasification proceeds at a much higher rate than hydrogasification. Carbon conversions 30 to 40% higher than those achieved with hydrogen can be achieved with steam at comparable residence times. It was concluded that steam/wood weight ratios up to 0.45 promote increased carbon conversion but have little effect on methane concentration.

Other recent work shows that Potassium carbonate-catalyzed steam gasification of wood in combination with commercial methanation and cracking catalysts can yield gas mixtures containing essentially equal volumes of methane and carbon dioxide at steam/wood weight ratios below 0.25 and atmospheric pressure and temperatures near 700°C. Other catalyst combinations were found to produce high yields of product gas containing about 2:1 hydrogen/carbon monoxide and little methane at steam/wood weight ratios of about 0.75 and temperatures of 750°C. Typical results for both of these studies are shown in Table 10.

These reports establish that the steam/wood ratios and the catalysts used can have major effects on the product gas compositions. The composition of the product gas can also be manipulated depending on whether a synthesis gas or a fuel gas is desired. Preliminary studies at GT on the hydroconversion of biomass have led to a conceptual process called RENUGAS for producing SNG. In this process, biomass is converted in a single-stage, fluidized-bed, noncatalytic reactor operating at about 300 psig, 800°C, and residence times of a few minutes with steam-oxygen injection. About 95% carbon conversion is anticipated to produce a medium-Btu gas which is subjected to the shift."

Reaction, scrubbing, and methanation form SNG. The cold gas thermal efficiencies are estimated to be about 604.

10. LIQUEFACTION

Research on the development of liquefaction methods for biomass and wastes has increased in recent months. The effort is still small compared to gasification research, but several potentially practical injection methods have been reported. There are essentially four basic types of liquefaction processes: fermentation, direct thermochemical, indirect thermochemical, and natural. Highlights of ongoing work in each of these categories are summarized in this section.

Fermentation: Much work is in progress on the development of suitable fermentation conditions and organism selection for the production of carboxylic acids, alcohol, glycols, and ketones. Some of the work is concentrated on chemical production while other projects are directed towards fuel applications. The greatest effort is devoted to improved ethanol processes because of the intense interest in gasohol. Projects are also underway to develop a total biomass utilization scheme in which wood chips are extracted with hot aqueous butanol to yield an enzyme degradable cellulose fraction for ethanol production, a partially degraded hemicellulose fraction for butanol production, a butanol-lignin extract for use as fuel, and a polymer-grade lignin fraction. Studies are also being conducted to convert pentoses from corn stalk-derived hemicellulose hydrolysate to butanediol, ketones, and other products, and to produce carboxylic acids from aquatic and terrestrial biomass by acid-phase anaerobic digestion. After this, the acids are subjected to Kolbe electrolysis to form alpha hydrocarbons or ketones on pyrolysis of the calcium salts of the acids. These projects are in the laboratory stage of development.

Direct Thermochemical: There has been a dearth of information on hydroliquefaction of biomass, but one report has appeared on the direct hydrogenation of wood chips by treatment at 100 atm and 340-350°C with water and a Raney nickel catalyst.

The wood is completely converted into an oily liquid, methane, and other hydrocarbon gases. Batch reaction times of 4 hours yield oil amounts of about 35% weight of the feed. Ethanol is discussed in more detail in a separate section.

The oil contains about 12% weight oxygen and has a heating value of about 16,000 BTU/lb. Distillation yields a major fraction that boils in the same range as diesel fuel and is completely miscible with it.

A modification of the PERC process has been tested under continuous liquefaction conditions in DOE's Albany, Oregon pilot plant using Douglas fir wood chips. The original PERC process consisted of a sequence of steps: drying and grinding the wood chips to a fine powder, mixing the powder with recycled oil (30% powder to 60% oil), blending the mixture with water containing sodium carbonate, and treatment of the slurry with synthesis gas at about 4,000 PSIG and 700°F.

The Lawrence Berkeley modification consists of partially hydrolyzing the wood in slightly acid water and treating the water slurry containing dissolved sugars and about 20% solids with synthesis gas and sodium carbonate at 4,000 PSIG and 700°F on a once-through basis. The resulting oil product yield is approximately 1 barrel per 900 tons of chips and is roughly equivalent to No. 6 grade boiler fuel. It contains about 50% phenolics, 18% high boiling alcohols, 18% hydrocarbons, and 10% water.

An economic analysis of the process by SRI and Rust Engineering Co. indicates the oil can be manufactured for about $\$6/10^6$ BTU. Further tests are in progress. It should be pointed out that this type of product, although referred to as an oil in the literature, cannot be upgraded to refined products by conventional refinery practice.

Pyrolysis of biomass and wastes produces gaseous, liquid, and char products. Short residence time pyrolysis, sometimes referred to as flash pyrolysis, affords higher liquid yields. The largest plant in the United States for the purpose of producing liquid fuels (oil) by flash pyrolysis is the 200-ton/day system.

In El Cajon, California, there's a plant that uses shredding and air classification of MSW to produce a fluffy material for pyrolysis. The plant also employs magnetic separation of ferrous metals, screening, and froth flotation to recover glass cullet, and an aluminum magnet for aluminum recovery. The pyrolysis section of the plant originally involved high-speed transport of a mixture of recycled char and organic material through the reactor. The plant commenced operations in May 1977 and managed to produce several thousand gallons of oil. However, due to operating problems in the pyrolysis section and the cyclone separation units downstream of the pyrolysis reactor, the plant was shut down in June 1978 and mothballed in September 1978. Currently, Occidental Research Corporation is negotiating with San Diego County to further develop the pyrolysis design. As with the PERC process, the oil product was proposed as a replacement for No. 6 fuel oil.

The type 2 oil couldn't be refined conventionally due to its relatively high oxygen and nitrogen contents. Work is now beginning based on IGT's HYFLEX™ process, which uses a hydrogen atmosphere at moderate to high pressures and temperatures in the 700°C range for only a few seconds. This process converts biomass into hydrocarbons. Short residence times promote maximum liquid yields, and it's believed that the product produced by these hydropyrolysis conditions should have a higher intrinsic value than the heavy flash pyrolysis products previously described. The product is believed to be convertible into a gasoline blending stock.

The conversion of synthesis gas into paraffins and olefins via Fischer-Tropsch processes and into methanol is a well-established chemistry. Synthesis gas from biomass provides the same product spectrum. The integrated production of synthesis gas by pyrolysis, catalytic conversion to hydrocarbons, and lower molecular weight alcohols, along with isomerization of the hydrocarbons to gasoline, has now been developed in PDU equipment operated continuously at feed.

The rates are about 25 lb/hr. Feedstocks under investigation include RDF and agricultural residues. The pyrolysis system consists of a dual fluidized bed unit (pyrolyzer and combustor). Typical feedstock-to-gas yields are 75-85%. Reactor temperatures of 500-1,000°C and pressures of 0.5 psig have been studied. Subsequent conversion to liquids in a fluidized bed catalytic reactor gave a liquid yield of about 20-100 gal/ton of pyrolysis feed. Passage of the hydrocarbon product through a fixed-bed catalytic reactor gave 50% volume yields of liquid product per volume of liquid feed. The product at 300-500°C and 400-600 psig has an 80-100 octane rating. It was concluded from this work that liquid fuels equivalent to commercial products can be produced by the use of biomass. Another indirect route to liquid fuels from biomass involves the coupling of pyrolysis of organic wastes to yield gases high in light olefins, compression and purification of the olefins, and polymerization to yield gasoline. The conditions found to be optimum for RDF were about 750°C with steam dilution for pyrolysis times of less than one second. Slightly more than half of the energy contained in the waste can be recovered in the gasoline precursors. Using temperatures of about 400-500°C and pressures of about 700-1,000 psig, the purified olefin mixture is polymerized.

The product yields 90% of which boils in the gasoline range. The estimated average yield is about 1.8 bbl/ton RDF (MAF) at a 50% efficiency in energy recovery. Preliminary economic analysis indicates that polymer gasoline is currently competitive with petroleum derived gasoline. An indirect route to biomass liquids that has received much attention is Mobil's process in which methanol is converted to hydrocarbons over zeolite catalysts. The New Zealand Government has approved Mobil’s technology as the heart of a 13,000-bbl/day synthetic gasoline plant designed to meet one-third of the nation’s needs in the mid-1980's. Negotiations are in progress. The methanol for this plant will

The text should be corrected as follows:

Natural gas can be used, but it is also possible to use biomass. Another zeolite catalyst application was recently reported by Mobil, which provides another indirect route to hydrocarbon liquids from biomass. In this process, biomass-derived oils such as corn, castor, peanut, and jojoba oils, as well as Hevea latex, are converted in high yields to gasoline by passage over zeolite catalysts at 400-500°C. In addition to gasoline, which is the major product, fuel gas (C1-C2), liquid petroleum gas (C3-C4), and light distillate are formed. The product mix is similar to that obtained from methanol, and constitutes high-grade gasoline with an unleaded research octane number of 90 to 96. Product distributions for methanol, corn oil, and Hevea latex are summarized in Table 11. Experimental results show that when isoprene or dipentene, the decomposition products of latex rubber in the reactor without catalyst, is passed over the zeolite catalyst, the same product spectrum as that formed by the latex is produced. It was therefore suggested that polyisoprene rubber first depolymerizes to lower molecular weight units which then interact with the catalyst.

Natural production of polyisoprene by biomass has been recognized for many years. It formed the basis of commercial production of natural rubber on Hevea brasiliensis plantations. Recently, new screening studies of over 300 plant species have shown that about 30 species may serve as useful sources of hydrocarbons. Most are vigorous perennial species relatively rich in oils and hydrocarbons and adapted to wide areas of North America. A most interesting species, Copaifera langsdorffii, is a tree which grows wild in the Amazon. Mature trees are about 1 m in diameter and 30 m high. A 1-1/2 in. bung hole yields about 10 to 20% of oil from four such holes and the tree can be grown at a density of 100 trees per acre. This corresponds to about 15,000 l/acre/year (94 barrels/acre/year). It is believed that the tree can grow in a few places in the United States such as Florida.

Alcohol Fuels Ethanol

It appears that ethanol as a motor fuel has sparked more controversy among energy specialists than any other synthetic fuel. Nevertheless, it is now commercially marketed on a large scale in the United States as gasohol (10 vol % ethanol - 90 vol % unleaded gasoline). Out of all the possible biomass- and waste-derived fuels, ethanol has received the most Federal support.

As indicated in Tables 3 and 4, 43 out of 76 projects on energy from biomass and wastes were chosen for feasibility study and cooperative agreement awards under Public Law 96-126. This breakdown is shown in Table 12; the dollar awards ($53,971,000) comprise about 78% of the total dollar awards given to projects on energy from biomass and wastes under this law. In addition, about $378 million in loan guarantees have been awarded by the U.S. Department of Agriculture for ethanol fuel plants, as shown in Table 13. The U.S. Department of Energy is also negotiating loan guarantees for seven other plants, as shown in Table 14.

Presuming that all of the plants listed in Tables 12, 13, and 14 are built, the total alcohol production would be about 1,726 million gallons per year, or about 1.5% of U.S. gasoline consumption in 1979.

Ethanol Research

Much of today's research on ethanol has been focused on improving cellulose hydrolysis processes, increasing ethanol yields, reducing fermentation times, and achieving higher net energy production efficiencies. Significant experimental data have been reported on improved enzyme-catalyzed hydrolysis of low-grade cellulosics and on the continuous hydrolysis of cellulose to glucose via flash hydrolysis using dilute sulfuric acid.

For example, hydrolysis of water slurries of newsprint with 1% sulfuric acid in the range of 235-240°C at a residence time of 0.22 min yielded 50 to 55% of the theoretical glucose yields in a plug flow reactor. These results are believed to be of commercial interest. Another short-residence time sulfuric acid hydrolysis process feeds a hydropulped slurry of newsprint or...

Sawdust is fed into a twin-screw extruder device which extracts water from the slurry. The resulting high-solid cellulose plug is then hydrolyzed with acid, which is injected into the feeder. The residence time-temperature-glucose yield relationships are about the same as those of the plug flow reactor experiments. The EPA, the sponsor of this work, estimates that ethanol might be produced by this process for $0.85-$1.00/gal, $0.60/gal for hydrolysis, and $0.30-$0.40 for fermentation and distillation.

Recent approaches to improving the alcoholic fermentation process itself include the use of bacteria instead of yeasts to shorten fermentation times; continuous fermentation techniques; simultaneous saccharification and fermentation of low-grade cellulosics with enzymes and yeasts; thermophilic anaerobes for the one-step hydrolysis and fermentation of cellulosics; packed columns containing live, immobilized yeast cells, or both enzymes and yeast cells through which glucose solutions are passed; and recombinant-DNA techniques to develop new yeast strains for rapid conversion of starch to sugar.

For example, packed columns of live saccharomyces yeast cells entrapped in carrageenan gel are reported to convert 20% aqueous glucose solutions containing nutrients to 12.8 vol % ethanol solutions in 2.5 hrs. Biomass not normally used for alcohol production, such as pineapple, has also been evaluated for alcoholic fermentation. This plant species, which requires much less water than sugarcane or cassava for growth, was projected to yield ethanol quantities per unit growth area higher than those of sugarcane or cassava.

Since distillation of the fermentation broth to separate the ethanol consumes relatively large amounts of energy, several methods are being studied to try to improve post-fermentation processing. Drying of the partially concentrated alcohol solution with dehydrating agents including corn and corn derivatives is reported to be effective for producing nearly...

"Anhydrous alcohol; the energy content of the ethanol is ten times that needed for dehydration. Other techniques for reducing energy consumption use azeotropic agents, low-energy distillation, and membrane filters. Another possible route to anhydrous ethanol is to use a solvent for direct extraction of ethanol from the aqueous solution; little data seems to be available on the potential energy consumption benefits of this method which could, in theory, produce gasohol directly without distillation. A few projects are underway to develop this technique. No recent reports could be found on the thermochemical production of ethanol via hydration of ethylene derived from biomass. However, an interesting non-biological method has been reported on - the conversion of furfural from rice hulls, corn cobs, and material from the southern pine forest to ethanol. Furfural undergoes ring cleavage and reduction in the presence of lithium metal and alkyl amine solvent to form ethanol. The use of less expensive lithium salts in amine solvents bombarded with gamma rays may also promote the same reaction. These reactions are under laboratory study.

Methanol is a suitable fuel for internal combustion engines too, although it does have several advantages and disadvantages when compared with ethanol. Biomass derived methanol has also not been receiving near the attention that has been given to ethanol. For example, only one of the 71 projects in Table 3 is directed to methanol from biomass. The current emphasis for future methanol fuel plants is concentrated on coal-based processes. Interestingly, even though such processes are relatively well established from a technological standpoint, none is online in the United States. Natural gas is the prime raw material. Methanol has not been produced in any appreciable yield by fermentation. Currently, most of it is manufactured by conversion of synthesis gas, usually by the so-called low-pressure process developed by Imperial Chemical Industries in the 1960s. Subsequent

Research to develop new methanol processes has usually been patterned after the ICI method which uses heterogeneous copper oxide catalysts to reduce carbon monoxide. Recently, homogeneously catalyzed reduction of carbon monoxide to methanol and methyl formate at 1300 atm and 225 to 275°C in the presence of solutions of ruthenium complexes was discovered. This observation could be the forerunner of new catalytic systems for methanol manufacture.

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2. BIOMASS ENERGY SYSTEMS: AN OVERVIEW

Presented at the Symposium FUELS AND FEEDSTOCKS FROM TROPICAL BIOMASS at the Caribe Hilton Hotel, San Juan, Puerto Rico on November 24 and 25, 1980.

Contributed by The Biomass Energy Systems Division, U.S. Department of Energy, Washington, D.C.

BIOMASS ENERGY SYSTEMS: AN OVERVIEW

Table of Contents:

Biomass Energy Systems: An Overview

Presented by Dr. Beverly J. Berges, Acting Director, Biomass Energy Systems Division, U.S. Department of Energy, Washington, D.C.

INTRODUCTION

During the early 1970s, it became apparent to Congress that renewable energy sources should be developed to reduce the nation's growing dependence on foreign oil and the dwindling domestic supplies of oil and natural gas. In 1974, the Energy Reorganization Act (P.L, 93-438) and the Solar Energy Research, Development and Demonstration Act (P.L. 93-473) established the Energy Research and Development Administration (ERDA) as the responsible federal agency in solar energy RD&D.

The Biomass Energy Systems Program (BES) was originally organized under the name "Fuels From Biomass Program" in ERDA's Division of Solar Energy. The Department of Energy Organization Act of 1977 (P.L. 95-97) consolidated the energy functions of the Federal Energy Administration, ERDA and other federal agencies into the Department of Energy on October 1, 1977. At that time, BES was placed in the Division of Distributed Solar Technology and in the 1980 reorganization, it became a Division within the Office of Solar Applications for Industry.

In fiscal year 1977, $6 million were, for the first time, appropriated for ERDA to develop fuels from biomass. The budget authority has increased nearly ten-fold since that time. The fiscal 1980 budget for BES has grown to $55.5 million, of which $22 million was used to initiate the

Office of Alcohol Fuels. This dramatic increase in funding reflects the expectation of biomass to be the largest energy contributor among all solar technologies in this century. The Biomass Energy Systems Program was reoriented in FY 1980 from primarily technology and engineering development to include commercialization activities as well. The overall strategy is to balance the near-term, mid-term, and long-term energy options. The present emphasis is on those technologies which can make an energy contribution in the next five years. At the same time, presented by Marilyn Ripin.

2. Support is being given for the development of production and conversion technologies which will begin to contribute to our energy supplies after 1985, and long-term R&D is being initiated on those concepts with high technical and financial risks but potential for high payoff after the year 2000.

PROGRAM FOCUS

Within each of the major activity areas, there are barriers which must be eliminated or engineering problems to be solved for a particular biomass technology to become a viable alternative energy option. In every case, efforts are supported to reduce the financial risk to the industry of developing and commercializing biomass technologies. In addition, the majority of activities, particularly those involved with technology development, are aimed at reducing the manufacturing costs to accelerate market penetration. Some of the more specific barriers and problems are enumerated below with examples of activities aimed at removing these impediments.

Commercialization activities are being conducted to accelerate the use of wood as fuel in the near term. Direct combustion technologies are being considered for the generation of industrial process heat/steam, the generation of electricity, the cogeneration of process heat and electricity, and the production of space heat for residential applications. There are several issues or barriers which must be addressed before the potential of wood as a fuel will be realized.

Realized. First, in order to develop regional wood utilization plans, an accurate estimate of the total above ground biomass must be made. Current national estimates include only the merchantable volumes of trees and exclude the tops, branches, and small or defective trees. The methodology needed to estimate total biomass will be developed and implemented on a national and regional basis in conjunction with the U.S. Forest Service. Assessments will also be made to determine the regional market potential for wood fuel to provide a focus for the regional utilization plans. The lack of an identifiable and reliable wood supply infrastructure is currently inhibiting its use. Evaluations are being made of land ownership patterns, transportation systems and costs of delivering wood. Cost-shared site-specific feasibility studies will be conducted to determine the wood available to potential industrial and utility users. For the residential sector, two retail wood outlets have been established in the Southeast to demonstrate the reliability of stick wood fuel supplies. Another potential deterrent to wood burning is the increasing concern about emissions and their effect on health and the environment. BES is currently funding studies to quantify and reduce the emissions from stoves and furnaces, and will fund research in cooperation with EPA on the potential health effects caused by wood combustion. There is also a need to provide up-to-date technical and economic data on the use of wood to potential producers, suppliers, and users. Cost-shared demonstrations of direct combustion systems are planned to encourage the acceptance of this technology by non-forest products industries and utilities. In addition, a technical assistance team has been established in the Northeast to provide information and direction to interested industrial/utility concerns, as well as those interested in residential wood burning. Commercialization activities will also be directed at the agricultural sector. In cooperation with the Science and Education department...

The Sustainable Forestry Administration (SFA) of the U.S. Department of Agriculture and BES will conduct a program aimed at achieving greater on-farm energy production and use through the anaerobic digestion of animal manures, the direct combustion and low BTU gasification of agricultural residues, and the processing and use of vegetable oils as a substitute for petroleum-based diesel fuel. Farm energy needs include space and process heat, electricity, and shaft power. There is a need to match the energy requirements with the available feedstocks and appropriate conversion technology.

The major problem surrounding the anaerobic digestion of animal manure is informational in nature. The agricultural sector has not been convinced that this technology is both technically and economically feasible under appropriate circumstances. Plans are to construct and demonstrate a number of on-farm digestion systems to encourage wider user acceptance. Direct combustion and low BTU gasification systems designed to use crop residues will be constructed and demonstrated for several applications including crop drying and shaft power for irrigation. Concurrently, these systems will be fine-tuned to alleviate material handling and storage problems.

Several issues are currently unresolved concerning the substitution of vegetable oils for diesel fuel. Tests will be conducted to determine if available processing equipment for oilseed crops is cost and energy effective when used on-farm. Similarly, the performance of vegetable oil in farm equipment engines will be evaluated as well as the need for modifications to provide for efficient operation. In addition, research on the chemistry of these oils will be directed at identifying useful by-products and quantifying combustion characteristics.

Technology Development

A wide-ranging program is being pursued for the development of biomass production and conversion systems. The production research is aimed at increasing the biomass resource base, through silvicultural, herbaceous, and aquatic crop development. Activities involve... [Page Break]

The text is not only focused on developing production systems but also on the harvesting, processing, and delivery technologies needed to supply the biomass to a conversion facility. Silvicultural research activities are primarily aimed at filling gaps in information and developing the necessary technologies for growing and harvesting woody biomass from both energy plantations and natural stands.

Species are being identified regionally for cultivation on short-rotation energy farms on various types of land, including arid and semi-arid ones. The species screening efforts are closely linked to the quantification of the cultural techniques, energy inputs, and costs associated with increasing yields. Different schemes will also be evaluated to increase the fuelwood output from natural stands during commercial harvests.

The currently available harvesting equipment is designed primarily for handling large and relatively uniform logs. It is inefficient and costly to deliver small and defective trees, tops, and irregular pieces from logging sites and short-rotation plantation material using this equipment. Therefore, improvements and specialized equipment and systems will be designed and tested to harvest such materials and process them into a uniform size for transport and use. Equipment will also be modified or designed to handle these materials effectively on a wide variety of terrains, such as steep slopes, wetlands, and small woodlots.

The herbaceous species production program is in the early stages of development and deals with non-woody plants that are not traditionally cultivated. A regional approach will be used to determine the extent to which these systems will be practical based on land availability and potential end-use applications. Both natural stands and those under cultivation will be evaluated.

As cultivation and harvesting techniques are quantified, efforts will also focus on matching the biomass with the appropriate conversion technology to produce the desired energy product(s). The aquatic species program includes four categories.

Of aquatic plants: microalgae, macroalgae, floating plants, and emergent plants, all are capable of rapid growth and can provide biomass yields that surpass those of terrestrial plants. Microalgae, which can be grown in saline, brackish, and wastewater can supply up to 85 percent of their mass in easily extractable hydrocarbons. Land-based systems are under development that maintain a circulation of nutrients and carbon dioxide as well as stabilize the pH and temperature. A special problem area under investigation is defining those environmental conditions which enhance lipid and hydrocarbon production. Macroalgae, such as giant kelp and other seaweeds, have the capacity to produce and store proportionately large amounts of carbohydrates. The engineering problems associated with the development of land-based and nearshore systems for macroalgae are similar to those for microalgae. Nutrients must be supplied to maintain yields sufficient to support the operating and structural costs of the system and stable environmental conditions must be provided. Floating aquatic plants, particularly water hyacinth, have been shown to be highly productive as well as effective wastewater purifiers. The advantage of both factors is being taken into account through the integration of wastewater treatment with biomass production and conversion systems. Major limitations associated with this concept are the restricted geographical range of water hyacinth and the high rates of water loss through transpiration. These problems are currently under investigation. A major problem area common to microalgae, macroalgae, and floating plant systems is harvesting. In each case, large amounts of water must be processed in proportion to the biomass recovered. Emergent aquatic plants, such as reeds, cattails, and bulrushes represent a potentially significant feedstock resource. The U.S. has extensive marshland, which has been estimated to be greater than 42 million acres. However, information must be developed with respect to the cultivation, management, and

Biomass is in the carrier mix. It is expected that increasing the ratio of biomass to carrier fluid will improve not only the energy balance but also the manufacturing costs. Anaerobic digestion research is aimed at gaining a more comprehensive understanding of the biochemistry of methane production from crop residues. Comparisons are being made between thermophilic and mesophyll bacterial systems. A significant drawback to anaerobic digestion is the long retention times needed to convert the cellulosic feedstocks. Various pretreatment schemes are being tested to enhance the overall process. In addition, economically beneficial uses of the digester effluent are being sought, including cattle feed and fertilizer, to eliminate disposal costs.

Exploratory research is being conducted to support the activities of the entire program. Longer-term projects, like the development of terrestrial plants that produce hydrocarbons and the photobiological, photoelectrolytic, and photochemical production of hydrogen, are included. A fundamental understanding of these renewable energy options must be gained before full-scale engineering development is warranted. Research has been initiated on developing hydrocarbon-bearing plants for semi-arid and arid regions. Species screening activities are attempting to determine those species with the greatest potential to synthesize desired hydrocarbons. Another problem area is the extraction and characterization of these fluids. Work is underway on the development of chemical process techniques for the extraction of plant material after harvest. Potential market applications are also being identified and will be evaluated to determine the most suitable energy end use of the hydrocarbons. The demand for hydrogen as a chemical feedstock in the U.S. is growing steadily and expected to continue in view of the attention being given to synthetic fuels. Low-cost hydrogen production systems will be needed to complement this emerging industry. Several approaches are being considered.

Investigation is underway to produce hydrogen photobiologically. The main focus of the basic research is the biochemistry of hydrogen production by photosynthetic bacteria, algae and cell-free or in vitro systems. Phototlectrolysis is closely related to photovoltaic hydrogen production, except that the photoactive semiconductor material serves not only as the solar collector but also as the electrode. Development is ongoing for semiconductor materials which possess a suitable wavelength threshold and are resistant to corrosion. Research efforts in photochemical hydrogen production systems are centered on increasing the solar conversion efficiencies of promising processes.

In conclusion, the Biomass Energy Systems Program is exploring numerous combinations of feedstock, conversion process, and end product, all of which have the potential to contribute to our energy needs. Specific barriers and problems have been, and will continue to be identified, and solutions will be sought to mitigate them. Commercialization efforts are expected to expedite the acceptance of biomass technologies by industry in the near term and lead to significant energy contributions by the year 2000. Furthermore, the Department of Energy (DOE) will continue to play a vital role in supporting the research and development of promising technologies.

HERBACEOUS LAND PLANTS AS A RENEWABLE ENERGY SOURCE FOR PUERTO RICO

Presented To The Symposium FUELS AND FEEDSTOCKS FROM TROPICAL BIOMASS. Caribe Hilton Hotel, San Juan, Puerto Rico. November 24 and 25, 1980.

Contributed By THE UPR CENTER FOR ENERGY AND ENVIRONMENT RESEARCH, Biomass Division, Rio Piedras, Puerto Rico.

HERBACEOUS LAND PLANTS AS A RENEWABLE ENERGY SOURCE FOR PUERTO RICO

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'Herbaceous Land Plants As A Renewable Energy Source For Puerto Rico' by Alex G. Alexander, a Lead and Senior Scientist at the CEER-UPR Biomass Division, Rio Piedras, Puerto Rico.

Abstract:

Herbaceous tropical plants are a renewable energy source of major importance to many tropical nations. They convert the radiant energy of sunlight into chemical energy, which is stored in plant tissues (cellulose, hemicellulose, lignin) and fermentable solids (sugars, starches). Because all tropical plants do this - even those commonly regarded as "weeds", they constitute an inexpensive, renewable, and domestic alternative to foreign fossil energy.

The vast majority of herbaceous tropical plants have never been cultivated for food, fiber, or energy. A major screening program would be needed to identify superior species and the most

effective roles they can play in a domestic energy industry. Other herbaceous plants, such as sugarcane and tropical forage grasses, have been cultivated for centuries as agricultural commodities. As energy crops, important revisions in management will be needed to maximize their energy yield.

Two broad groups of herbaceous plants are seen to have an immediate potential for reducing Puerto Rico's reliance on imported fossil fuels: The tropical grasses (of which sugarcane is the dominant member) and the tropical legumes. Managed for its maximum growth potential, sugarcane is an excellent source of biofuel fermentation substrate, cellulosic ethanol, and the sweetener sucrose. Other tropical grasses store relatively little extractable sugar while equaling or moderately surpassing sugarcane in yield of cellulose dry matter. The

The latter might soon become an economical source of fermentation substrates. Certain legume species are also very effective producers of biomass. Herbaceous tropical legumes are perceived as a potential source of biological nitrogen for energy crops unable to utilize nitrogen from the atmosphere.

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Herbaceous Land Plants As A Renewable Energy Source For Puerto Rico

INTRODUCTION: Herbaceous Plants In Perspective

For this presentation, the term "herbaceous" refers to nonwoody plants having some potential as renewable energy sources. Ordinarily, a herbaceous plant will complete its lifecycle in one growing season or one year. It is comprised of relatively succulent tissues as opposed to the drier and more fibrous tissues of woody perennial species. This distinction between succulent and woody species becomes much less clear in the tropics. Herbaceous plants may grow continuously rather than seasonally, and some species will do so for many years. For example, a 6-month-old stem of napier grass can be far more "woody" than most forest trees of equal age. Similarly, an 18-month "ratoon" crop of sugarcane, though still "herbaceous," can yield more fiber per acre than virtually any form of higher plant in a comparable period of time.

Literally thousands of terrestrial plant species can be regarded as potential energy sources. A majority of these are herbaceous seed plants which complete their growth and reproductive processes within a single growing season of a few months duration. They are widely distributed from arctic regions to the tropics (1,2,3). They are equally diverse with respect to their growth and anatomical characteristics, their cultural requirements, and their physiological and biochemical processes (29). Yet, all have the capacity to convert sunlight to chemical energy and to store this energy in the form of biomass. An oven-dry ton of herbaceous biomass represents about 15 x 10^6 BTUs of stored energy.

The direct firing of one such ton, in a stoker furnace with a high-pressure boiler having 70% conversion efficiency, would displace about two barrels of fuel oil. Alternatively, as cellulosic materials (10), much of the dry biomass could be converted to fermentable sugars, alcohol, and a range of chemical feedstocks (Figure 1). In addition to their fibrous tissues, some species also produce sugar or starch in sufficient quantities to warrant extraction and conversion to alcohol. The total soluble sugars of sugarcane comprise roughly 1/3 of the whole plant, or about 40% of the millable cane stem (11).

2 The “Irish potato (Solanum tuberosum) is frequently used as a fermentation substrate during periods of low market value. Other species store energy in the form of natural hydrocarbons (12,13). The majority of herbaceous land plants have never been cultivated for food or fiber. 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, seeding 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. Plants such as ragweed, redroot pigweed, and lambsquarters are recognized for their persistent growth habits while otherwise regarded as common pests. However, the value of such species could rise dramatically as biomass assumes a future role as a renewable, non-fossil energy resource.

2. Prior Studies with Herbaceous Plants

While it is not correct to say that herbaceous land plants have been overlooked as a domestic energy resource, only a small number have been examined closely for this purpose. 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 oil embargo of 1973. Throughout their history as

Cultivated crops, such as corn, sweet sorghum, sugarcane, and Napier grass, have evolved extensive technologies for their cultivation, harvest, post-harvest transport and storage, and for their processing and marketing. Other tropical plants, some with very fine botanical or agronomic attributes and confirmed histories as excellent biomass producers, have been generally ignored as energy resources. Pineapple, cassava, plantain, and papaya are examples of underutilized tropical biomass species. Aside from sugarcane and “allied” tropical grasses, relatively little attention has been given to herbaceous land plants specifically as sources of fuels and chemical feedstocks. Studies were initiated recently at Battelle-Columbus Laboratories on common grasses and weeds as potential substitutes for fossil energy. Plants showing promise as boiler fuels include perennial ryegrass, reed canarygrass, sudangrass, orchardgrass, bromegrass, Kentucky 31 fescue, lambsquarters, and others. A range of species have indicated some potential as sources of oil, fats, protein, dyes, alkaloids, and rubber. Such plants include giant ragweed, alfalfa, jimsonweed, crambe, redroot pigweed, dogbane, milkweed, and pokeweed. In 1978, the U.S. Department of Energy issued an RFP for herbaceous plant screening as a means to close the information gap in this area of biomass energy development. The DOE objective has two phases: First, to identify promising species for whole plant biomass production in at least six different regions of the U.S., and second, to perform field evaluations on at least 20 species per region, with a view toward identifying those most suitable for cropping on terrestrial energy plantations. Arthur D Little, Inc, was selected to conduct Phase I. Six regions were designated on the basis of climatic characteristics, land availability, and land resource data provided by the U.S. Soil Conservation Service. A list of 280 potential species was prepared on the basis of published research.

Literature and personal interviews were used as sources. These sources were scrutinized based on botanical and economic characteristics, with a focus on previously uncultivated species. Certain agricultural plants were also taken into consideration. Factors such as yield potential, cultural requirements, tolerance to physiological stress, production costs, and land availability were taken into account when ranking the candidate species of each region (2). Plants with yields less than 2.2 tons/acre (5 metric tons/hectare) were eliminated. Comparisons were drawn between potential energy crop species and six categories of economic plants, including tall and short broadleaves, tall and short grasses, legumes, and tubers. Approximately 70 species were recommended for the program's second phase (field screening). Some of these plants (Fodder-root pigweed, lambsquarters, Colorado river hemp, ragweed) have no previous history as cultivated crops, and their cultural needs remain unknown. Other species (Bermuda grass, Kana, red canary grass, Sudan grass) have been cultivated and improved for decades.

HERBACEOUS TROPICAL PLANTS

The initial steps taken by the DOE to evaluate herbaceous land plants will help clarify their value as a renewable energy source for the U.S. mainland. No comparable effort has been undertaken for species in Puerto Rico or for tropical regions in general. The rest of this presentation concerns two broad categories of tropical plants common to Puerto Rico: tropical grasses and herbaceous tropical legumes. Whether intentionally or not, a lot of experience has been gained with each group over many decades.

1. Botanical Considerations

The correct selection and management of tropical herbaceous plants are aided by an understanding of their functions as botanical entities. Above all, biomass energy workers must recognize four decisive characteristics: (a) each species is a living solar collector of potential value, but it operates for its own benefit rather than that of humans; (b) an ability to effectively utilize a

Limited or irregular water supply; (c) an ability to harvest solar energy on a year-round basis, if correctly managed for this purpose; and (d) the biomass-producing potential of each species is a function of two discrete growth phases i.e., tissue expansion and tissue maturation. (e) Photosynthetic Energy Conversion: Although not an efficient process, photosynthesis is the only system of solar energy conversion on earth that has operated at any appreciable magnitude. SOLAR ENERGY CONVERSION TO BIOMASS light ($2O_2$ + H_20 + CO_2 + Energy Storage = 114 KCal/Mole CO_2) with any appreciable economy, for any appreciable period of time. The earth's plants store annually about 10 times more energy than is utilized by man, and about 200 times more than is consumed as food (20). Photosynthesis consists of two phases: (a) Energy capture, yielding chemical energy and reducing power; and (b) the reduction or “assimilation” of atmospheric CO_2. The carbon reduction phase is accomplished by three distinct pathways (C3, C4, and CAM). Each pathway is found among tropical herbaceous plants, but the C3 pathway is probably the most widely distributed. CAM plants, which assimilate carbon at night, are relatively less important even though their utilization of water is generally more efficient than for C3 species. The C4 pathway was at first thought to reside only in sugarcane and related tropical grasses (21,22,23). It was soon found in temperate plants such as Zea, Sorghum, and Amaranthus (34-38). The C4 species constitute a kind of apex in photosynthetic proficiency (5,9,23), aided to some extent by CO_2 compensation point, a “lack” of photorespiration, and a capability to utilize both lower and higher light intensities than do C3 and CAM species (Table 1). An important aspect of photosynthetic energy conversion often overlooked in higher plants is their “spectral proficiency,” that is, their ability to convert different regions of the sun's spectral energy distribution. Ironically, more than 60 percent of incoming solar

Energy is received at wavelengths shorter than 50 nm, while most plants are apparently photosynthetically active at wavelengths longer than 600 nm. There is some evidence that Saccharum species have major photosynthesis activity in the blue-violet to blue-green region (25,26). Photosynthetic action spectra have been determined for approximately 30 agricultural plants, but a vast majority of herbaceous land plants have not been examined in this context.

Energy Conversion vs Water Utilization Efficiency: Tropical herbaceous plants such as sugarcane, corn, and sweet sorghum require about six inches of water per month to sustain maximum growth (27,28,29). Most tropical plants will not receive that quantity of water as rainfall, nor are they likely to be given this quantity as irrigated crops. Their water utilization efficiency will be markedly influenced by the specific pathway of carbon reduction. C4 species should tend to reduce more carbon per unit of water transpired than C3 species, but less than plants using the CAM pathway. C4 plants such as sugarcane (4,27, Chap. 4) have a lower mesophyll resistance (yy) than other plants, favoring in turn a steeper CO_2 gradient between the atmosphere and photosynthetic reaction sites in the leaf. CAM plants have an rq comparable to C3 plants, but they assimilate carbon at night when transpirational water loss is at a minimum. The CAM pathway in effect is a plant water conserving mechanism.

It must be said that there is no region of the continental U.S. that is really suited to the production of tropical grasses. Even in Puerto Rico, located only 18 degrees north latitude, a very definite “winter” effect is exerted on the growth rates of sugarcane and napier grass (Table 2). It is also important to recognize that growth is a 24-hour process as well as a 12-month process. The photosynthetic and tissue-expansion systems that operate each day are fully dependent on the nocturnal transport and mobilization of growth-supporting compounds. For this reason, the tropics are again favored by their warm nights for biomass production (27). Possibly the most desirable growth characteristic of all for herbaceous species is the ability to produce new shoots continually throughout the year, year after year, from an established crown. This is a predominant characteristic of sugarcane and certain other tropical grasses, both related and unrelated to Saccharum species. Such plants do not require the periodic dormancy and rest intervals so important to most temperate species. Nor is this compensated by the intensive flush of May-June growth by temperate plants. Over the course of a year, the slower-growing tropical forms will out-produce them by a factor of three or four. A less obvious but utterly critical feature of the perennial crown is its continual underground contribution of decaying organic matter to the soil. This process proceeds concurrently with the continuous renewal of underground crown and root tissues. For this reason, the long-term harvest and removal of above-ground stems, together with the burning off of “trash,” does not have an adverse effect on sugarcane lands. There are soils in Puerto Rico that have produced sugarcane continuously for four centuries without destruction of their physical properties or nutrient-supplying capability. On the other hand, seasonal crops such as field corn and grain sorghum do not develop a perennial crown. For these plants, a good case can be made against the

Removal of above-ground residues from the cropping site.

Tissue Expansion vs Maturation: A common misconception holds that biomass growth involves mainly a visible increase in size, and that per acre tonnages of green matter are a reasonably accurate indicator of a plant’s yield potential. It is also frequently assumed that the moisture content of plant tissues is generally constant at around 75 percent, and that dry matter yields can be calculated rather closely from green weight data. These assumptions are not correct in any case.

7. These assumptions are particularly erroneous with respect to herbaceous tropical species. In virtually all herbaceous tropical plants, "growth" consists of discrete, phasic processes of tissue expansion followed by maturation. The tissue expansion phase produces visible but succulent growth consisting mainly of water (in the order of 88-92 percent moisture). The maturation phase corresponds to physiological aging and senescence, that is, to flowering and seed production, slackening of visible growth, yellowing and loss of foliage, and hardening of the formerly succulent tissues. During this period, the dry matter content will increase by a factor of two to four in a time interval that may be shorter than that of the tissue-expansion phase. An excellent example of this is the hybrid forage grass Sordan 70A, which more than doubles its dry matter yield in a time-span of only two weeks (i.e., during weeks 8 to 10 in a 10-week growth and reproduction cycle) (Figure 2). For this reason, the optimal period of harvest must be determined with care for each candidate species. For most herbaceous tropical plants, the production of dry matter can be plotted as an S-shaped curve, as shown schematically in Figure 3. Dry matter content will not ordinarily exceed 10 to 12 percent during the period of rapid tissue expansion but will begin to rise dramatically at some point in time that is characteristic of the individual species. Dry matter will rarely increase beyond 40 percent in herbaceous plants. Attempts to...

Hasten the rise by withholding water, or to delay it by using growth stimulants, have met with limited success in tropical pastures (30).

2. Management as Energy Crops

Certain characteristics of a promising tropical plant as a biomass energy resource were described in the preceding sections. In translating such plants to a well-managed, energy-plantation scenario, some straightforward steps must be taken to assure maximum returns from production expenditures. These will include:

(a) Correct land preparation, including land leveling and planning where needed.
(b) Correct design and installation of the irrigation system.
(c) Correct seedbed preparation.
(d) Careful selection and treatment of seed.
(e) Correct seeding relative to depth, density or row spacing, and season.
(f) Reseeding of vacant space when necessary.
(g) Correct pest control programs, including administration of control on weekends and holidays when required.
(h) Maintenance of correct irrigation, fertilization, and cultivation programs.
(i) Correct timing and synchronization of harvest operations.
(j) Correct selection and use of harvest equipment.
(k) Post-harvest maintenance of land and machinery.

For most biomass crops, the costs of these measures will accrue whether they are performed correctly or not. The decisive factor will be the skill and motivation of the operation's field managers. In the author's opinion, good management can best be assured for Puerto Rico when production is retained in the context of privately owned plantations that are operated for personal profit.

(l) Harvest Frequency: Of all management operations, the correct harvest period for herbaceous tropical plants is probably the least understood. It is here that prior experience with a given species can lead one astray when trying to maximize its energy potential. Once the diphasic nature of biomass growth and maturation is recognized (Figure), the importance of harvest frequency is also underscored. The optimal period for harvest in the maturation curve.

The optimal harvest period for one species will differ significantly from another, even among varieties within the same genus and species. For this reason, it has been helpful to categorize potential tropical grasses into distinct groups based on the time interval that must pass after planting to maximize dry matter yield (30). The management and harvest requirements of each group will also vary.

Accordingly, tropical grasses were organized into "short, intermediate, and long-rotation" categories (30). As illustrated in Figure 4, the schematic maturation curves for type species of each category vary greatly over a course of 12 months. For example, harvesting sugarcane at the 10-week intervals favorable to Sordan 70A would yield little dry matter. Similarly, any delay of the Sordan harvest beyond 12 weeks is a waste of time and production resources.

Napier grass, an "intermediate rotation" species, is more than a match for sugarcane at two- and four-months of age, and will nearly equal sugarcane yields at six months. However, thereafter, sugarcane will easily outproduce.

In this context, a short-rotation species should be harvested four or five times per year, an intermediate-rotation species two or three times per year, and a long-rotation species no more than once per year. This need for careful attention to the maturation profiles of candidate species is highlighted by yield data for sugarcane and Napier grass harvested at variable intervals over a time-course of 12 months (Table 3).

It is also evident that while Sordan and Napier grass attain rather level plateaus for dry matter, sugarcane continues to increase dry matter beyond 12 months (Figure 4). Sucrose accumulation profiles are very similar for sugarcane. For many years, sugar planters have taken advantage of this feature by extending the cane harvest interval beyond 12 months.

The Puerto Rico sugar industry, for instance, harvests two crops— the "gran cultura" (16 to 18 months between harvests) and the "primavera" (10 to 12 months between harvests).

Hawaiian sugarcane is commonly harvested at 20 to 24-month intervals. Energy Crop Rotations: From Figure 4, one would surmise that the energy plantation manager should plant a herbaceous species such as sugarcane and leave it there - up to 18 months if possible - before harvest. In addition to maximum fiber, he would also harvest fermentable solids as a salable by-product. This reasoning would probably be correct in a tropical ecosystem suited to Saccharum species and where a regional tradition exists for sugar planting. However, these circumstances do not exist in many countries having an otherwise good potential for growing biomass. For example, there is no region of the U.S. mainland suited for 12 to 18-month cropping of sugarcane, although there are vast regions there suited to some form of tropical grasses. Hence, a future energy planter in Florida, Louisiana, southern California, or southern Texas might seriously consider whether he should harvest a 6 to 8-month crop of sugarcane per annum or two crops of rapier grass in the same timeframe. Equally important is the fact that some countries will not be able to afford a land occupation of 18 months by a single energy crop. This is especially true of densely populated, developing tropical nations having an urgent need for domestic food production. In such cases, a short rotation species such as Sordan may be the popular choice for energy planting since it can be sown as a stopgap between the harvest of one food crop and the planting of another. In this capacity, it would also prevent soil erosion and weed growth while acting as a scavenger for residual nutrients leftover from the prior food crop. Seasonal climate changes will also be a factor in the rotation of biomass energy species with conventional food and fiber crops. Short-rotation tropical grasses such as Sordan are ideally suited to the tropics, but they can be grown on a seasonal basis during the heat of summer in most temperate regions. Such plants could be propagated to maturity in a... [Page Break]

The time frame from mid-June to mid-August, in a given year, the same site could produce a cool season food crop (a Brass species, spinach) or a cool season forage (ryegrass, fall barley) both preceding and following the biomass ‘energy crop.

(C) Solar Drying, Compaction, and Delivery: A perceptive observer of mainland biomass conferences will recognize a consistent weakness in harvest equipment and harvest technologies for maximized crops of biomass. This is most evident in woody biomass scenarios where conventional forest harvesting technology is either not applicable or simply doesn't exist in the context of silviculture energy plantations.

The outlook for harvesting herbaceous tropical plants is considerably better, but a good deal of research remains on harvest and postharvest technology, together with equipment redesign and modification. The vast majority of herbaceous tropical land plants will have relatively low-density stands at harvest (less than 10 green tons/acre) and can be mowed adequately with a conventional sickle-bar mower.

Aside from low plant densities, its chief limitations are: (a) A requirement for dry, upright stems (it has difficulty with wet, lodged material), and (b) the cutting process is confined to a single slice near the base of upright stems. In other words, it is essentially a mechanized sickle for severing stems rather than conditioning them for drying.

A more suitable harvest implement is the “rotary scythe conditioner,” a machine which “mows” herbaceous plants by shattering the stems at 3 to 5-inch intervals. This implement has been totally effective on mature Napier grass stands of about 40 green tons/acre (16,31). It functions nearly as well in lodged material as in upright stems. An added advantage is its relatively trouble-free operation. The number of parts subject to malfunction have been reduced to an absolute minimum.

The solar drying of herbaceous energy crops would be very similar to conventional hay-making operations. For light materials, the same rake and tedder designs used in haymaking will be applicable.

"Quite adequate. Drying tests with mature Napier grass indicate that an additional one to two days drying time will be needed due to the thickness of the plant stems (17,31). Such relatively heavy materials have not been handled well by conventional forage rakes operating from the tractor’s PTO system.

However, it is expected that a different rake design, i.e., the “wheel” rake, will perform adequately under these conditions (31). The baling, or compaction, of light herbaceous materials similarly should pose no serious difficulties. The standard hay baler today is actually a compactor. It produces conveniently-sized cubes with a controlled density range of roughly 12 to 20 pounds/cubic foot. A typical bale would be a rectangular cube weighing 60 to 70 pounds and easily handled by one man in transport and storage operations or in feeding cattle.

A baling machine of more recent design is the “round” or “bulk” baler which performs as a windrow wrapper rather than a compactor. It produces large cylindrical bales weighing up to 1500 pounds each (33,34). Since no appreciable compaction is involved, the mass density is relatively low - in the order of 10 to 12 pounds/cubic foot. More recent modifications enable this machine to produce cube-shaped bales which are more economical of space during transport and storage. The round baler has given very good performance with solar-dried sordan, and with solar-dried Napier grass aged up to six months at the time of harvest (17,31). Both front and rear-end loaders suitable for handling these bales are marketed as conventional tractor attachments.

There are two types of balers for sugarcane bagasse: the baling press and the briquetting press (35). The first type is a hydraulic press employing the same compaction principle used for hay. The bagasse is baled in a semi-green state and the formed cubes are tied with twine or wires to prevent them from re-expanding. Their density will range from 25 to 40 pounds per cubic foot. Bales of this type must be stacked carefully to prevent spontaneous..."

Combustion, that is, with sufficient space between them to allow air circulation. The briquetting press operates with dry bagasse having a moisture content of 8 to 15 percent. This press provides high pressures in the order of 5,000 to 15,000 psi. Under these conditions, extremely compact cubes are produced which retain their form without the use of twine or wires. For herbaceous biomass that has been solar-dried and baled, it should be possible to deliver it to processing or storage sites without appreciable difficulty with existing equipment.

Ordinarily, such materials would be loaded directly in the field on a low-bed truck. Standard bales (60-80 pounds) can be loaded manually or with mechanical loaders requiring only one laborer on the truck for final positioning of the bales. Bulk bales would be stacked two layers deep on the truck bed with tractor-mounted loaders.

The same truck would transport the biomass to a final processing or storage facility without intermediate transshipment operations. In the case of sugarcane, the harvested whole stalks or stem billets are hauled in carts to the adjacent mill. The same materials are sometimes carted to an intermediate reloading point for truck delivery to more distant sugar mills.

Delivery costs will vary considerably with the individual biomass production operation. As a general feature, a 30-ton, low-bed truck with driver can be hired for about $200 per 24-hour day. Loading equipment with operators must be stationed at each end of the delivery run. In an ideal biomass production operation, i.e., one managed by a private farmer for profit, the landowner would probably own and help operate the truck and accessory equipment. An estimated delivery cost for solar-dried biomass on a 20-mile run would be $6.00 to $8.00 per ton.

Obtaining Correct Cost Data: A seriously misleading trend is to base the production costs of a herbaceous biomass candidate on its published yield performance as a conventional food or fiber crop. Yet, this is done routinely by otherwise...

Highly qualified analysts have provided important insights (36,37,38,39). Sugarcane, for instance, is an appropriate example. In Puerto Rico, sugarcane managed for sucrose yields 25 to 30 tillable tons per acre year at a cost of about $600.00/acre (41). As an energy crop, it can yield 80 to 90 tons per acre year with only moderate increases in production costs (40,41).

The data on Napier grass can be similarly misleading. There is a wealth of printed matter on the yields of Napier grass managed as a tropical forage crop, that is, when harvested repeatedly at five or six-week intervals at moisture contents approaching 90 percent. As an energy crop, Napier grass produces roughly two to three times more dry matter per annum at less cost than the cattle forage (16,40).

The concept of an “energy plantation,” especially as applied to herbaceous plants, raises the specter of intensive production operations, a continual forcing of lush green plants to production levels beyond their usual means, and a frequent coming and going of assorted machines, all with sinister implications for the land and environment. Our own experience with tropical species indicates that just the opposite will happen (16,31,40,41).

The decisive factor is the acceptance of herbaceous species as sources of dry matter rather than as food or forage commodities. This means that the plants’ maturation phases rather than human activities will be the main source of increased yield. The increased inputs of water and nutrients are actually extensive rather than intensive.

13 factors; a disproportionately greater time lapse is allowed for these to be assimilated in growth and maturation processes. The presence of heavy equipment will be reduced by more than half.

Expenditures for transportation, fuel, labor, pesticides, seed, and seedbed preparation will also be lowered by a significant fraction. Land rentals, plus pre-and post-harvest land maintenance costs, will be about equal to conventional food and forage cropping operations. There is no point in the herbaceous energy plantation scenario where

One can clearly perceive the producer doing more; however, there are many points where he is doing less. Again, it is largely the plants' inherent capacity to produce dry matter, and the grower's good sense in permitting them to do so, that validate the energy plantation as a correct and profitable enterprise.

TROPICAL LEGUMES 1: The Need for Alternative Nitrogen Sources

Cost and energy balance data for tropical grasses managed as energy crops underscore an imperative need to lower inputs of chemical fertilizers, particularly nitrogen-bearing fertilizers (16A0AL). A characteristic feature of the tropical grasses is their need for a significant input of nitrogen (N) to maximize yield (40,4243). For sugarcane, fully half of the total energy expenditure in optimizing dry matter can be traced to elemental N (41).

Unfortunately, Puerto Rico must import nitrogen in the form of nitrates, ammonium sulfate, and urea, at a time when both the manufacturing and importation costs of these sources are drastically increasing. Since the early 1960s, the local sugarcane industry has been underutilizing mineral N due to high fertilizer costs. Since 1974, these charges have become all but prohibitive for adequate field management of the cane plant.

The option of developing tropical legumes as a local N source was an attractive concept for Puerto Rico more than 25 years ago (44-48). Little was done by way of investigating the co-production of legumes and tropical grasses, although some work was done on soybean intercropping with food crops (46,49,50). A rather extensive range of wild, hardy, and highly adaptive legumes was almost entirely overlooked as potential N resources. Even today, some of the most productive herbaceous legumes on the Island (Phaseolus spp.) are widely regarded as weeds and are destroyed by pre- and post-emergence herbicides.

2. An Underexploited Tropical Resource

The following is a revised version of the text:

The U.S. National Academy of Sciences initiated a listing of 150 "promising" species (51). This list was quickly expanded to 400 species when brought to the attention of plant scientists worldwide. As the study progressed, an additional 200 species were nominated as potentially valuable resources for developing nations. Out of more than 600 candidate legumes, nearly half received top ranking by at least one plant scientist. This is a clear reflection of legume adaptability to the variations of soil, rainfall, temperature, and sunlight found in the ecological life zones of the world's tropics (51,52,53).

3. Puerto Rico's Native and Imported Legumes

A large number of legume species—both herbaceous and woody—are found in Puerto Rico, but their modern taxonomy remains obscure. This is partly due to the inherent difficulty in distinguishing clearly between species at the genus level. While individual scientists have shown periodic interest in wild legumes, there has been no concerted effort by island research institutions to evaluate this family as an agricultural resource (54, 44).

The earliest systematic survey of Puerto Rican legumes dates back 75 years. It was published by J.R. Perkins as a contribution to the U.S. National Herbarium (55). The study is based on specimens obtained by the Royal Botanical Museum of Berlin. Perkins also used materials collected by Urban. She generally followed the nomenclature of Watt, Urban, Cook, Collins, and other reliable authorities of that period but did not work with specimens in the field.

Interestingly, the editors of the "Contributions" series initially delayed the publication of this work, anticipating a complementary study on the "agricultural relations" of Puerto Rican legumes. However, the latter did not appear, and Perkins' work was published as a separate account.

Perkins described 67 genera and 141 species of legumes in Puerto Rico. She noted an apparent lack of endemic species. Only one genus (Stahlia), with eight species, was considered native to Puerto Rico.

Most were common to the Antilles, Central America, and South America. In 1974, Woodbury and coworkers (56) compiled a list of indigenous Puerto Rican legumes consisting of three sub-families, 24 genera, and about 50 species (Table 4). Nodulation was extensive in both acidic and neutral soils. Nearly all of these species were thought to have potential agricultural value (56). The entry of new legumes into Puerto Rico probably dates to the interisland movements of pre-Columbian times. The Caribs are thought to have used plant materials for food, shelter, utensils and clothing (57). The process was definitely accelerated by the steady arrival of Europeans in the sixteenth century. In nature, a discrete species could be confined to a single hill, or require many centuries to spread even to its preferential habitats on the Island (57). This process was also sped up by the advent of roads and human commerce throughout Puerto Rico. In recent decades, the entry and dispersal of new species could have occurred in a matter of hours. This is particularly true of small-seeded forms accompanying farm produce as "weeds," or as totally unnoticed occupants of highway vehicular traffic. For example, the species Phaseolus lathyroides is quickly discernable along roadsides and refuse areas in virtually every Puerto Rican town and district.

An immediately attractive concept for tropical legume exploitation is their use as biological N sources for tropical grasses. Certain legume species would contribute an appreciable quantity of cellulosic biomass as well. Alternatively, some biomass potential in tropical grasses could be sacrificed in selecting candidates especially well suited for co-production with legumes. From prior observation, there appear to be at least 80 to 100 wild legumes having some potential for either co-production or intercropping with tropical grasses. The real number is probably much larger. Some of the more obvious legume candidates include species of the genera Glycine.

Phaseolus, Sesbania, Desmodium, Lespedeza, Vigna, Leucaena, Acacia, Puereria, and Cassia (Cable 5). These range in size from small vines and bushes to semi-dwarf trees. All would be managed as herbaceous N sources, including woody species in their juvenile growth period. Each category has a potential contribution to make in the production of short, intermediate, or long rotation tropical grasses (Table 5).

16 Many additional legumes could be imported for evaluation as energy crops. As many as half of the 600 species identified by NAS (S1) are potential candidates. Examples of these include Medicago, Lathyrus, Coronila, Cofanus, Crotalaria, Sesbania, and Vicia. Some are only partially represented on the Island, while others, such as the "Colorado River Hemp" (Sesbania exaltata) have only recently come to the attention of local biomass researchers. Certain legumes not ordinarily classified as “tropical” would be fully accepted if they serve the needs of tropical grasses.

20. Line 2. 13. 7

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Table 1. PHYSIOLOGICAL ATTRIBUTES OF SACCHARUM AND ALLIED GENERA. Comparison of various physiological attributes.

Table 2. SEASONAL INFLUENCE ON DRY MATTER YIELD. Comparison of total yield for different periods for Sugarcane and Napier Grass.

Table 3. DRY MATTER YIELD vs HARVEST FREQUENCY. Comparison of yield and harvest frequency.

Table 4. TROPICAL LEGUMES CLASSIFIED AS INDIGENOUS TO PUERTO RICO (1974). Various species and their characteristics.

Figure 2.

The storage and production of organic matter are dependent upon environmental conditions. In tropical environments with adequate moisture and fertile soils, the production of organic matter and the storage of biomass are both high. Higher storages of organic matter, but slower rates of production, are characteristic of very wet environments. In arid environments, both storage and production of organic matter are low. Brown and Lugo (1981) have described these patterns, which are summarized here in Figures 1 and 2. Figure 1 shows the patterns of organic matter storage according to Life Zone designation, and Figure 2 shows the pattern of organic matter production in terms of rates of litter production according to Life Zone.

Due to the close relationship of these parameters with Life Zone, it follows that the Life Zone composition of a country is an important factor in its natural ecosystems, determining the potential biomass yield for energy purposes. Humans can alter the rates of production and storage of organic matter of forest ecosystems within certain limits by using a variety of management techniques. For example, by selecting the proper species and overcoming environmental limiting factors, rates of organic matter production can be accelerated.

Irrigation can compensate for the lack of rain in arid environments, and fertilization may help overcome the poor fertility of leached soils in wet environments. The higher yields thus obtained are not free and they must be considered in relation to the costs associated with overcoming environmental limitations. This is particularly true for energy procuring systems which must be proven to yield net energy.

In Puerto Rico, we have forests representative of 6 of the 30 forested tropical and subtropical Life Zones (Ewel and Whitmore 1973). The distribution of these Life Zones sets an upper limit on the potential production and storage of organic matter that the Puerto Rican forest stands can produce and sustain. Within each Life Zone, there is a great diversity of plant associations and successional stages.

The text further modifies what the island forests can, and actually do, produce in terms of organic matter. The fact that we have 164 separate soil series (Lugo-Lépez and Rivera, 1977) represented in the 880 thousand hectares (ha) of the island provides an indication of the potential diversity of forest types in Puerto Rico. It is not our objective in this paper to analyze this diversity of forest types but, instead, to calculate the amount of organic matter now stored and being produced by the forests of Puerto Rico, to look at the changes in organic matter storage that have occurred in our history as a result of changes in land uses, and to determine the feasibility of using forests for biomass energy production.

Current rates of storage and production of organic matter in Puerto Rican forests

From the work of Ewel and Whitmore (1973), we know the Life Zone distribution on the island (Table 1). The most recent forest inventory (1973) by the Department of Natural Resources shows that forests cover 375.8 thousand ha or 41.5% of the island. We do not know the Life Zone distribution of these forested areas. However, we assumed that the very wet Life Zones (Rain, Lower Montane Rain, and Lower Montane Wet) are completely forested, and that the remaining forested areas are distributed by the same proportions that the Life Zones are distributed, i.e., 61% Moist Forest, 25% Wet Forest, and 14% Dry Forest. The resulting distribution of forest area in Puerto Rico is given in Table 1. Using the regression equations in Fig. 1 and areas of forests in Table 1, we arrive at the estimates of storage of organic matter in Table 2.

The results show that the moist and wet forests store the largest amount of organic matter with the Moist Forest Life Zone storing almost twice as much organic matter as the Wet Forest Life Zone and more than half of the total storage for the island. Within a given Life Zone, the soil may store from almost as much organic matter as the vegetation to about less than half as much. For the island as a whole, the organic matters are crucial.

Organic matter storage in the soil constitutes approximately 33% of the total. Using Table 1, we multiplied forest area estimates by rates of organic matter production in order to estimate the potential organic matter production of the forests in Puerto Rico. Two calculations were made, as seen in Table 3.

The maximum possible production, or gross primary production, was calculated from data reported in three studies conducted in Puerto Rico, which used CO2 exchange methods (Dugger 1978, Lugo et al. 1978, Odum 1970). Net primary production, equivalent to the actual amount of organic matter stored by plants after their respiratory demands have been met, was estimated by assuming that net primary production was twice the litter production (Brown and Lugo 1981). Litter production data was obtained from Dugger (1978).

Figure 2 shows that gross primary production on a unit area basis peaks in the Rain Forest Life Zone and is lowest in the Dry Forest Life Zone. On an island-wide basis, the Wet Forest Life Zone contributes the most to primary production (52%). The Moist Forest Life Zone is second, and the other Life Zones exhibit negligible amounts.

The rates of net primary production are an order of magnitude lower than gross primary productivity. This is a reflection of the high respiration rate of tropical vegetation. The Moist and Wet Forest Life Zones account for almost all (90%) of the net primary production of the island's forests. However, on a unit area basis, the differences among Life Zones are small (the range is 10-14 tons per hectare per year—t/ha.yr), with the exception of the Lower Rain Forest and Dry Forest Life Zones, which exhibit much lower rates of net primary production (about 4.5 t/ha.yr).

In Table 4, we reconstruct the known history of forest coverage in Puerto Rico. This is necessary to estimate past rates of storage and net production of organic matter by our forests. The highest estimates are for the period prior to discovery when the island was nearly all forested. The maximum potential of storage (208 x 106 t) and net production (8.5...

The production of 108 t/yr of organic matter can be expected from the island's natural forests, which was observed at the time of the island's discovery. The lowest estimates occurred early in the century when Puerto Rico was highly dependent upon the land for food and energy. Since then, forest storage and net production of organic matter have approximately doubled, with much of this recovery of forests occurring during the last 20 years.

FEASIBILITY OF USING NATURAL FORESTS FOR ENERGY PRODUCTION

As a starting point of this discussion, we will use the present (1973) net organic matter production potential of 3.8 x 106 t/yr and an organic matter storage of 94 x 106 t for the island (Table 4). Because Dry Forests recover slowly from any disturbance and very wet forests on slopes are difficult to harvest physically and economically, we will reduce the storage and net organic matter production values to 84 x 106 t and 3.4 x 106 t/yr, respectively. However, the net production value includes leaves and roots which we estimate represent 60% of the net production, leaving 1.4 x 106 t/yr available for use in the form of wood.

In previous analyses of forestry potential in Puerto Rico, Wadsworth has suggested that 344 x 103 ha of land in Puerto Rico is suitable for pine (Pinus caribaea var. hondurensis) production. These forest lands are located in the Subtropical Moist and Wet Life Zones. Assuming all these lands were available for pine plantations, annual wood production would be 6.1 x 108 t/yr (Table 5). However, 56% of these lands are now forested, leaving 153 x 103 ha available for reforestation with pine. These would yield 2.7 x 106 t/yr (Table 5), if they were covered with pine plantations.

The energy consumption in Puerto Rico was 88.6 x 1012 kcal of fossil fuels in 1973 (Sincher-Cirdona et al., 1975) and 90.2 x 1012 kcal of fossil fuels in 1979 (Office of Energy, Personal comm.). Using the island's 1979 energy consumption and the forest production values shown in Table 6, one finds that in terms of heat

Equivalents, the best we could expect from the forests would be 30% of today's total energy consumption. To achieve this rate of energy production (30% of the total), much of the island would have to be planted with pine or with any species that produced organic matter at a similar rate (Table 4). If the energy production through forest biomass is corrected for quality in order to get a better idea of the capacity of the fuel to do work, we could expect 15% of the total island's energy demand to be satisfied by plantations. Natural forests could yield 4% of today's total energy demand (in fossil fuel equivalents) and a combination of natural forest and plantations could yield 10% of the fossil fuel equivalents used today in Puerto Rico.

The above calculations may appear conservative because we have not used all available forest lands to produce biomass for energy. Yet, lands that were not included are not suitable for fast biomass production because they are too dry or too wet. We have also not included leaves and roots in the calculations because these should be left behind to maintain site fertility through decomposition. Their use to generate energy would be questionable anyway. Also, we have only used the net energy production of the forest lands in the calculations and have not included the standing crop of biomass energy stored in the forests.

It is very important that Puerto Ricans do not depend on the standing stock of wood in the forests, but rather adjust demand to the forest's annual net production. The standing crop of wood (about 75% of total biomass in vegetation) now present in the forests amounts to a fossil fuel equivalence of 159 x 10^12 kcal or enough to supply current energy demand for 1.8 years. However, once destroyed, this standing crop could not be replaced for another 20-50 years during which time the island would be deforested and without the use of its forests. To avoid this catastrophe, the energy demands on the forests of the island must be proportional to the

The annual production rate of the forest, along with its standing crop of biomass, must be protected. If the analysis of energy needs vs. forest production of potential energy is based solely on electric demand, a more optimistic scenario can be predicted. The justification for such an approach is that a significant fraction of the total energy consumption in Puerto Rico is in forms that would be hard to satisfy using wood (e.g. gasoline for vehicles). However, the use of wood for electric generation is a more realistic use of the resource. The approximate total electric consumption in Puerto Rico in 1978 was 11 x 10^12 kcal of electricity or 44 x 10^12 kcal of fossil fuel equivalents (about half of the total energy consumption of the island). Using results from Table 6, we find that plantations could satisfy 31% of this demand in terms of fossil fuel equivalents, and the combination of natural forests and plantations could supply 21% of the electricity demand (also in fossil fuel equivalents). When the island turns again to forests for energy, we will have to decide on the use of plantations vs. the use of natural forests. We will not address in this paper which alternative is the best. However, one advantage of plantations is the rapid rotation which allows for the production of significant amounts of wood in a short time (10-12 years). Natural forests also produce high amounts of biomass in a short time (13-15 t/ha.year in the first 6 years, see Brown and Lugo 1981), but not as much in the form of wood. Ultimately, the decision will have to be made based on criteria such as the net energy yield of each alternative and, implicit in the net energy yield calculation, the environmental cost of maintaining productive plantations year after year. Our ability to make an adequate calculation along these lines at this time is nil.

CONCLUSION

In summary, the energy future of Puerto Rico is bleak, particularly in light of the current high rate of fossil fuel consumption on the island and the expected increases in the price of oil.

Earlier in history, the island was dependent on its forests and lands for food and energy. There is much to learn from the energy use strategy of the island during this period. In Table 7, we summarize the energy use and energy sources of Puerto Rico in 1910 when the island had a population density of 125 people/km², which is 34 times lower than today. At that time, the energy use of Puerto Rico was 70 times lower than it is today, and the energy source was primarily solar, in stark contrast to the current predominance of fossil fuels.

By comparing the energy use of 1910 (Table 7) with the energy production potential of our forests in Table 6, it is clear that with adequate forest management, the forests of Puerto Rico could have catered to all the energy demands of the island. Table 6 reveals that the forests of the island had the capacity to meet all this demand. However, during the time of Murphy's study, the forests were being cut three times faster than they were growing. Consequently, the island imported about 90% of its wood demand.

By 1916 (Table 4), the island had lost 79% of its forest resources. What we learn from this historical record is that without proper management, and despite a low population density (relative to today), natural forests can disappear very quickly - in less than 15 years according to Murphy's 1916 study. This loss occurred because the demands on the land exceeded the land's capacity to convert solar energy.

One hopes that we have learned a lesson in land management and that the degraded conditions caused by senseless use of the land do not return to Puerto Rico in the future. However, considering the small amount of energy that can be concentrated via forests relative to the current uses of fossil fuels, it implies that standards of living must decline when fossil fuels disappear from the market. As this happens, there will likely be efforts to maintain an abnormally high intensity of energy use by harvesting standing forests. To avoid serious long-term harm to society, forest cover must be protected and only the annual rate of organic matter production, not the total stock, should be harvested.

This storage should be used. The annual rate of production adds up to a maximum of 15% of the 1979 energy demand and 31% of the electrical demand (both in fossil fuel equivalents). Since these calculations are based on high yields obtained in experimental plantations, it is likely that actual values are much lower.

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Organic Matter Storage (t/ha) Mix. Total Organic Matter - Vegetation and Soil. Relationship between total organic matter storage and organic matter storage in vegetation and in soils grouped into six Life Zone groupings, and potential evapotranspiration to precipitation ratio (PET/P). The equations describing the relationships are significant ($p = 0.05$) and are: total organic matter storage (t/ha) = 625 + 281 x PET/P ($R^2 = 0.99$), organic matter storage in vegetation (t/ha) = 392 - 169 x PET/P ($R^2 = 0.90$), and organic matter storage in soil (t/ha) = 224 - 112 x PET/P ($R^2 = 0.96$). From Brow and Lago (1980).

Litter Production Fig. 2. Total and Leaf and Fruit Litter Production vs. PET/P (mm/mm). Relationship between total litter production and leaf litter production and potential evapotranspiration (PET). From Brow.

Table 1. Areas of Life zones and forests in mainland Puerto Rico, 1973
Life zone - Area (ha) - Forested Area (ha)
Dry Forest - N/A - 50.85
Moist Forest - 532.61 - 222.66
Wet Forest - 2.48 - 8.83
Rain Forest - N/A - N/A

Subtropical Forest - 20.91 - 10.91
Mainland Forest - N/A - 80.19
* All zones are subtropical. From Evel and Whitmore (1973).

Table 2. Storage of organic matter in Puerto Rican Forests
Life zone - Total storage (ton/ha) - Average PET/P - Organic Matter (ton/ha)
Dry Forest - 1.72 - N/A - N/A
Moist Forest - 55.3 - N/A - N/A
Wet Forest - 25.0 - 0.29 - 36.1
Rain Forest - N/A - 0.21 - N/A
Subtropical Forest - N/A - N/A - 38
Mainland Forest - 94.2 - 0.1 - 16.6
* PET/P = Potential evapotranspiration to precipitation ratio for the mid-temperature and precipitation values of Life Zone (c.f. Brown and Lugo 1980 for details).

Detailed © From regressions in Fig. 1.
Table 3. Production of Puerto Rican Forests Life Zone Gross Primary Production Net Primary Production
* (email) ao'ey (imax okey Dey
Forest 19.08 23 ae 0.24
Moist Forest 36.26 19.2 98 2as
Wet Forest ug. 25.4 14.0 1.26
Rain Forest uot 0.2 14.0 0.02
Lower Montane Forest at 10.4 on er
Forest s2.0° - ak
Fern Forest om 8.5 3.79
* Calculated as 2 x leaf Litter production (Brom and Lugo 1981); Litter production data are from Dogger (1978) and Brom and Lugo (1981), © ope et at. (1978). Usser (1978) dun (1970). © Extrapolated (by eye) from relationship between PET/P ratio and gross primary production of the 4 other Life Zones.
Table 4. Historical trends in the storage and production of organic matter in Puerto Rican Forests.
Storage Net Primary Production Forest Area" Sn Vegetation Production
202 na ao 08
(ive) usa e262! 208.0
Bes as 178.78 45.5 1
1950 ass.2f 54.9 2
ana 375.8 m2
* We assumed very wet Life Zones (Rain, Lower Montane Rain, Lower Montane Wet) were always forested and the remaining forested areas were distributed by the same proportions the Life Zones were distributed. From PET/P ratio in Table 2 and regression in Fig. from net primary production estimates (g/ha) Sa Table 2. Assumes 95% of the island forested and ed area was in Moist Forest Life Zone. Zon and Sparkhavke (2923). Puerto Rico's Department of Natural Resources Inventory Program.
Plantations in Subtropical Moist and Wet Forest Life Zones In Puerto Rico (Kadevorth, pers. coms.)

Area* Wood Soil Conditions (m³/h) Production (m³/yr)
164 8 shallow clay Zone 280 2.08

ror.” bee 6.08
Presently non-forested: Deep clays B aaa
Deep sands and shallow clay loams % a8
Tra, 159 2.70
* Excludes prime agricultural land
1 ‘Using 19.5 g dry weight/ha.yr for deep clays and 16 g dry weight/ha.yr for sandy and shallow loams (not including bark).
Table 6. Energy content of biomass production in forests of Puerto Rico.
Forest Type asco Production (g/m³/yr)

The text should read:

It's a life support system, especially considering the losses that the Sugar Corporation has incurred. There are many who will welcome its downfall for reasons other than the elimination of financial deficits. Like King Cotton in the Southern states, sugar's human contribution never matched its economic contribution. This is because of the nature of its introduction, cultivation, and processing. Very few of the people most closely associated with its production were ever able to live a good life on account of sugar. From the beginning, it depended upon large amounts of involuntary labor or the labor of very desperate people. Cutting cane by hand is, and still remains, a very unpleasant task. Those who did it were assured of an income only a few months of the year. Worst of all, for the general welfare, the income went mainly to those who owned the land and others who owned the sugar after it left the land.

The expression "sugar island" has connoted an overpopulated, poverty-stricken, racially mixed, socially uprooted, politically explosive society dominated by a few powerful figures from within and without. Seldom has the wealth generated by sugar served as a springboard, or what economists call an "export base," for genuine economic development. The Virgin Islands, whose European and African settlement was predicated upon sugar, have now abandoned the crop completely with hardly a regretful look back. National leaders from Cuba to Barbados have vowed to purge the captivating weed from their islands, but sugar keeps hanging on and coming back.

Sugar comes back because demand for it continues to grow around the world, causing the price to soar every time there is a temporary supply setback in some important sugar-producing areas. In this, it is hardly different from all commodities, whether they be rice, beans, coffee, cocoa, cinnamon, or sow bellies. Right now, we are on one of those upward spirals as the price of sugar has risen from 8 cents to 42 cents per pound in the last 17 months. But this very volatility of price ultimately constitutes just another issue.

Page in the catalog of the ills of sugar. Small national economies are heavily dependent on this one commodity and ride the same kind of prosperity-poverty cycle over long periods.

2. Each year, the sugar worker experiences the same cycle. Sugar also hangs on because of the miraculous quality of the crop itself. In the words of Dr. Alex Alexander, "Sugarcane (Genus Saccharum) is the finest living collector of solar energy, which functions on a year-round basis to store this energy in the form of fermentable solids and fiber." This remarkable ability of sugar to

collect and store solar energy in huge quantities per acre of land has been at the root of its success as a luxury human consumption crop, and this property portends extremely favorably for its continued success in the world and its revival in Puerto Rico.

Translating the amazing biological productivity of sugar cane into economic terms, Erich Zimmerman made an estimate in the 1940's that the proceeds of the sale of Puerto Rican sugar extracted from the cane grown on one acre bought in terms of corn, oats, rice, wheat, dried beans, and potatoes, the products of 8.2 acres in the continental United States. At today’s sugar price, the ratio might well be higher.

For a host of reasons - I'm sure I will not be able to list them all - Puerto Rico in the 1980's is the right place at the right time for sugar, not for sweetness, but for fuel. Going down the list of sugar's ills, one can see that they would not or need not apply if the crop is grown for fuel. First, as a fuel, sugar would free itself of the curse of commodities, the rising and falling of price on the world market. At least for the foreseeable future the price of energy is going only one way, up. This would be an excellent way for an oil-less island such as Puerto Rico to hitch a ride on OPEC's wagon.

Next, whatever happens to sugar’s price, the island economy has grown too big for sugar ever to be as dominant as it has been in the past. There is no reason for it to become an export crop again. Using Combustion Equipment’s

Estimates of energy output in its proposed 15,000-acre project suggest that, even if we could plant the acreage of 1952 again, we could replace only 20% of our total petroleum imports in 1978. The domestic market is more than big enough to absorb all that could be produced. Alternatively, as the Center for Energy and Environment Research envisions, the liquid portion of the cane could be used to satisfy the needs of the local rum industry, which are significant. Again, the output is tied to a product whose price is not subject to the vagaries of world commodity markets. Either way the product is used, it becomes an integral part of our modern economy rather than an anachronistic appendage standing in the way of development.

Perhaps the most welcome departure from the past offered by an energy cane regime is the possibility of operating the sugar mill throughout the year. In the year just completed, the average grinding period for the seven mills still operating was 112 days, with an average time lost of 42 days for a final effective average of 70 days out of the 365. In a society geared to year-round work and the 40-hour week, one must wonder what our 3,000 sugar mill workers do the remainder of the year, or if anyone could afford to keep them on the payroll for 365 days.

With regard to another of sugar's traditional evils, Puerto Rico has already recognized the bad social consequences of too great a concentration of ownership of the land, and this has been dealt with. There are legal safeguards against the re-emergence of massive corporate control of the Puerto Rican patrimony. In any energy cane project, we must be sure that they are adhered to.

Continuing on the positive side of the ledger, alternative fuels of this type are very high on the national agenda in the United States, the idea being to lessen dependence on imported oil. The 1.6 billion dollars that Puerto Rico spends annually on foreign oil weakens the dollar and lowers U.S. living standards every bit as much as would the same purchases by the state of Kansas.

Electoral votes aside, there is just as good a reason for the United States Department of Energy to support energy self-reliance in Puerto Rico as in the mainland. Perhaps, with Puerto Rico's growing strategic importance in the Caribbean, there is even more reason. The recent agricultural emphasis in Puerto Rico has been upon food production to substitute for imports. Given the high level of local food purchasing power and the high cost of transportation of many food items, this policy makes a great deal of economic sense. Where freshness is of paramount consideration, it also makes sense to produce some items that can be imported more cheaply. The fact that 56 percent of agricultural income in Puerto Rico in 1979 was made in the import-substituting commodities of meat and dairy products is an altogether healthy development. We can apply the same logic and make similar inroads into the vegetable and fruit produce section of the supermarkets. But we should also recognize the limits of any food-import-substituting policy. Unless the people are willing to accept a drastic change—one might say reduction—in their standard of living, Puerto Rico will continue to import most of its food. One need only take a stroll through the local supermarket and ask himself as he goes through, “Could that product be made here? If so, should it be made here? If it were made here, how much would it cost to persuade people to buy it?” Product by product, the would-be Puerto Rican producer finds himself up against companies which, for a wide variety of reasons, have risen to the top in a tough game of survival of the fittest. The two main advantages most of these companies have over the would-be Puerto Rican producer are economies of large scale production and superior resources for product design and marketing. The first advantage stems from the relative proximity of abundant land, well suited for certain temperate zone food crops, on which very capital-intensive techniques can be used. The second advantage is a function of the wealth.

And experience of the companies. We can't match either of these in the foreseeable future. As a substitute for imports, fuel from sugarcane would have some definite advantages over food. We would continue to cultivate a proven tropical crop. We could then sell the final product in a certain inflated market. The food market is far more competitive. Fuel would not be faced with the brand-name identification problem. Suitably priced, it will sell. And the need to substitute for fuel imports is even greater than for food. In 1979 we imported $1.78 billion in fuel versus $1.20 billion in food.

Biomass for energy has also been compared unfavorably with food on moral grounds and on employment grounds. Addressing the moral question first, we must admit that a great deal of the energy created would be wasted. Working in buildings whose design necessitates heavy air conditioning expense and simmering in traffic jams reminds us constantly of the squandering of energy. But at the same time, energy is an important part of all our necessities; our vital transportation, our shelter, our clothing, and indeed, our food.

We should be reminded, furthermore, that not one of the big three money crops in Puerto Rican history could be regarded as a necessity, those being sugarcane, coffee, and tobacco. The widespread cultivation of grains for animal feed in the United States is also an extremely wasteful use of land, nutritionally speaking. And a recent news report stated that the premier agricultural state in the United States, California, may now count marijuana as its principal money crop. From a moral standpoint, people can do, and have done, a lot worse things with their land than producing energy.

On the employment question, I think we must face the fact that no modern agricultural project will generate the same level of employment per acre as did traditional agriculture, nor will it create the same number of jobs per acre as does sugar production currently. The only way that could be done would be for us to turn back the

Clock in wages and living standards, or for the government to provide massive subsidies as it is currently doing through the Sugar Corporation. Even with considerably less employment per acre, total sugar-related employment could be increased over time, as land that had been in sugar before is put back into sugar. Of equal importance is the fact that the jobs would be year-round and, if the project is basically sound, the jobs would be much more secure and better paying than most agricultural jobs at present. Our main consideration in the revitalization of agriculture should be restoring productivity in economically sound projects, not the number of jobs we can sustain per acre of cultivation. We arrive then at the basic question to be answered, "Is the growing of sugarcane for the purposes of energy economically sound? Will it yield a sufficient return on investment to be worthwhile for a private company?" I don't think anyone can answer that question with complete assurance at this time. We won't really know until it is tried on a commercial scale in Puerto Rico. The numbers I have seen tell me that such a project would have a very good chance to succeed. If biomass for energy makes sense anywhere in the United States, then sugarcane in Puerto Rico does. It is the most energy-efficient crop yet tested and Puerto Rico is the best place under the U.S flag to grow it. If its time has not yet come, it soon will, if fuel prices continue in their inexorable upward course. Finally, we must recognize the very large stakes in the world energy game. Our supplies of food, mainly from the United States, are relatively secure. One need only open today's newspaper to be reminded that our supplies of fuel are not. We are still experiencing an energy crisis even though the word is no longer in vogue. Puerto Rico is accustomed to looking to the United States for leadership in times of crisis. We now have the opportunity, with a successful biomass-to-energy project, to provide leadership for the United States. We should not pass up this opportunity.

"Seize that opportunity.

2. 'THE DECLINE OF SUGAR REFINING IN PUERTO RICO: HISTORY AND PRESENT OUTLOOK' Presented at The Symposium on FUELS AND FEEDSTOCKS FROM TROPICAL BIOMASS at Caribe Hilton Hotel, San Juan, Puerto Rico on November 24 and 25, 1980. Contributed by M.A. ROMAGUERA & ASSOCIATES, Mayaguez, Puerto Rico.

DECLINE OF SUGAR REFINING IN PUERTO RICO: HISTORY AND PRESENT OUTLOOK by Mariano A. Romaguera, Mechanical Engineer, and Consultant at PR Sugar Corporation. Over a period of years, the output of the Sugar Industry in Puerto Rico has experienced a decline—from a peak of 1,310,000 tons of raw sugar produced in 1953 to a production level in 1980 that was slightly over 176,000 tons. Major factors in this decline have been:

- Lack of agricultural labor caused in part by the migration of workers to the continental U.S.
- Forced field mechanization without a logical transitional period.
- Deterioration in the performance of cane varieties resulting in lower yields in tons cane/acre and in sucrose content in the cane. This deterioration has been accelerated by...

Although the production of raw and refined sugar usually go hand in hand in the sugarcane industry, this has not been the case in Puerto Rico. Refined sugar production was linked directly to the capability of selling the refined product to the mainland and this capability was restricted; the federal government set limits on the amount of refined sugar that was permitted to be sold to the continental U.S. in order to assure a large market share to mainland refiners. Even at the time of peak raw sugar production, Puerto Rico refined a maximum of slightly over 240,000 tons, and although raw sugar production has plummeted to roughly 15% of its former level, refined sugar output has only decreased to about 40%. In 1943 there were six refineries producing refined sugar, some utilizing the Suero Blanc process, others using activated carbon. At present, there are two refineries operating with ample capacity to produce..."

Over 160,000 tons of refined sugar. Problems of Puerto Rican Refineries. The decline of raw sugar production has indirectly affected the operation of the existing refineries. Present address: Apartado AO, Cond. Torre Peral P.H., Mayaguez, Puerto Rico 00708.

The intermittent grinding, due in part to field mechanization problems and the necessity of continuous operation in refining, caused excessive consumption of fuel. Due to agricultural problems, the quality of the raw sugar left much to be desired. We have been plagued by low filterability, raw sugar of very high colors, high ash content, and poor overall performance. Since our existing refineries are tied up to our raw sugar houses, we are forced to accept this low quality prime material. Our local refineries, contrary to those in the Continental U.S.A., make only one grade of sugar. This means that our refineries cannot get by with second grade liquors that can be utilized by various industries. This places an added burden on our existing facilities.

Present Outlook

Whether we like it or not, the problems analyzed here will not pass away. The sugar industry outlook as a whole is one of restraint. Our Government is embarked on an agricultural diversification program that allocates enough land for cultivation of sugarcane to produce roughly the same amount of raw sugar we produced this year. The main purpose will be to supply our basic needs plus a small reserve, and the present production fits alright. Refined sugar will tend to maintain its present position, that is, a production level of around 110,000 to 130,000 tons of refined sugar, which is ample for our present needs.

The world market's latest projections indicate a sustained low production for the next two to three years. The cost of producing raw and refined sugar has increased three-fold in third world countries. This means that the present world market price for raw sugar, around 40 cents per pound, will not come down as it did in 1975 after the 63 cents per pound peak. Puerto Rico.

Experienced her greatest cost increases in the decade of 1970 to 1980. It's expected that this cost, although not stable, will rise proportionally at a lower rate than that of the rest of the world. Unless our local Department of Agriculture has a change of priorities, refined sugar production in Puerto Rico will maintain its present level. It is expected that, at present, changes in the refineries will improve somewhat; sugar could be produced in a single refinery, depending on the availability of sugarcane in the specific area. Although the present outlook is one of a very limited nature, present projections do not envision an increase in production. Statistical curves on production of raw and refined sugar have bottomed out. It is expected that this low plateau will maintain a stable, even line for the immediate future.

MARIANO A. ROUAGUERA & ASSOCIATES:

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4) Personal Records of Consultant.
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SPECULATING ON DECLINE OF SUGAR REFINING

YEAR OF PRODUCTION REFINED SUGAR

THE ENERGY CANE CONCEPT FOR MOLASSES AND BOILER FUEL. Presented To The Symposium FUELS AND FEEDSTOCKS FROM TROPICAL BIOMASS Caribe Hilton Hotel, San Juan, Puerto Rico. November 24 and 25, 1980 Contributed By THE UPR CENTER FOR ENERGY AND ENVIRONMENT RESEARCH, Biomass Division, Rio Piedras, Puerto Rico

"The Energy Cane Concept for Molasses and Boiler Fuel"

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"The Energy Cane Concept for Molasses and Boiler Fuel"

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Abstract:

Since 1977, the U.S. Department of Energy has sponsored research in Puerto Rico on sugarcane and other tropical grasses managed specifically as renewable energy sources. The term "energy cane" refers to sugarcane that is managed for its total growth potential rather than sugar.

The energy cane concept is more a concept of management rather than of varieties, species, or taxonomy. Averaged yields from three crop years indicate that more than 80 tons of millable cane can be produced per acre year. Production costs are roughly $10.12 per ton of millable cane, or about $840.00 per acre year. Juice quality was low, but sugar yields averaged about 5.5 tons sugar per acre (ESA). Yields for both biomass and sugar were considerably higher for energy cane than for conventional sugarcane in Puerto Rico. Production costs were higher on a per-acre basis, but lower per ton of cane.

While the energy cane studies are far from complete, the current data trends imply: Whether the PR sugar industry intends to produce sugar, molasses, or biomass, its goals can best be met by managing sugarcane as a biomass energy crop rather than a sugar crop.

"The Energy Cane Concept for Molasses and Boiler Fuel"

Introduction

The term "energy cane" was first coined in 1979 by Dr. Amador Cobas while preparing a symposium paper on alternative uses of sugarcane (1). He had observed, correctly, that sugarcane studies by CEER-UPR were emphasizing total biomass for energy rather than raw sugar, refined sugar, or molasses. It seems ironic that sugarcane is a better producer of biomass than sugar. As an agricultural entity, we have long associated this plant with the commercial sweetener sucrose. However, as a botanical entity, sugarcane is first and foremost an effective collector of solar energy. It is a solar collector that operates day and night, 52 weeks per year, to convert sunlight to storage carbohydrates. Its botanical "preference" is to store this energy in the structure of new plant tissues (Giver) rather than to accumulate it as soluble sugars (fermentable solids). Rarely, however, do growth-regulating factors such as climate, water, and nutrients allow sugarcane to sustain growth at maximum rates. In the upshot, sugarcane produces both fiber and fermentable solids in considerable abundance. The conventional sugar planter (with an eye for sucrose and backstrap molasses) will tend to constrain new tissue growth beyond that amount which is needed as a storage vehicle for sugar. For the energy planter, the tissues themselves are a prime objective and a salable commodity of potentially great importance. Hence, the energy cane concept is basically a concept of management. It is a concept of revised management for an existing plant resource, but one that focuses clearly on the energy-converting capabilities of sugarcane.

Energy Cane in Perspective

Sugarcane planting for energy will differ from conventional sugar planting in several ways: (1) yields will be higher and production costs lower; (2) juice quality will be lower and sugar yields higher; (3) the harvest season will be longer (approximately 8 months in Puerto Rico); and (4) W Romer, the President of the University of Puerto Rico, presently a consultant to the PR Energy Office CEER-UPR.

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2. Energy cane will be one of several tropical grasses contributing to year-round biomass utilization operations.

1. Yield and Cost Considerations

On a worldwide average, sugarcane planted for sugar yields about 22.6 tons of millable cane per acre per year (Table 1). Puerto Rico's average yield is moderately higher at around 28.0 tons per acre per year. This is a deceptive figure, however, since it reflects some adverse conditions prevailing in the industry today rather than the yield potential of the plant itself. For example, Puerto Rico's cane yields in the years immediately preceding 1936 averaged 45 tons of cane per acre per year (2). These yields were obtained with varieties much inferior to those available today.

Many reasons can be given for the modest cane yields shown by our sugar industry in recent years. It can be argued, for example, that it simply costs too much to plant sugarcane in Puerto Rico today. The average hourly wage has risen from 16 cents in 1939 to over $3.00 in 1981 (Table 2). Depending upon one's source of information, it cost between 22 and 35 cents to produce a pound of sucrose in Puerto Rico during 1979. During the same period, sucrose was priced between 12 and 15 cents per pound on the world market.

Today's sugarcane production operations in Puerto Rico cost approximately $600.00 per acre per year for "primavera" cane. The position taken by energy cane advocates is that yields can be more than doubled with production inputs costing only about 50% more than present operations, i.e., approximately $900.00 per acre per year. The decisive factor would be the management of production operations for maximum biomass rather than sugar. The higher tonnages realized from energy cane would also yield an appreciable quantity of sugar even though rendement values would be relatively low.

Since 1977, under sponsorship of the U.S. Department of Energy, CEER-UPR has conducted research on sugarcane and other tropical grasses managed specifically as energy crops (3,4, 5). Total dry matter is the decisive yield.

Parameters considered include varieties, row spacing, harvest frequency, fertilization, and water supply, rather than focusing on sugar or cattle feed. Averaged yields for three crops (the plant crop plus two ratoon crops) indicate that more than 80 tons of millable cane can be produced per acre per year (Table 3). Production costs are approximately $10.12 per ton of millable cane, or about $840.00 per acre per year (Table 4).

The energy cane studies in Puerto Rico are ongoing, however, results to date strongly suggest that the yield and cost data from Puerto Rico's commercial cane industry are not a true indicator of sugarcane’s potential as a local energy resource. Instead, they appear to be an artifact of government policy and other unfavorable circumstances for the continued planting of cane as a sugar crop in Puerto Rico.

2. Juice Quality and Sugar Yield

A significant feature of energy cane management is the continuous forcing of growth processes and crown expansion. There is no clear-cut period of growth decline, maturation, and natural ripening as seen in the final months of a well-managed sugar crop. A primary need of the cane plant at this time is to hydrolyze sucrose to invert sugars; these in turn serve as sources of carbon and energy for the structuring of new plant tissues. Relatively little sucrose accumulation is expected in the plant's storage tissues.

Analyses for three crops of energy cane verified the relatively low quality of these plants as a sugar crop. There were variations among crops, varieties, and row spacing, but sucrose content rarely exceeded 8.0 percent for any treatment. Average Brix and fiber values were about 12 to 14, and 16 to 18, respectively.

In computing sucrose yields on a per-acre basis (tons sugar/acre, or TSA), the poor quality of the cane was effectively compensated by the high tonnage of millable stems. The three-crop averages for standard and narrow row spacing were 6.04 and 5.13 tons sugar/acre, respectively.

(Table 5) - "Narrow row spacing is already eliminated as a practical consideration for Puerto Rico, so a super-yielding capability of about 6.0 Tons per Acre (TSA) is assumed for energy cane. It should be noted that a sucrose value of 6.0 tons per acre per year is more than double the yield attained by the Puerto Rico Sugar Corporation in recent years. A yield of 4.0 TSA would be considered good by present standards. It should also be noted that the 6.0 TSA value for energy cane refers to sugar in the field, not sugar that has been recovered in the mill. Low yields by the Puerto Rico Sugar Corporation's TW Variety NCo 310, a standard row spacing in the first ratoon crop, yielded the highest sucrose content to date at 10.26.

Low yields are less a reflection of sugar in the field than of inadequate harvest equipment and procedures used in recovering this sugar (15). For energy cane, it is believed that by combining a continuous whole-cane harvester (the Klass Model 1400, or a suitable modification of this machine) with revised management of harvest operations, a sucrose recovery of at least 70% will be obtained. If so, a final sugar value in excess of 4.0 TSA could be realized for energy cane. This would exceed by a significant margin the sucrose yields presently obtained by Puerto Rico's sugar industry.

MAXIMIZING ENERGY CANE BIOMASS

1. The Worst Case Scenario

The cost estimates presented in Table 4 represent a “worst case” scenario in which indicated costs are higher than an energy planter would reasonably expect to pay. There are several reasons for this:

(a) The assumed production operation is that of a private farm family having only 200 acres planted in energy cane. This family would need to hire major equipment items (cane planter, cane harvester, delivery trucks) together with licensed equipment operators.

(b) A private farmer will not ordinarily charge himself for “land rental” and “management” (items 1 and 14, Table 4). These two entries make up about 15% of the total production cost.

(c) No Federal credits or subsidies are considered for

This operation is a future alternative fuel enterprise in which one or more products are used as fuel substitutes. The energy planter could be eligible for some level of government support.

A fourth reason relates to the use of yield averages rather than practical yield trends. The energy cane yield shown in Table 4 is an average figure derived from several varieties, row spacings, and cropping years. An energy planter is a practical man, not a statistician; he will employ the superior variety, row spacing, and cropping interval for his region. In this instance, the superior variety is NCo 310, at standard row spacing, yielding 92 tons/acre of millable cane as opposed to the average figure of 83 tons/acre actually used in making the cost estimates.

A fifth reason was the omission of energy cane trash as a biomass yield component. In the cane sugar industry, the term "trash" refers to dead and leaf sheath tissues that have desiccated and detached from the sugarcane stem. During the course of a year, an appreciable quantity of trash will accumulate. This material is normally left in the field or eliminated entirely in a pre-harvest burning operation. Energy cane studies by CEER-UPR (6) indicate that significant tonnages of trash are produced by both sugarcane and Napier grass (Table 6). For variety PR 980, the trash component made up more than 23% of the total dry matter yield (Table 7).

In future energy cane enterprises, where cellulosic materials are a valued product, the trash will be harvested and credited to the total biomass yield. Moreover, because trash can be solar-dried and baled independently of cane-milling and bagasse drying operations, the "production" costs for the trash fraction could be significantly lower than the costs for millable cane.

2. The Best Case Scenario

As noted above, a revision of field management objectives is vitally important in attaining the maximum biomass yields from sugarcane. It is equally important to recognize that the experimental energy cane yields obtained to date are...

Only a fraction of the ultimate yield potential for energy ‘cane has been achieved. From 1977 to 1980, we were obliged to use the best conventional cane varieties then available in the sugar industry. These included varieties 3, 4, and 5. Each of these varieties had been bred for sugar planting rather than ‘energy planting. Even when using the most productive variety and row spacing, forcing growth with increased water and nutrient inputs, and crediting trash to the total yield, the maximum output would be around 90 millable tons per acre per year, or about 33 dry tons per acre per year. It is highly likely that the upper yield potential for energy cane lies in the order of 150 tons of millable cane and 50 tons of dry matter per acre per year.

The potential for yield improvement through hybridization of Saccharum is indeed enormous. The interspecific cross, which is known in a limited number of crop plants, is common among the extant species of Saccharum. The intergeneric cross, extremely rare among agricultural plants, is relatively common between Saccharum and other genera of tropical grasses. Thus, controlled crosses for increased yield proficiency can be made between Saccharum and such diverse genera as Sorghum, Erianthus, Miscanthus, Zea, Sclerostachya, Pennisetum, and Bambusa.

Within the genus Saccharum, the potential for yield improvement is similarly much greater than is generally recognized. Ironically, the genetic makeup of most commercial sugarcanes derives from only five or six gametes from among thousands within the genus Saccharum; other genera that will cross with Saccharum contribute nothing at all. Cane breeding programs still utilize germplasm from the ancient Indonesian variety “Kassoer,” and S. sinense germplasm from “Chunnee” and “Co 281.” Some breeding programs have no S. robustum germplasm from any source in their parental lines. Arceneaux notes that we have “barely scratched the surface” of the known S. spontaneum pool, while many authorities have complained of the sparseness of S. robustum and S. sinense.

Germplasm in modern interspecific hybrids. As aptly stated by Price (13), "The great diversity of wild plants that hybridize with sugarcane has been sparsely used.” In terms of production input costs, the yield gains expected via cane breeding should be largely free. For example, the production inputs already expended in attaining 83 tons of energy cane (Table 4) represent a kind of input plateau, beyond which additional expenditures would not be needed irrespective of the variety or species being grown. Critical inputs such as 400 pounds of elemental nitrogen per acre per year, or 4.5 acre feet of irrigation water per acre per year, are optimized factors to be utilized more effectively by future hybrid canes. Basic charges for seedbed preparation, labor, harvest and delivery operations, and a range of capital investments will change proportionately little as productivity increases from 80 to 150 tons per acre per year. Absolute yield increases are not the only improvements to be gained through Saccharum hybridization. Additional benefits could include: (a) Increased disease resistance; (b) increased tolerance to insect pests; (c) improved suitability for mechanical harvest; (d) improved suitability to extended harvest season; and (e) improved composition (higher sucrose and cellulose, lower ash and sulfur). There are potential benefits of even greater importance. Examples of these include an increased adaptability to marginal land and rainfall regimes, and an increased tolerance to cool climates.

YEAR-ROUND PRODUCTION

1. Multiple Species Management

Rico's current milling season spans a six-month period from January to June. Individual mills operate for only three to five months since there is insufficient cane to maintain a longer grinding season. Therefore, the long "downtime" for Puerto Rico's sugar mills results in an uneconomical use of some very costly capital investments. Similarly, a conventional sugar mill is a less than optimal source of feedstocks for biomass processing and utilization operations requiring year-round inputs.

An essential feature of energy cane management would be the extension of milling operations to about eight months. For Puerto Rico, this period would stretch from early December to early August. The increased yields of millable cane would enable the energy cane industry to operate year-round; in fact, cane could be ground almost continuously throughout the year if sufficient tonnages were available. However, in Puerto Rico, this would not be practical owing to the heavy rains which occur from August through November. Nonetheless, the sugar mill itself could be used continuously as a center for biomass drying, processing, storage, and electrical power production.

Integration of Maturity Profiles: As indicated elsewhere, sugarcane, like other herbaceous plants, must be harvested after a period of tissue maturation to maximize its dry matter yields. Energy cane will require at least 12 months between harvests to complete its tissue expansion and maturation processes. A broad range of planting and harvest dates must be planned and coordinated by field managers to ensure an eight-month supply of millable cane.

To assure a year-round input of mature biomass, energy cane production would be integrated with several other categories of tropical grasses. The energy planter would produce a series of short, intermediate, and long-rotation species with chronologically distinct maturation profiles. The profiles of three such species (Sordan, Napier grass, sugarcane) are graphically illustrated in Figure 1. Through this method, botanically mature biomass can be supplied year-round.

Biomass could be harvested at 2- to 3-month intervals for Sorghum, at 4 to 6-month intervals for Napier grass, and at 12- to 18-month intervals for energy cane (Table %).

8 (b) Solar Drying vs Mechanical Dewatering: As diagrammed schematically in Figure 2, energy cane would supply about 2/3 of the annual feedstock input for a proposed processing and utilization center for tropical biomass (17). This cane would be partially dewatered in a conventional mill tandem, and then further dehydrated by use of waste stack heat.

The remaining 1/3 of the incoming feedstock would consist of thin-stemmed, fibrous, non-sugar bearing tropical grasses. These would not be sent to the sugar mill for dewatering; rather, they would be solar-dried and baled in the field as part of the harvest operation. The baled material would have a moisture content of approximately 15 percent. It would be sent to the processing plant for storage and subsequent utilization during the 4-month period when no energy cane is being milled.

This biomass can be supplemented with a range of miscellaneous materials, i.e., weeds, roadside clippings, tree branches, crop residues, etc. (Figure 2).

There are many advantages of multiple species usage as biomass feedstocks: (a) The year-round sowing season is utilized to the maximum possible degree; (b) an energy planter can capitalize on the divergent growth habits of discrete tropical species; (c) solar drying can contribute as an economical means of water removal; (d) dry biomass is made available as an alternative fuel each day of the year; (e) sugar mill facilities are maintained in operation for a longer period of time; (f) employment is increased in field and factory operations; and (g) new jobs are created for rural suppliers of supplemental biomass (for off-season processing).

2. Alternative Products From Energy Cane

The energy cane concept was first proposed to the Commonwealth Government in 1979 (17), essentially as a sugar mill modification project as diagrammed in Figure 2. At that time

Puerto Rico is in growing need of two products from energy cane: (a) Fiber, as a boiler fuel substitute, and (b) fermentable solids as a feedstock for the local rum industry (18). Both products are more urgently needed today than they were in 1979.

(a) Fiber Alternatives: Several new options emerged during the past year for energy cane utilization. It is now unlikely that the fiber components would be burned directly in sugar mill furnaces for electrical power production. CEER-UPR has received repeated inquiries on the availability of tropical grasses for pelletized fuel manufacture. The same materials may have a role as backup fuels for Puerto Rico's future coal-fired power plants.

Because of new developments in cellulose conversion technology (19), bagasse or solar-dried tropical grasses might eventually serve as fermentation substrates. Of considerable interest to CEER-UPR are recent advances by Combustion Equipment Associates, Inc, in the development of powdered biomass fuels that can be burned as an oil substitute in existing oil furnaces. One CEA product, AGREFUEL, apparently can be manufactured from sugarcane bagasse and other tropical grasses.

CEER-UPR has partnered with CEA and the Battelle-Columbus Division in seeking Federal support for feasibility studies on the production of AGREFUEL from tropical grasses in Puerto Rico and Florida.

(b) Sucrose And Fermentable Solids: The total diversion of energy cane sugars to high-test molasses, as indicated in Figure 2, would be reconsidered in light of recent price increases for sucrose on the world market. Less than a year ago, sucrose was valued at only 14 cents per pound while local production costs exceeded 20 cents per pound. Under these circumstances, it was advisable to send the entire sucrose component of energy cane to the rum industry as a constituent of high-test molasses. As of October 1980, the value of sucrose has risen to 41 cents per pound. Under current circumstances, it could be profitable to recover part of the sucrose.

For local consumption or for sales abroad, this might be accomplished at minimum cost by retaining the first strike at the sugar factory, representing perhaps 60 percent of the sucrose contained in the raw juice. The remainder would go to the rum industry as a component of a moderately lower quality high-test molasses.

In summary, it is in the production of dry matter rather than sugars or nutritive components that the tropical grasses most naturally excel. An appropriate example of this is seen in the genus Saccharum. Of the six extant species of this genus, only one (S.offeinarum) has any appreciable aptitude for storing sugar, but the entire group of species is proficient in producing dry matter. Even the high-sugar yielding members of S. officinarum, given a warm climate, an adequate soil, and high inputs of water and nutrients, will opt to produce biomass rather than sugar.

Energy cane is sugarcane managed to maximize its growth potential rather than sugar. The U.S. Department of Energy has sponsored energy cane studies in Puerto Rico since 1977. Although this work is not complete, data trends for three crop years indicate that yields of both biomass and sugar can be increased appreciably over those obtained in recent years by the PR Sugar Corporation. Production costs were higher on a per-acre basis but lower per ton of cane, owing to nearly threefold increases in yield. Similarly, juice quality values for energy cane were lower than conventional sugarcane, but sugar yields per acre (TSA) were higher by virtue of the increased cane tonnages.

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Table 1 MILLABLE CANE PRODUCTION POTENTIALS

Parameter	Tons/Acre Year
World Average	22.6
Puerto Rico Ave. (1979)	28.0
FR Energy Cane (1980)	83.0
Estimated Theoretical	12.5

Without trash.

N. I. Janes (20), 1980.

Table 2 HOURLY WAGES IN PR CANE INDUSTRY

Year	average ($/hour)
1939	0.16
1957	0.35
1968	0.69
1977	2.10
1981	3.19

US Dept. of Labor, 1980.

Estimated,

Table 3 AVERAGE MILLABLE CANE YIELDS AT STANDARD & NARROW SPACING

Tons/Acre At Row Spacing crop
Plant 75.8
First Ratoon 92.0
Second Ratoon 84.0
Mean 83.9

12-month harvests. Average of Three varieties

Table 4 PRODUCTION COSTS FOR MILLABLE SUGARCANE MANAGED AS AN ENERGY CROP

Land Area: 200

"Acre Production Interval: 22 Months. Millable Cane Yield: 83 Short Tons/Acre; Total 16,600 Tons.

Cost Analysis (per site):
1. Land Rental, at $0.00/Acre: 30,000
2. Seedbed Preparation, at $15.00/Acre: 3,000
3. Water (500 Acre Feet at $25.00/Ft): 12,000
4. Water Application, at $48.00/Acre/Year: 9,600
5. Seed (For Plane Crop Plus Two Ratoon Crops), 1 Ton/Acre/Year at $15.00/Ton: 3,000
6. Fertilizer, at $80.00/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, 2 Man Year (2016 hours at $3.00/hr): 6,048
10. Cultivation, at $5.00/Acre: 2,000
11. Land Preparation & Maintenance (Pre- & Post-Harvest): 600
12. Delivery, at $2.78/Ton/3 Miles of Haul: 46,200

Subtotal: 152,706
20% of Subtotal: 15,275
Total: 168,023

Cost/Ton (168,023 ÷ 16,600) = 10.12
Cost/Acre (168,023 ÷ 200) = 840.15

This is as per contract no. DE-AS05-T0071. Labor which is not included in other costs is also considered."

Table 5: AVERAGE TONS SUCROSE/ACRE (TSA) AT STANDARD & NARROW SPACING

TSA, At Row Spacing:
- Crop 150 cm: Plant 5.38, First Ratoon 5.83, Second Ratoon 6.20, Mean 6.06
- 50 cm: Plant 4.29, First Ratoon 5.13, Second Ratoon 5.69, Mean 5.13

Note: Average of three varieties.

Table 6: TRASH YIELDS BY CANE AND NAPIER GRASS

Species Variety Dry Tons/Acre/Year:
- Cane PR 980: 6.81
- No 310: 4.27
- PR 64-1791: 4.27
- Napier Grass Merker: 3.20

Note: Average of three 12-month crops and two row spacings.

Table 7: TRASH YIELD AS % OF TOTAL CROP

Variety (% of Total):
- BR 980: 23.5
- No 310: 35.5
- PR 64-1791: 16.7
- Napier Grass: 8

Note: Average of three 12-month crops and two row spacings.

Table 8: CATEGORIES OF TROPICAL GRASSES FOR BIOMASS

Type | Maturation Time (Months) | Category | Species
- Short Rotation: 1-3 months, Sorghum
- Intermediate Rotation: 4-6 months, Napier Grass
- Long Rotation: 12-18 months, Sugarcane

Figure 1: Sugarcane DRY MATTER (X)

AGE OF SPECIES (WEEKS): 20, 30, 70, 30

Relative maturation profiles for Sorghum, Napier Grass, and Sugarcane over a time-course of one year. These plants... (text continues)

The text is representative of the short, intermediate, and long-rotation cropping categories, respectively.

Figure 2 FIELD OPERATIONS SOLAR-DRIED GRASSES

'75% GREEN CANE: 8 MONTHS 1000 TONS/DAY

COGENERATION 'SUR BAGASSE PLANT BIOMASS DRYER + BAGASSE: 8 MONTHS

HIGH-TEST MOLASSES

BIOMASS FUEL STORAGE

'CROP RESIDUES

'WOODY SPECIES

Integration of energy cane and other biomass sources to produce a year-round fuel supply for an industrial-scale cogeneration plant, plus high-test molasses for the production of rus. Basically modified sugar mill, major innovations found in Field Operations and the Biomass Dryer make possible the continuous operation.

SOIL AND WATER MANAGEMENT CONCEPTS FOR ENERGY CANE PLANTATIONS

Presented To The Symposium FUELS AND FEEDSTOCKS FROM TROPICAL BIOMASS

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SOIL AND WATER MANAGEMENT CONCEPTS FOR ENERGY CANE PLANTATIONS

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A SOIL AND WATER MANAGEMENT SYSTEM FOR ENERGY CANE

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Soil And Water Management Concepts For Energy Cane Plantations

William F. Allison, Head, UPR Department Of Agricultural Engineering, Mayaguez, Puerto Rico

ABSTRACT

WATER inputs approaching that of pan evaporation are essential to the growing of sugarcane for biomass production, as the crop growth responds directly with water inputs to this level. Excessive water retards growth, requiring surface and subsurface drainage along with good irrigation management. A soil-water management system must be compatible with the mechanical harvesting system which generally requires a smooth flat soil surface that can be accomplished by land forming and grading.

The text follows:

Followed by precise planting and cultivating. The present address is: Department of Agricultural Engineering, UPR Mayaguez Campus, Mayaguez.

INTRODUCTION

Sugarcane has, for centuries, been recognized for its large growth potential as well as for its high content of fermentable solids, including sucrose. Therefore, when the need arose to develop alternative fuels and chemical feedstocks to substitute for fossil fuels, sugarcane became one of the prime candidates. It has proven to be one of the superior candidates in climatic zones in which it's suited. However, water, along with a warm climate, is a basic need for the crop. The growth rate and production of sugarcane are directly related to water availability and management.

SUGARCANE RESPONSE TO WATER INPUTS

Within limits, the growth of sugarcane responds directly to soil water availability, requiring approximately 137 kg of water to produce one kg of dry matter, as presented in Figure 1. Generally, the plant is unable to survive in nature and produces its minimal crop when annual rainfall is less than 1000 mm (40 inches). As water inputs increase above minimal to equal pan evaporation, sugarcane growth increases in a direct relationship. As water availability begins to exceed pan evaporation, growth tends to decrease, as illustrated by Figure 2.

From Figure 2, one can conclude that water inputs equaling pan evaporation result in the highest levels of production, with higher rates of water inputs reducing production just as lower rates do. Therefore, when water is abundant and cheap, a water input equaling pan evaporation is ideal. However, when water supplies are in short supply or expensive, the proper input is about 86 percent of pan evaporation, since a reduction in water input of 14 percent only causes about a 5 percent reduction in growth.

Research has clearly shown that excess soil water reduces production from 30 to 60 percent, depending on the degree of water excess. Normally, sugarcane...

The text responds to the lowering of the water table to depths of 75 to 100 cm, with the greatest response occurring from lowering of the water table from the soil surface to 75 cm. Thus, to obtain high production of sugarcane, inputs of water should be in the order of 85 to 100 percent of pan evaporation during the growing period when the plant has a full leaf surface. There should be lesser inputs at crop initiation and toward maturity, as shown in Figure 3.

In lands having subsurface drainage problems, water tables should be held below 75 cm. When irrigation is the major source of water, then water tables should be maintained below 100 cm and preferably below 180 cm. This is because of soil salinity problems that are invariably associated with irrigated agriculture. Sugarcane, with its extensive root system, is able to fully utilize the water storage capacity of the soil and thus does not respond to light frequent applications of water as well as to larger quantities applied less frequently. This was very capably demonstrated by Evart in Hawaii (2). This ability to utilize the soil water storage capacity generally lowers the cost of irrigation because irrigation cost is normally associated with frequency.

THE NEED FOR IRRIGATION TO OPTIMIZE GROWTH

As previously discussed, sugarcane needs water constantly; however, few climates provide this constant input of water even in humid areas. This is because rainfall is generally seasonal, with dry periods exceeding 120 days being quite common. Usable water storage in the soil seldom exceeds 15 to 20 cm, with monthly demands of the crop being on the order of 8 to 17 cm, depending on the stage of growth and season of the year. As can be observed from Figure 3, the crop demand exceeds the probable rainfall of the south coastal plains of Puerto Rico every month of the 45 month top level, except for the first four-month period when the crop is initiated. Even this slight precipitation excess can be stored in the soil for future use or preferably utilized to leach the excess salts.

The text should read:

From the root zone that have accumulated from irrigation. Figure 3 clearly illustrates the need for irrigation to give suitable levels of production and to provide for the survival of the plant. The 3400 mm of rainfall over the 45 month crop cycle, if totally effective, would only produce about 126 tons of dry matter (56 tons/acre, or about 15 tons/acre year), and more likely only about 100 tons/ha. With adequate irrigation, the production should be on the order of 277 tons dry matter/ha. This represents an increase of 177 percent with an input of approximately 4070 mm (160 inches) of effective irrigation. Similar comparisons can be made of the other climatic zones of Puerto Rico, but the greatest need for irrigation is along the southern coastal plains from Guayama to Boquerón. However, during certain periods of the year, water deficiencies exist throughout the island.

3 THE NEED FOR DRAINAGE TO OPTIMIZE GROWTH

As has already been discussed, water is a necessary input to make sugarcane grow. However, too much water in the system has a depressing effect on production. Thus, both surface and subsurface drainage is required to adequately manage the water resource to optimize production. In one area severely affected by both surface and subsurface drainage near the mouth of the Anasco River, on the Island's west coast, this author supervised research and field trials in 1968-70. The production history of this area was in the order of 16 tons of dry matter/ha/year. With adequate surface drainage, the production was increased to 33 tons/ha/year, and with both surface and subsurface drainage the production rose to 56 tons dry matter/ha/year, an increase of some 40 tons/ha, with 23 tons attributed to subsurface drainage. Similar results were obtained on the north coast near Vega Baja.

A SOIL AND WATER MANAGEMENT SYSTEM FOR SUGARCANE AS A BIOMASS CROP

In the past, sugarcane has been managed for the production of sucrose. The factory merely controlled the quality of the feedstock delivered for processing. The miller demands raw...

The material should be high in sucrose, clean, and contain only enough fiber to provide energy for the process. Specifically, the miller requires only the mature portion of the stalk, free of silk, leaves, tops, and trash. As a biomass crop, the objectives include the production of fiber and fermentable solids, of which sucrose is only a part and not the controlling portion. Soil fertility, tilt, and structure, along with crop variety and management, are just as important as water in the growing process. However, the harvesting of the crop is also highly important. A silviculture management system for biomass production must be compatible with mechanical harvesting.

The mechanical harvesting of sugarcane for its sucrose is a formidable task, especially considering the traditional methods associated with past culture. As a biomass crop, mechanically harvesting the total above-ground portion of the crop becomes even more challenging, especially at first glance. Problems with mechanical harvesting are caused by field practices, such as furrowing and ditching, along with the separation of the tops, leaves, and other undesirable material from the stalk that contains the sucrose.

Furrows are particularly undesirable in the mechanical harvest for biomass production since they trap and hold plant material that may fall into the furrow, making harvest more difficult and dirty. The separation of extraneous material may not be required for biomass harvest as this material has an energy value that is greatly reduced when dropped on the ground and soil is picked up when harvesting this residue. The soil contributes to the ash content in the processing and utilization of this material.

Therefore, for biomass production, field surfaces need to be uniform and flat. This requires land forming and grading for irrigation and drainage. With land forming, irrigation can be easily accomplished with border irrigation, which just happens to be the most economical method of applying irrigation water. On land unsuitable for land forming, the center pivot or... [Text ends here]

The wheel line system of sprinkler irrigation may be used. Harvest is best accomplished when the top 45 cm of the soil is dry because harvest equipment can severely compact the soil and materially reduce the production of succeeding crops. Subsoiling can give temporary relief for soil compacted by the harvest equipment, provided the compacted soil is relatively dry. The subsoiling of wet soil may be of no benefit and can even create a more severe problem. Harvesting systems have been developed that can harvest the biomass energy cane provided they have been made as part of the planning and management process. Bringing the whole plant to the mill greatly simplifies field harvesting and in Puerto Rico would probably have little effect on mill performance. In many cases, harvesting the whole plant would probably enhance milling, as soil content could be almost eliminated by having flat field surfaces and never dropping the crop on the ground.

SUMMARY: Sugarcane growth responds to water and soil management. A fertile soil in good physical condition in Puerto Rico can produce approximately 27 tons of dry sugarcane biomass per month when provided with adequate water management. Irrigation is required throughout the island to maximize production, but the south coastal plains having the least rainfall give the highest returns.

5: Irrigation is necessary. The north, east, and west coastal plains require both surface and subsurface drainage to remove excess water. Biomass plantings need to facilitate mechanical harvesting which can be greatly enhanced by preparing flat uniform field surfaces.

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Kg of Water Used 150 100 ° 200 400 800 3000 3200 4400 Grams of Dry Matter Fig. 1. Dry matter produced in a controlled environment compared to water used. (Redrawn from Jen-Hiu Chang et al.).

Percent Relative Production 0.6 0.8 1.0 1.2 Relative Water Availability Fig. 2. The effect of water availability on cane production

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HYBRIDIZATION OF TROPICAL GRASSES FOR FUEL AND ALCOHOL Presented To The Symposium FUELS AND FEEDSTOCKS FROM TROPICAL BIOMASS (Caribe Hilton Hotel, San Juan, Puerto Rico November 24 and 25, 1980) Contributed By THE UPR CENTER FOR ENERGY AND ENVIRONMENT RESEARCH Biomass Division, Rio Piedras, Puerto Rico

HYBRIDIZATION OF TROPICAL GRASSES FOR FUEL AND ALCOHOL Table of Contents

HYBRIDIZATION OF TROPICAL GRASSES FOR FUEL AND ALCOHOL Featuring Chul! Plant Breeder And Director.

AES-UPR Sugarcane Breeding Program, Gurabo Substation, Puerto Rico.

ABSTRACT: In view of the increasing interest directed towards the tropical grasses as a renewable energy source for Puerto Rico, a review is presented of our initial exploration of the genetic potential for biomass in these grasses, with special reference to the genus Saccharum. The potential parental material, combinations, and the preliminary evaluation of performance for F1 progenies for biomass production rather than sugar are discussed. On the basis of available information, it is believed that there are extensive opportunities for the plant breeder to develop new biomass resources within Saccharum and the allied tropical grasses. These can be developed through breeding and selection specifically for the attributes of high yield for total dry matter and fermentable solids.

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TROPICAL GRASSES AS AN ENERGY CROP: Puerto Rico's dependence on imported fossil energy has spurred local interest in energy resources that are both renewable and domestic. Among energy alternatives for Puerto Rico, the U.S. National Academy of Sciences has identified biomass as the most important renewable energy source for the island’s intermediate future (17). If managed as a major agricultural activity, NAS estimates that up to 10 percent of Puerto Rico's electricity could derive from biomass fuel. CCEER-UPR estimates are considerably higher (20).

1. Biomass Potentials: Species such as sugar beet, cassava, maize, sweet sorghum, and tropical grasses have been recently considered as candidate crops for the production of boiler fuels and alcohol (2,6,10,11,12,15). However, considering the island's needs, climate, and historical background, the tropical grasses likely have the largest potential as an energy crop for Puerto Rico. Within this group of species, sugarcane is widely reputed to be a relatively efficient collector of solar energy. It can perform stellar solar energy conversion.

Collector operates on a year-round basis in the tropics and seasonally in subtropical regions. Tropical grasses are well qualified to produce biomass. The maximum growth rate (dry matter production) for C3 plants has been placed at 34 to 39 g/m2/day, while C4 species such as sugarcane, corn, and sorghum can produce up to 54 g/m2/day. Thompson estimates that irrigated sugarcane should have a photosynthetic efficiency of 1.7 percent; rainfed cane in South Africa has an efficiency of about 1.1 percent. These figures correspond roughly to 11.0 and 7.5 g dry matter/m2 day, respectively.

DOE-sponsored studies in Puerto Rico revealed an average DM yield of 21.5 g/m2/day on a year-round basis, and 27.1 g/m2/day on a seasonal basis (180 days). The theoretical maximum yield for sugarcane has been estimated in the order of 280 millable tons/ha/year, or about 113 tons/acre/year. Workers in Puerto Rico attained 92 green tons cane/acre/year, with the first ratoon crop of conventional sugarcane varieties managed for total growth. It is believed that yields in the order of 150 green tons/acre/year could be commonplace if certain breakthroughs are achieved in the breeding technology for Saccharum species.

The Puerto Rico sugar industry is currently producing about 28 green tons/acre/year as an island-wide average. The hybrid tropical grasses Sordan 70A and Sordan 77 are leading candidates for short-rotation energy crops in Puerto Rico. Each was produced from sorghum-Sudan grass parents. Pennisetum sp. (pearl millet and napier hybrid) are superior intermediate rotation species. Such grasses under management as solar-dried forages could fill the timeframe when sugarcane bagasse is not available as a fuel or cellulose feedstock in Puerto Rico.

Sorghum x Sudan grass hybrids have also been produced by the Dekalb Company, and several appear to be more tolerant of arid conditions than Sordan 70 and Sordan 77. Breeding studies in Puerto Rico have utilized a male-sterile Rhodesian.

Sudar-grass has been used to develop superior F1 hybrids. Some of these have produced more than 20,000 kg/ha of dry matter in 140 days (14). These local hybrids should be locally screened as candidates for short-rotation energy cropping.

2. Alcohol Potentials
Sweet sorghum, as an alcohol source, has been evaluated by DOE contractors in the U.S mainland (12). Total U.S. production from this plant has been estimated to be in the order of 25 to 30 billion liters of ethanol per year, at a cost of $0.32 per liter, by the year 2000. For ethanol production from sugarcane, yield estimates amounting to 3,700 to 15,000 liters/ha have been published (4,11). A net energy ratio (energy output/energy input) ranging from 1.9 to 2.7 has been reported for rainfed and irrigated regions, respectively, in South Africa (15). As discussed by Samuels (19), alcohol

from sugarcane in Puerto Rico is typically depicted in terms of rum production rather than total ethanol per acre or ethanol per ton of cane. Rum distillers usually utilize "blackstrap" molasses (from which part of the sucrose has been removed) for this purpose, but they also use "high-test" molasses (molasses from which sucrose has not been removed). The composition of molasses can vary considerably, depending on the variety of cane planted and the management it has received from the time of planting until delivery at the sugar mill. One gallon of blackstrap molasses contains approximately 6.8 pounds of sucrose and will yield about 0.75 proof gallons of rum. On average, sugarcane in Puerto Rico yields about 6.0 gallons of blackstrap molasses and 17.6 gallons of high-test molasses per ton of cane (19). One gallon of high-test molasses will yield around 1.13 proof gallons of rum.

3. Genetic Potential for Biomass in Saccharum

The genetic potential of the genus Saccharum as an energy crop is substantial, but for the most part, this potential remains unexplored (2,6,10). In Puerto Rico, as in other places, the breeding of Saccharum with fuel and fermentable solids as the key objectives has not

The following text has been corrected for spelling mistakes, grammar and punctuation:

1. Initial Evaluation of Saccharum spontaneum: Our first attempt to identify candidate clones for biomass production rather than sugar was made with original S. spontaneum clones and S. spontaneum hybrids. These candidates were derived from F1, BC1, and BC2 generations imported into Puerto Rico from USDA collections during the mid-1970s. The importations were made by the AES-UPR Sugarcane Breeding Program in an effort to broaden the genetic base of our local germplasm pool (6). As a result, the S. spontaneum hybrids US 67-22-2 (BC2), B 70701 (F1), SES 231 (S. spont.), and an unknown (wild) S. spontaneum hybrid were identified as having exceptional promise as biomass producers (3).

Fermentable solids. It should be noted that when sufficiently high tonnages of millable cane are harvested, the per acre yield of sugars can be very appreciable even from cane having otherwise low juice quality (18). Other promising clones include US 76-7 and US 76-82, each a second back cross progeny of the S. spontaneum parent US 56-15-8 (Table 1). The latter clone, a Thailand S. spontaneum, has already demonstrated exceptional growth potential and is a source of genetic material for breeding high-tonnage cane (9). US 56-15-8 was imported into Puerto Rico during September of 1980, together with other canes viewed as potential breeding stock for developing high-biomass yielding hybrids. Out of nine intergeneric hybrids imported into Puerto Rico during October of 1978 (6), only US 61-666 (Saccharum x Sorgo rex) and US 6437 (Saccharum x Selerostachya fusca) have demonstrated good biomass potential in small field observation plots. These are continuing under survey as biomass resources in 20° x 20° plots at the AES-UPR Gurabo Substation.

Hybridization Program for Saccharum 1, 1978 Breeding Season

In view of an enormous, untapped genetic potential in the genus Saccharum (2,6,10), a limited hybridization program for biomass was initiated by the author during the 1978 breeding season. This work is being performed in conjunction with the AES-UPR Sugarcane Breeding Program. Three crosses were performed in which biomass rather than sugar was the primary objective. In the first cross (US 67.222 x B 70701), both parents are regarded as superior biomass producers in their own right. Two additional crosses were designed to incorporate germplasm of an extremely vigorous S. spontaneum hybrid into high-yield and high-juice quality canes previously developed by the AES breeding program (7). The S. spontaneum hybrid is an early-flowering cane found in the wild near Piedras and Bayamon. It served as the male parent in these crosses. The two female parents are mid- to late-season flowering, but some synchronization of

Tasseling was attained by using the "cut back" method on select stands of the early-flowering male parent (3). The highest selection rate (16.3%) was obtained from the cross PR 67-245 x S. spontaneum hybrid (Table 2). The Brix, fiber, and sucrose values were determined for each of fourteen F hybrid progenies and their parents using the pot ratio method (Table 3). Samples consisted of five whole canes from each hybrid. Within this progeny group, Brix values ranged from 8.32 to 12.63, and fiber ranged from 17.7 to 25%. By contrast, the parental clones (PR 67-245 and the S. spont. hybrid) indicated Brix values of 16.25 and 4.68, respectively, and fiber contents of 13.1% and 40.14, respectively. The highest sucrose content (rendement) for the same 14 progeny was 9.16%, for the selection PR 794.2. The lowest sucrose content was 4.87%, recorded for PR 79-4-1 (Table 3). These initial results seemed to indicate that fairly good juice quality could accompany the high fiber and vigorous growth expected of first generation (F) hybrids of S. spontaneum. F progenies of the cross US 6722-2 x B 70701 indicated a remarkably vigorous growth performance plus a high number of stems/seedling. A majority were characterized by long internodes, a trait apparently inherited from the male parent B 70701. In order to accelerate the evaluation process leading to better selections, twenty-four of some 47 selected hybrids, along with their parents, were planted in a field-plot trial at the Gurabo Substation during May of 1980. A partially balanced incomplete block design with three replications was employed. Experimental plots consisted of single rows, 10 feet in length and spaced five feet apart. A 15-5-10 fertilizer ration was applied at the rate of 600 lbs/acre to each plot at the time of planting. Samples consisted of 10 stems harvested from each plot at approximately five months after planting. Stem length and diameter measurements were recorded together with total green weights. The plant number was calculated on a per hectare basis.

The basis was computed from the total stem counts for the three plots of each progeny. Stem volumes per hectare were then computed from available data (Table 4). In terms of stalk volume per hectare, the selection PR 79-1-10 exceeded that of the female parent (US 67-22-2) by approximately 90 percent (Table 4). This value derives from both high stem counts and an exceptional length of stems. An additional five F1 hybrids exceeded the female parent in stem volume by more than 40 percent. This seems to suggest that the cross US 67-22-2 x B 70701 has a high probability of producing offspring with outstanding growth potential.

2. The 1979 Breeding Season

Additional crosses were performed during the 1979 breeding season in which biomass was the primary objective (Table 5). All crosses but one were designed to maximize fiber and fermentable solids. Three clones served as male parents: US 67-22-2, 87 NG 54 (S.robustum), and the wild S spontaneum hybrid. They were crossed with a series of high-yielding, good to high juice quality canes developed in Puerto Rico or introduced here by the AES-UPR sugarcane breeding program.

Unfortunately, certain crosses of considerable interest (NCo 310 x US 67-22-2, NCo 310 x B

70701, and B 70701 x 57 NG 4) failed to produce sufficient viable seed. These crosses will be attempted again during the 1980 breeding season. Judging from the initial growth and tillering performances of F1 progeny, the crosses PR 980 x S. spontaneum hybrid, PR 67-1070 x S. spontaneum hybrid, and PR 68.355 x 57 NG 54 all appear to be potentially good sources of new genotypes favoring the biomass attribute (Table 5).

The clone US 67-22-2, serving as a male parent, was hybridized with a series of high-quality canes developed locally or abroad as conventional sugar varieties. Since US 67-22-2 is an early-flowering cane, crossing with intermediate- and late-flowering canes was accomplished by a leaf-trimming technique developed to synchronize the period of tassel emergence (8). The apparent effect of this method is to delay tasseling by

Restricting the production or translocation of an unknown flowering hormone produced in the sugarcane canopy, a large number of selections from these crosses are presently under evaluation in field-plot trials at four AES-UPR substations.

CONCLUSION: Only a very limited hybridization program for high biomass has been attempted to date in Puerto Rico. Nonetheless, in view of certain highly promising selections that have already emerged, and from seedling performance trends with very limited amounts of seed, it is safe to state that a whole range of new opportunities await the plant breeder seeking superior biomass-yielding hybrids in the genus Saccharum. It is very probable that these opportunities extend to the "Allied" tropical grass, and to other genera of tropical grasses that will cross with Saccharum but have never been examined as energy crops per se.

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The following section of the text is unclear and seems to be a combination of unrelated words and symbols. It might be an error or code that needs decoding.

Table? (Progress for Biomass in Saccharum During the 1978 Breeding Season) AES-UPR Gurabo Substation. Seedlings First Selection, Parentage Planted Selections Rate (3) __ objectives PRIS (US 6720-2 as a 3 Biomass and x Fermentable Solids 3 PR 79-2 PR 6502 Bocas and * Fermentable Solids Sop. Types RTE PR 67-245 a2 a 16.3 Biomass and * Fermentable Solids 8. op. hybrid

Table 3. (Qualitative Features of Fourteen Progeny from a Cross Between a Wild S. Spontaneum Hybrid (Male Parent) and the Commercial Hybrid PR 67-265 Progeny. Course, Fiber, and Sucrose Levels for each Progeny, as indicated by the following numbers.

Table 6. (Results of the Book, Predicted Mouse-Derived Case of the 6-245 Rose. Details are unclear due to the incomprehensible text.)

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Puerto Rico is highly dependent on imports, relying on them for 99 percent of its energy and 88 percent of the molasses used for its rum production. The need for alternatives to imported petroleum is urgent. One such alternative is "energy cane," a concept of sugarcane management developed by the CEER-UPR Biomass Division, sponsored by the U.S. Department of Energy. Energy cane is sugarcane managed for the maximum yield of combustible materials rather than sugar.

One method to evaluate such an alternative is to determine its "energy balance," that is, the energy value of other fuel forms replaced, particularly fuel imports, less the energy value of inputs. These inputs could be energy products themselves or products like machinery which required energy in their manufacture. This paper concludes that, despite some conceptual difficulties with energy balances, they are a useful first-stage screening device for new energy systems.

Energy balances are estimated for two alternative uses of energy cane. In Alternative A, cane is milled to produce bagasse and high-test molasses (HTM) for the rum industry. The bagasse, along with cane "trash," is dried and burned to supply the mill and other plants with steam. The energy output/input ratio is estimated at 11.4 when bagasse consumed by the mill is excluded from both inputs and outputs. When included, the ratio is 4.0.

In Alternative B, the HTM is converted to ethanol for gasohol. The ethanol ratio is 1.8, and the overall ratio is 2.9:1.

Current events such as the war between Iran and Iraq, the hostages held by Iran, the renewal of fighting in Lebanon, and other Middle East developments of the past few years highlight Puerto Rico's risk in depending on imports for 99% of its energy and 88% of the molasses used in the manufacture of rum, which supplies about one seventh of the recurring revenues of the Commonwealth Government.

ENERGY BALANCES FOR FUEL AND ALCOHOL FROM PUERTO RICO ENERGY CANE

INTRODUCTION

The current geopolitical tensions in the Middle East underline Puerto Rico's dependence on imports for 99% of its energy and 88% of the molasses used in the production of rum. This dependency represents a significant risk, as rum production contributes to about one seventh of the recurring revenues of the Commonwealth Government.

In the last few years, under the leadership of the Center for Energy and Environment Research of the University of Puerto Rico and primarily with funds from the Department of Energy, a great deal of work has been done to develop alternatives to imported petroleum fuels. Some of the most successful efforts are the result of work by CEER’s Biomass Division. This division has developed a number of energy crops which appear to be ready for commercial production and are definitely competitive with petroleum fuels. One of these crops is "energy cane," sugar cane chosen and managed, not for nutritive values, but for its yield per acre of combustible solids. As shown by Table 2, page 19, impressive yields have been attained.

Unfortunately, the yield record of Puerto Rican agriculture has been fairly miserable for years, so it is hard for those not familiar with the Division's work to believe the results. Also, the numerous controversies over the energy balances of corn-based ethanol for gasohol have created a large number of doubting Thomases as to the net energy benefits available from energy crops.

This paper, then, explores the conceptual problems of energy balances, describes a system for producing biomass for direct combustion, and high-test molasses for rum (Alternative A) or for ethanol for gasohol (Alternative B). The energy balances are found to be significantly favorable in all cases, but policy questions about the use of molasses are raised. Energy output/input ratios of 40 are estimated for alternative A and 2.9 for alternative B, including bagasse consumed in process as both input and output (see Table 6).

2. Anyone who sets out to estimate an energy balance for all but the simplest processes will find the mathematics fairly straightforward. But the underlying concepts are full of hidden assumptions and other intellectual booby traps. Indeed, the estimator will be somewhat in the position of an economist who tries to calculate the real economic situation of an internationally

The text is associated with a funded organization that operates in numerous countries, each with distinct currencies, consumption patterns, price structures, and inflation rates. The organization's BIUs, like the Special Drawing Rights of the International Monetary Fund, only appear to be comparable. Hence, it is necessary to discuss some methodological complexities prior to beginning the task.

1. All BTUs Are Not Created Equal: It is a well-established fact in the industry that different fuels possess distinct characteristics in terms of combustion, control, convenience, pollution, etc. These fuels are not easily substitutable for a specific use, especially at short notice. Even when substitution is viable, it often demands a time and cost-intensive process of equipment conversion or replacement. Furthermore, a particular fuel such as natural gas may be favoured over a wide range of prices due to qualities other than its calorific content. It might even require a law, regulation, or severe supplier issues to persuade a manufacturer to make a switch. This applies to fuels of different origins (e.g., biomass fuels vs. petroleum fuels) and fuels of the same origin, where one is transformed into a higher form (e.g., bagasse to fuel pellets). In summary, BTUs, like prices, only tell part of the story. Nevertheless, many researchers casually compare fuel values or quote costs per BTU based on high heating values (HHV), as if different fuels were interchangeable boxes of laundry soap purchased from a supermarket shelf.

In her review of recent biomass energy cost literature, Kathryn A. Zeimetz noted just over a year ago, "None of the estimates include the cost of conversion from chemical energy in unprocessed biomass to a more usable energy source...". A significant flaw is that in current research, the estimates of the costs of, and the land needed for, biomass production per energy unit are calculated on the total energy content (HHV) of the harvested biomass. Therefore, if

For energy values to be comparable, different fuels must ultimately be expressed in terms of some common denominator such as steam of a given psi, gasoline equivalents, electricity, or the fuel whose imports will be reduced by the proposed alternative energy source. Sometimes, of course, the practical difficulties will be insurmountable, but at least the attempt should be made.

The foregoing applies to energy balances as well, even though they can be expressed in dimensionless terms, i.e., in terms of energy ratios. This is because the production of energy, or its transformation to a higher form, each require energy as an input. And, in many cases, the energy input will consist of several fuels other than the one which constitutes the output.

For example, in the case we will study, diesel fuel, among others, will be used to produce energy cane on the farm. In turn, energy cane will be used to produce bagasse in the cane mill and also high-test molasses (HTM). The bagasse serves as fuel for the mill and possibly the distillery, where the HTM is turned into still another fuel, ethanol.

2. Energy Balances Are Neither Eternal Nor Universal

Outside of residential use, energy is normally but one of many inputs to the production of goods and services, albeit an important one. Thus, a given energy balance is a function of such factors as costs and prices, laws and regulations, markets, operating and maintenance practices, past investment decisions, and technology, not just immutable physical laws.

In the case of biomass energy facilities, we must add agricultural patterns, climate, rainfall, and soil conditions. Since most of these factors change from time to time, and some may be highly site-specific, a given energy balance may not "travel well" nor be valid for your children.

3. Define Your Processes

Precisely because of the first two difficulties, one should specify the critical aspects of the manufacturing and combustion processes for which a given energy balance is calculated. This serves as an illustration of the complexities involved.

Involved, see Table 1 on page 18, which shows possible relations between bagasse moisture content and boiler efficiency, based on Hawaiian experience. Moreover, in translating increased output of one fuel into savings in the use of another, one must also take account of the different combustion systems which may be involved in each case.

For example, if one ton of bagasse with 3% sugar and 30% moisture has an HEV of 11,540,000 BTU/short ton by Hessey's formula, it will not substitute for No. 6 fuel oil with an HUV of 6,216,000 BTU per barrel in accordance with the ratio 11,540/6,216 = 1.86 barrels per ton.

Assume it is possible to burn the bagasse in a cane mill boiler at 74% efficiency, and the fuel oil, in a utility boiler, at 85% efficiency. Ignoring psig differentials, on a steam equivalent basis, the correct ratio would be 1.62, or about 13% less. On an electricity equivalent basis, due to differences in generating facilities, the ratio would be even lower.

The problem is not solved by resorting to comparisons based on low heat values, instead of high ones. It is true that low heat values assume that the water vapor, formed by the oxidation of free hydrogen in the fuel, goes up the stack, rather than condensing and releasing useful heat. This is often realistic. However, what if stack gases are used for drying? Moreover, in any case, there are other causes of heat losses in boilers. These include moisture in the atmosphere, moisture in the fuel, how tightly the latter is bound, incomplete combustion, variations in fuel composition and moisture content, and the stack gas ambient temperature differential.

Moreover, if electricity is the common denominator, one must take account of energy losses in the turbine and generator stages. In addition, scale effects are important. An energy balance carefully estimated for one size of plant may not be valid for one 25% smaller or 25% larger. Also, in dealing with proposed facilities, one must be aware of possible differences between standalone operations.

Facilities and those operated in tandem with co-product processors differentiate between grass-roots construction and the conversion or upgrading of existing facilities (3). In summary, the safest procedure appears to be defining the combustion system, from fuel to common denominator or end product. If system efficiency is not easily approximated, it's recommended to estimate all significant sources of energy loss, one by one, starting with the HAV of the boiler charge. The latter is often used as both an energy value and as the denominator in calculating efficiency. It's important to note that the entire facility, which includes the combustion system, must also be defined. Boiler fuel is rarely the only energy input to an energy-producing or transforming system. LU utny = 8,345 - 22.14 - 83.63W, where S = sucrose % and W = moisture % (in BTU/lb). See (2), Figure 1, page 25.

Section 4. What Are Energy Inputs? Should we consider only energy inputs consumed in the form of energy? What about the energy used to transport inputs to the facility under study, or the energy consumed in the fabrication of buildings, structures, and equipment used by the facility, or the energy consumed by the employees of the facility in their work? How should these inputs be measured? There are no straightforward answers to this issue (4). One could indefinitely trace back product and energy flows, in a form of infinite regress. Fortunately, "one remove" (direct energy consumption by inputs) is usually sufficient to capture significant energy inputs of the indirect form. However, this is not a trivial question, for what inputs to include and what not helps to define the boundary between the thermodynamic system and its surroundings. It is this thermodynamic system which truly determines the energy balance, rather than the battery limits of the alternate fuel facility.

Section 5. What Are Energy Outputs? Typically, energy outputs are considered to be either (a) salable energy products or (b) these, plus other products which

Substitute for purchased fuels. However, waste heat (such as stack gases) used in the facility, or even heat losses in the combustion system, could also be considered output which the facility "manufactures" and "sells" to itself. There are no rules engraved in stone, however, the energy balance and the energy ratio will obviously be different, depending on the method used.

6. Externalities

It is well known, from cost-benefit analysis and environmental impact studies, that most human activities have effects (both favorable and unfavorable) which are not captured by or reflected in their accounting, costing, pricing or statistical systems. Indeed, many of these effects can only be expressed in energy or monetary terms crudely, if at all. To the extent that an alternative fuel facility has an impact outside the "system," defined for purposes of the energy balance, or changes the "energy behavior" of other facilities and organizations, we should try to take these effects into account. Such externalities may be particularly critical in calculating the energy balance for gasohol systems.

7. What Are We Trying To Optimize?

An energy balance is a "snapshot" of only one aspect of a human activity. It is not complete, any more than it is eternal or universal. Nevertheless, it is a snapshot of a very important aspect. How then to take it into account? What is an energy balance good for? If you are a "one issue" person and that issue is energy conservation, the answer is obvious. However, most people and most countries have multiple objectives which, in an imperfect world, can only be partly attained. Thus, we are forced to estimate and evaluate trade-offs between more of this, and less of that. Given the state of the analytical arts, the best way to do this as a practical (not an ideological) matter, would seem to be to optimize the economics of a system, subject to energy, environmental and other constraints. However, this does not relegate energy balances to the sidelines. They can provide a useful screening device for...

"Determining the classes of facilities to be studied by the optimizing process is essential. Regardless of what we optimize, we still must define what it is we want to achieve with energy. What is to be our principal criterion for separating energy sheep from energy goats? Is it to save total energy, decrease energy imports, increase energy efficiency, decentralize society—or some combination thereof? If we are primarily concerned about the security of supply, and I believe Puerto Rico should be, then we would emphasize the second goal. However, we should acknowledge that imported BTUs saved have a greater social and economic value than an equal number of domestic BTUs consumed. Also, we need to understand that businessmen do not necessarily perceive a new fuel made locally by a new firm with a new technology as "more secure" than No. 6 fuel oil made from imported crude oil.

8. The Allocation Problem

Energy production from biomass frequently results in multiple products (some non-energy) from integral processes. Many costs and inputs, including energy, may therefore be both joint and variable with respect to outputs.

9. Standard processes exist for their manufacture. Thus, any errors in estimating the energy value of the inputs to the agricultural sector are of small consequence in the energy balance of the entire system.

SYSTEM DESCRIPTION: CANE MILL PHASE

In this phase, we hypothesize a conventional Puerto Rican cane mill modified to burn efficiently 100% bagasse dried by flue gases to 30% moisture. The mill is assumed to grind 5,000 green tons of millable cane per day, six days a week, eight months a year. Such a facility would require more than 12,000 planted acres of energy cane, or somewhat less than 15,000 acres of farmland, in the supporting agricultural phase. The materials balance and flows for the biomass energy system through the cane mill are shown in Figure 1, page 25. An inspection of this figure shows two obvious inputs, "loose trash recovery" and "millable cane." There are also three obvious products, the loose trash as a source."

In terms of energy sales, bagasse is used as a source, along with HTM. But what about bagasse for process heat? Since we have the option to convert this material into energy sales and purchase No. 6 fuel oil to supply process heat, we may consider it a product. In this case, we should also consider it as an input. Immediately, three challenges arise: What is an input? What is an output? And how do we allocate the joint inputs of energy?

As previously, we evaluate outputs based on the energy value of the displaced No. 6 fuel oil, using Hessey's formula and the same assumptions, except that trash is assumed to have zero sugar and 15% moisture, serving as boiler feed. Note that steam is the common denominator. If the excess steam cannot be sold or used economically, or if it has to be converted to electricity, the energy balance, however calculated, would be less favorable. This argument supports further processing of excess biomass before burning.

Let's first consider Alternative (A), where all HTM is used for rum production. There are several ways we could allocate the joint energy inputs; but to keep things simple, let's always allocate them in proportion to the oven-dry weight of the outputs, whatever they may be. Still, we can consider two allocation methods.

According to the first method, output consumed for process heat is excluded from both inputs and outputs. Agricultural energy inputs are allocated by oven-dry weight among the three sources of external sales: loose trash, bagasse for energy sales, and HTM.

According to the second method, the bagasse used for waste heat is both an input and an output. Agricultural inputs must be allocated among all combustibles. Process heat is allocated between bagasse and HTM.

These two methods (and potentially others) result in different co-energy balances and energy ratios, as shown in Table 4 on page 21. If we were to include waste heat used in drying the bagasse as an additional input and output, the energy balance would be affected.

The balance would "undoubtedly increase over method No. 2, while the energy ratio would decrease again. In the case of Table 4, both the energy ratio and the volume of inputs turn out to be quite sensitive to the definition of inputs and outputs. This suggests that one should be very careful about comparing ratios for different facilities, especially where they have been executed by different economies. Even where the estimates of inputs and outputs are carefully done, the ratio may be very sensitive to changes in the scale of operations. More meaningful would seem to be the net energy balance as compared with some resource commitment. For example, Table 4 implies that there will be a reduction in crude oil imports of 30 to 34 barrels per year, for every acre planted to energy cane. (The assumed alternative to biomass energy is No.6 fuel oil, but we further assume that a reduction in one barrel of this product backs out one barrel of crude. Obviously, because of refinery balances, there are limits to such an assumption in the short run). Alternatively, we might compare the net energy balance with the initial data outlays required to establish the biomass energy system as a going concern. As for allocation methods, the author is inclined to those which treat energy produced and consumed in the same facility as both an input and an output, whenever the alternative is to purchase energy. Otherwise, an essential input will not be treated consistently over time or over facilities. However, it must be recognized that our own energy use or efforts to use waste heat may lower the energy ratio, even when they increase the balance, as happened in Table 4. If people are misled by this, it will tend to penalize efforts for energy conservation and efficiency. One may even conceive of cases where use of our own energy or waste heat may lead to reduction in the balance, in exchange for savings in cost and/or an increase in the security of supply, the stability of costs, etc. Once again, we are back to trade-offs. Regardless of these difficulties, Alternative (A) seems to be a very...

"Profitable" operation from an energy point of view. Moreover, the energy balance and ratio of this alternative do not reflect two important energy benefits from this project. The first is the increased security of supply which comes from substituting a domestic source of energy for a foreign one. The second is the fact that the energy balance in terms of imported fuels is even better than shown by Table 4. All of the outputs displace imported petroleum, but a good portion of the agricultural energy inputs probably represent the use of oil produced in the US.

With regard to Alternative (B), another allocation method comes to mind. Since all products are now energy products, we may value them in terms of the barrels of imported crude which they back out of the economy, assuming that one barrel of product is equivalent to one barrel of crude oil. In the case of the HTM, it is valued on the basis that one gallon of HTM will yield about 0.64 gallon of ethanol, calculated from reference (8), and one gallon of ethanol will directly replace 0.8 gallon of gasoline. In the case of the other products, they are valued in terms of No. 6 fuel oil equivalents, as before, divided by 6.216 million BTUs per barrel. Inputs are then allocated in accordance with the appropriate crude oil equivalents.

The results of allocation method No.3 are shown in Table 5. For the energy obtained by the direct combustion of biomass, the results are more or less like those obtained from method No. 2 (See Table 4). However, we have balanced the first two phases of Alternative (B) in the same way as we will balance the third, distillery phase. Also, we know how many BTUs of input we must "carry forward" to this latter phase. Finally, the balance for ethanol in Table 5 gives us a preliminary notion of what the final balance will be for that product.

System Description: Distillery Phase

The design of the fermentation and distillation processes for ethanol, and the choice of fuel for the distillery, are perhaps the most

Critical factors in determining the energy balance for a biofuel system are due to the wide variation in energy inputs that are possible. This variation, plus additional variation induced by differences in feedstocks, byproducts, and byproduct energy accounting, explains most of the wide differences in energy ratios for gasohol systems.

As previously noted, these differences have generated considerable controversy and confusion. According to the Office of Economic Assessment of the U.S Congress, an energy-efficient, stand-alone corn ethanol for gasohol distillery can consume the energy equivalent of half a gallon of gasoline in order to produce a gallon of ethanol, which directly replaces 0.8 gallon of gasoline as an additive in gasoline.

For these and other reasons, in some cases, it may not be possible to achieve a favorable energy balance for a gasohol energy system. And to achieve a favorable balance in terms of imported energy alone, it may be necessary to approve laws which (a) prohibit the use of imported fuels in ethanol distilleries for gasohol, and (b) require the use of lower octane gasoline for blending into ethanol.

Following is a range of estimates as to the BTUs consumed in operating an ethanol distillery, per gallon of ethanol produced (from molasses, except as noted):

Source BTUs/Gal
Chambers, et al. (11) 141,500
Hopkinson & Day (10) 43,400
Missehorn (12) Conventional Process 36,600—46,600
Two-Pressure Distillation 25,000
OTA com (3) Natural Gas & Waste Heat 29,250
Petroleum Fuels -46,800—70,200
Coal 50,000—70,000
Rodriguez-Torres & Horta (8) 108,000
Ofoti & Stout (13) 68,400
Schroeder Process (corn (14)) 31,900

Data from Table 2 are for distillation, fermentation, and heating only.

Now, accountants, please note that all BTUs are not equal. Ideally, Table 5 (and Table 6) should be expressed entirely in crude oil equivalents. BTUs of No. 6 are retained to facilitate comparison with Table 4.

Those who must prepare monthly financial statements have invented various ingenious allocation techniques to deal with such situations. Unfortunately, the only way to optimize such processes economically is to ignore the allocation methods and maximize the total contribution of all products to joint costs, after deducting from revenues those costs associated with one product exclusively. Under the circumstances, any allocation of costs is arbitrary and liable to be suboptimal, no matter how reasonable the particular allocation method is. An analogous optimization procedure could be defined in energy terms. However, it would prevent us from calculating a meaningful energy balance for an individual product. Thus, we must allocate joint energy inputs among outputs in one of several rational ways, with the understanding that what we are doing is somewhat arbitrary and should not be used for optimization of the overall system.

SYSTEM DESCRIPTION: AGRICULTURAL PHASE

We shall now describe the agricultural phase of a system to produce biomass energy products in Puerto Rico from energy cane. The primary objective of this system is to reduce our dependence on imported crude oil. A secondary objective is to reduce our dependence on imported molasses for our rum industry. Two alternatives are considered: (A) The direct combustion of biomass energy products, with the HTM being used for rum; and (B) with the HTM used to manufacture ethanol for alcohol. This is not a complete biomass energy system. As indicated elsewhere, it should be complemented by intermediate-rotation crops, such as energy Napier grass (pasto elefante) and short-rotation crops, such as Sordan 70A. Furthermore, it is probably desirable to add a processing step to convert the dry grasses and bagasse into higher forms of energy, such as Combustion Equipment Associate's "Agrifuel" or "Woodex fuel pellets". However, the energy balance aspects of these other crops and steps are relatively straightforward and quite favorable, so they will be left for further investigation.

Another day. The agricultural facility comprises 60 "energy farms", each spread across 200 acres, planted with energy cane on a three-year planting cycle. Harvests take place at the end of every 12 months, and replanting occurs every three years. The yields are as described in Table 2 on page 19. For convenience, these yields are those obtained from experimental work at the Lajas (Puerto Rico) Substation of the Agricultural Experiment Station of the University of Puerto Rico. This work is funded by the Department of Energy and is carried out jointly with the University's Center for Energy and Environment Research (7).

These yields are considered attainable in commercial operations on cane lands throughout Puerto Rico for the following reasons (6):

1. Botanically, cane is a better fiber producer than a sucrose producer. Indeed, despite inferior varieties and emphasis on sucrose, Puerto Rico averaged yields of 45 green tons of millable cane during the early 1930's, compared with 28 tons today. (Some farms obtained 100 tons!)

2. The energy gain is totally managed to maximize the yield of combustible solids per acre, not the percentage of sucrose or other nutritive values. In particular, varieties, row spacing, harvest frequency, fertilization, water supply, and machinery have all been chosen with the former in mind.

3. The manager of a commercial energy farm would undoubtedly vary practices to meet soil conditions and climate in other locations. Irrigation would be used everywhere, to some degree, to better control water intake. Also, the manager could be expected to select the best variety for his location. In Lajas, the best variety was NCo 310, whose second ratoon crop attained 92 green short tons of millable cane per acre, with standard spacing, versus a three-variety average of 83.9 tons for the same crop.

4. Table 2 omits cane tops and attached dead matter, which are removed before the cane is sent to the mill. On a commercial farm, most of this material would be collected as a source of biomass energy, in addition to the

"Loose trash shown in the table. Note that trash can be solar dried, baled and burned or further processed, without milling. Breeding work has barely explored the potential of cane for producing combustible materials. Yields of 150 green tons and 50 oven dry tons per acre are reasonable long-term objectives. The energy inputs required for such an operation are estimated in Table 3, page 20. Because the primary sources of the data for energy per unit are numerous and the magnitude of the inputs is small relative to outputs, conversion problems not handled in the original are ignored. Note that, in terms of No. 6 fuel oil equivalent, at 148,000 BTU’s per gallon, we are talking, roughly speaking, about 189 gallons per acre per year, or 6.4 gallons per oven-dry short ton of combustible material. By comparison, bagasse dried to 30% moisture could displace 91 gallons of No. 6 fuel, per short ton of oven dry material. (In fact, if the No. 6 is to be burned in a cane mill boiler, the displacement would be even higher.) Moreover, over half the energy inputs to the agricultural phase are represented by the energy value of fertilizers, whose use can be controlled and measured quite closely. The chemical content of these products is also known with exactness.

13 From the above, we select the Misselhorn estimate of 25,000 BTUs per gallon, for the following reasons:

1. It is the lowest commercial scale figure for ethanol from cane.

2. Starcosa Gmbh, which supplied Brazil's first ethanol plant in 1960 (13,200 gallons per day), designs and supplies distillation systems based on the two-pressure concept.

3. This estimate is derived from an interpolated diagram and not a hodgepodge of pieces of data.

Now, per Figure 1, we obtain 1,643 gallons of HTM per acre per year. This yields (at 64%) almost 1,052 gallons of pure ethanol, so we will require 26.3 million BTUs of energy per acre per year to operate the distillery. Nearly all of this is in steam, which, per Table 4, can readily be supplied by the cane mill. Per (10), we estimate the..."

The text reads as follows after correction:

Energy is incorporated in the distillery itself at approximately 4% of the energy requirements for operations. Hence, our total energy inputs for the distillation phase are 27.3 million BTUs per acre per year. However, we have not yet disposed of all the energy considerations related to this phase. The fermentation process produces about 8 lbs of CO_2 per gallon of pure alcohol, which can be recovered, scrubbed, and purified for sale. The slops from the distillation process may be evaporated for cattle feed, concentrated for foundry core binder or for adhesives, or dried and calcined for the extraction of activated carbon and potash fertilizer. These byproduct processes introduce further energy inputs and raise problems of energy allocation (12, 15). Since the potential markets in Puerto Rico for additional amounts of such products in large quantities are speculative, we will omit them from the energy balance. Given the need for 12,000 planted acres plus to support the cane mill phase, we must distill around 12.7 million gallons of pure alcohol per year. This is equivalent to 13.4 million gallons of 98% alcohol, or about 41,000 gallons per day at a 90% operating rate. We have now completed the description of each phase and may proceed to estimate the final energy balance. Hopefully, the reader has become aware of the necessity of defining the process energy balance.

Table 6 shows the energy balance for the entire Alternative (B), in which all products are energy products. The total energy balance is broken down between ethanol and other energy products (the latter in fuel oil equivalents). Since allocation method No. 3 does not substantially change the results for the direct combustion products, the "Biomass" column in Table 6 may be considered to represent Alternative (A), which all HTM goes for the manufacture of rum.

In a compensatory manner, if this is done, there is an energy saving in the refineries. The Office of Technology Assessment estimates this saving at 0.36 gallons of gasoline equivalent per gallon of ethanol (3). For the purposes of Table 6, we have assumed that this saving would be only half as great in Puerto Rico, due to the lower octane in use here. Given the externality, Table 6 is not too different from Table 5, as the saving in refinery operations (which the Commonwealth could probably achieve) coincidentally compensates for most of the energy input to the distilling phase.

Again, the energy balance is favorable, both overall and for each of the components - ethanol for gasohol and bagasse for steam. Of course, bagasse is "more profitable" energy-wise than ethanol. The energy ratio for biomass is 4.0, versus 1.8 for ethanol. Overall, depending on refinery feedstocks, design, and operating conditions, imports of crude oil will be reduced by approximately 44 barrels of crude oil for every acre of energy cane planted and processed in accordance with Alternative B.

What the energy balance cannot answer is whether the incremental saving in gasoline costs and improvement in gasoline security of supply is worth depriving the rum industry of security of supply of molasses, and possible protection against exorbitant price increases by would-be satraps. However, we note commonwealth revenues of $21.00 per gallon of pure ethanol ($10.50 per proof gallon) for Puerto Rican rum sold in the states.

Also, we can solve most of the rum industry's problem with HTM, but only a small part of the motorists' problem. Gasohol, after all, is 90% gasoline, made from imported crude in Puerto Rico's case. In our opinion, the rum industry deserves priority in the use of HTM.

How do we compare?

Because of the wide variety of methods used for calculating energy balances and ratios, we must recalculate our figures almost every time we compare ourselves with others. However, the comparisons are always favorable. For example, see Table 7 (based on

The text has been corrected as follows:

The estimates were collected by Zeimetz (1) and also by Hopkinson and Day (10). The latter estimates an energy ratio of only 1:8, obtaining all process heat from bagasse and counting this heat as both input and output. As per Table 6, the corresponding ratio for Puerto Rico is 2.9. For corn-based ethanol, fractional ratios are possible (3)(13). The most critical factor in these comparisons is the energy cane itself, particularly the high yields per acre obtainable in a subtropical climate with management for energy, not nutrients. In other words, the energy balance is negative.

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18 Table 1. BOILER LOSSES AND BOILER EFFICIENCY
Boiler Bagasse Burner Keneas ‘Efficiency. This table is adapted from Table E=3, reference 15.

19 Table 2. ATTAINABLE ANNUAL YIELDS FROM ENERGY CROPS IN PUERTO RICO (short tons per acre planted)
Type of plant, harvest frequency, and row spacing.

The "Pisoothe Type of Material and Crop 150°"ce 0m Green Matter"! Plant crop (1st yr) 77.8 75.0 1st ratoon (2nd yr) 93.6 93.1 2nd ratoon (3rd yr) 63.9 83.0 Avg. for cycle 85.1 85.7 Dry matter contained in green matter: Plant crop as the ratoon 29.5 : 22.4 Avg. for cycle 26.4

Conveyed in loose trash: Plant crop 38 1st ratoon 6.0 2nd ratoon 5.7 Avg. for cycle 5.2 Total dry matter: Plant crop 25.4 25.4 1st ratoon 35.5 33.5 2nd ratoon 27.8 24.6 Avg. for cycle 29.6

For energy cane, available can include crops and attached seed pieces which are removed in the field. At 6-month harvest, loose trash picked up by baler with cutting. Sources: Ref (7), first quarterly reports.

Table 3: Annual Energy Inputs Required for Energy Cane in Puerto Rico

Energy Input, Unit, per acre, Energy per unit, Energy per acre (BTU)

Fertilizers: Nitrogen lb 400 33,333 13.33 8.30
Phosphorus lb 200 6,032 0.60 0.38
Potassium lb 200 4.167 0.83 0.52
Sub-total 14.76 9.20

Fuel (distillate) gal 64 138,690 8.86 5.52
Herbicides and pesticides 12.85 43,652 0.56 0.35
Labor hr 25 2,159 0.05 0.03
Machinery 3.37 2.20
Seed 183 2,410 0.48 0.27

Total 28.08 17.47

Note: Area refers to area planted. Fuel includes transportation.

Sources: Units per acre - reference (7)
Energy per unit (except fuel) - reference (10)
Fuel energy per gallon - reference (16)

Table 4: Energy Balance for Alternative A (High Test Molasses (HTM) to Rum)

Energy Balance (20% Average Annual Yield), Method 1, Method 2, BTU/acre

Energy output by source: Loose trash 5.2, 25, 25
Bagasse for process heat 6.2, - , 83.6
Other bagasse 9.6, 229.5, 129.5
Total outputs 20.0, 202.0, 285.6

Energy inputs: Bagasse for process heat - , 23.6, -
Less BTU's charged for process heat (28.0, 28.0)
From Table 3, less BTU charged for HTM (0.3, 0.2)

Total inputs 17.0, 73.8

Energy balance: Net energy gain 186.3
Outputs less Inputs
Energy ratio: Outputs/Inputs 16.0

"39 'Oven dry short tons, from Figure 1, evaluated at high heating value of No. 6 fuel oil displaced, on an equivalent basis. Bagasse, boiler efficiency is 94% replaced by Hessey formula (2) for oil sugar, 45% moisture material, then converted to oven dry basis. 4) Same as 3/, but with 31% sugar and 30% moisture. B/ See text for description of allocation methods No. 6, 85%.

22 Table 5: ENERGY BALANCE FOR ALTERNATIVE B (high test molasses to ethanol) AGRICULTURAL AND CANE MILL PHASES Energy balance (10°) Allocation method #3 Crude oil equivalent Ethanol Biomass Total BTU/acre BTU/acre BTU/acre Energy output by source Loose trash 7 - 72.5 72.5 Bagasse for process heat2/ 13.4 - 83.6 83.6 Other bagasse3/ 20.8 - 129.5 129.5 and 20.1 98.4 98.4 Total outputs 66.0 98.6 288.6 386.0 Energy input Bagasse for process heat 30.9 52.7 83.6 Agricultural phase 85 19.5 28.0 Total inputs 39.4 72.2 11.6 Energy balance Net energy gain (outputs less inputs) 59.0 26.4 272.4 Energy ratio Outputs/inputs 2.5 4.0 3.4 L/ From Table 4, except for HTH million B/ Converted to barrels of crude oil at 6.216/B10 per barrel of No. 6 fuel oil, and one barrel of No. 6 equals one barrel of crude oil. 3/ Assumes, per Table 2 and Figure 4, reference (8), one gallon of mt equals 0.6 gallons of ethanol (pure). Converted at 0.8 gallon of gasoline equals one gallon of ethanol, 4.914 million BTU per barrel of gasoline, which equals one barrel of crude oil. See also ref. (3). Crude oil equivalence may vary. 4) Allocated on the basis of appropriate crude oil equivalents of outputs.

23 Table 6: ENERGY BALANCE FOR ALTERNATIVE B (High test molasses to ethanol) (ALL PHASES) Energy balance (x106) Allocation method #3 Ethanol Biomass Total BTU/acre BTU/acre BTU/acre Energy outputs by source Loose trash - 72.5 72.5 Bagasse for process heat - 83.6 83.6 Other bagasse - 129.5 129.5 High test molasses 98.4 - 98.4 Octane reduction in refining (externality) 2.2 - 22.2 Total outputs 120.5 285.6 406.1 Energy input Distillery 27.3 - 27.3"

Bagasse for process heat: 30.9, 52.7, 83.6
Agricultural phase: 85, 195, 28.0
Total inputs: 67, 7a, 138.9
Energy balance and energy gain (outputs less inputs): 53.8, 213.4, 267.2
Energy ratio of outputs/inputs: 40, 29
Equivalent £0, 0.18 gallon gasoline per gallon of ethanol (One H).
Rate B.S. savings shown in table 7s.
References: 35, 2.
See text for source.
Sources: Table 5, except where noted.
In crude oil equivalents: 2.3, 4.0, 3.2

Comparison of Estimated Yields from Energy Crops 3/ (after Zeteots! Table 5)

Crop and "Dry ton" based type energy conversion per acre, per ton, per acre balance ratio.

Retonicol: 36, 148, wet day, 18.2, 55, 36.8
Text 2: aa, mea, A wa, own, Fie, 2,313.0, 155.6
Yootetane: 8.8, ne.4, 19.7, 788
MGtttornt?!: 63, a3, 0, oa, ns, 90
Paleo: a6, a ne, 24s
Reorasta2/ 4,613.0, ny, a2, sa
Denies: 38, 4.7, 139
Meas aitaite Tow: 330, ss, ona
Gushe: 3.23.0, 57, 36.03
Corn Missouri: 9,013.0, va, ane, m3, 38

Output value to heating value of dry harvested material with no allowance for losses in converting tons to higher forms of energy, nor for energy input to conversion process.

Puerto Rico Alternative (A) excludes high test molasses (M) used for rum and also excludes Mita share of energy input. Input energy represents value of fertilizers, fuel, and pesticides only.

Sources: Puerto Rico - Tables 3, 4 and 6 preceding. All other locations - calculated from Table 3, page 11, reference (1). With regard to Table 5, see also pages 12 and 3 of (1).

Figure 1 Materials Balance and Flow for Energy Cane in Puerto Rico (oven dry weight, except where noted)

5.2 ST/A Field 85.1 green ST/A Loose trash operations
Millable cane recovery: IS—1 (one acre: 122 lb/ST NC)
2,000 green lb/ST: Cane will operations (Bagasse)
13.6 320 Fermentable solids: 2.2 51
Total: 15.6 371 (cane juice)
8.6 ST/A Fermentable solids: 203 lb/ST KC
14.8 ST/A 6.2 St/A 1648 gas
For energy For process High test molasses sales heat
3/ See above.
19.3 gal/st

Key: ST/A =

Oven dry short tons per acre (61% moisture) 1b/St ~ pounds per short ton. 18/81 Me = oven dry pounds per short ton of (green) millable cane, B/) 16k of (green) millable cane. With 60% extraction (conservative) 37. Assumes stack-gas drying of bagasse to 30% moisture and 74% boiler efficiency. Calculated from Figure 5 reference. (@) AJ Assumes 10.5 pounds of fermentable acids per gallon.

BIOMASS FROM THE ENGINEERING PERSPECTIVE 2 9

Presented To The Symposium 5 FUELS AND FOODSTOCKS FROM TROPICAL BIOMASS

Caribe Hilton Hotel, San Juan, Puerto Rico, November 24 and 25, 1980

Contributed By THE UPR CENTER FOR ENERGY AND ENVIRONMENT RESEARCH, Biomass Division, Rio Piedras, Puerto Rico

FUELS AND FEEDSTOCKS FROM TROPICAL BIOMASS, November 24, 1980 — 4:00 PM.

PANEL: BIOMASS FROM THE ENGINEERING PERSPECTIVE

Ing. Julio Negroni, Chairman

Engineer Héctor Rodriguez presenting Sugar Factory Operations for Improved Energy Utilization.

Sugar mills in Puerto Rico operate their steam boilers at low pressures, resulting in inefficient thermodynamic conditions. Advantages of high pressure steam generation are presently being assessed. Two cases are compared. In one case, a 600 psi pressure boiler is considered with enough steam generating capacity to fully use the energy potential of the bagasse. This case requires disposing of excess steam in an associated industrial operation. The second case uses a smaller capacity boiler to satisfy the sugar mill steam requirements but excess bagasse will be available for sale.

Engineer Modesto Iriarte presents Biomass for Unity Boilers.

CEER has shown that biomass fuel can compete very favorably with coal in stoker-fired boilers. Cost comparisons include desulfurization systems for coal-fired boilers. Very recent studies by CEER show that biomass-derived fuels can still compete favorably with coal, in the planned PREPA suspension type pulverized coal-fired boilers. Flow process, energy and mass balances, costs, and biomass-derived fuel.

The specifications for a 4-fuel fabrication facility will be discussed. Engineer Rafael Sardina argues that biomass-fueled boilers are the lowest energy alternative, excluding nuclear power. Studies performed indicate that when nuclear power is excluded, biomass represents the lowest cost energy alternative when compared to OTEC, wind, photovoltaics, coal, and oil.

MEMORANDUM

Presented by: Miguel Angel Garcia Mendes

Event: Symposium on FUELS AND FOODSTOCKS FROM TROPICAL BIOMASS

Location: Caribe Hilton Hotel, San Juan, Puerto Rico

Date: November 24 and 25, 1980

Contributed by: THE UPR CENTER FOR ENERGY AND ENVIRONMENT RESEARCH, Biomass Division, Rio Piedras, Puerto Rico

MEMORANDUM

From: Miguel Angel Garcia Méndez

I appreciate having this opportunity to offer some observations at this important meeting of experts discussing the potential of fuels and feedstocks from tropical biomass as alternate energy sources. Since the beginning of 1977, I have been emphasizing to the Commonwealth government authorities, and specifically to the Governor of Puerto Rico, the need for a pragmatic approach to transform the sugar industry into one focused on the production of ethanol and biomass using molasses and bagasse respectively.

I have recently learned of the successful achievements of distinguished scientists, such as Dr. Alexander, De Bonnet, Dr. Smith, Dr. Werner, Dr. Gary Martin, Marcos Lugo Ramirez, Michael Senyi, J. Vine, G.T.A. Bends in Louisiana, Al Mavis in Illinois; engineer Fernando Caldas in Costa Rica; Dahiya, Bardegs, and Dhamija in the Agricultural University of Hissar in India; and a large number of chemists from Puerto Rico, Brazil, and other parts of the world. Among them are distinguished participants in this seminar who have been working to develop alternative sources of energy so as to free us from the economic tyranny set up by OPEC.

An encouraging movement is growing at an extraordinary pace.

Brazil has significantly increased the production of gasohol, with many plants converting to fuel engines that were previously powered by gasoline. I've learned that in the United States, over thirty plants are primarily focused on the processing of corn and are preparing to produce gasohol after investing millions of dollars. I believe that in Puerto Rico, we are now prepared to begin a new chapter in our agricultural/industrial history, the Energy Chapter.

The signs of success for this commendable endeavor include:

1) Puerto Rico has previously produced up to 1,320,000 tons of sugar from 13,200,000 tons of sugarcane (one ton of sugar from each 10 tons of cane) harvested from 450,000 acres.

2) To produce sufficient sugar for local consumption, less than 200,000 tons, but at a prohibitively high cost using traditional approaches, only about one-seventh of the land previously used for sugar is needed. This means that six-sevenths of the 450,000 acres previously cultivated are, in effect, surplus.

3) We also have thousands of uncultivated acres that would serve as a perfect base for tropical crops, increasing biomass production and fully utilizing the machinery and equipment that will produce molasses and/or gasohol from sugarcane.

4) Instead of employing technicians and laborers only 100 days a year (which used to be the norm during high sugar production periods), work could be almost year-round, increasing employment rates and boosting the island's economy.

5) The U.S. Department of Energy programs, backed by Public Law 95-238, authorize up to 2 billion dollars to stimulate the production of alcohol fuel. Also, under Law 932, the Synthetic Fuels Corporation provides loan guarantees and price guarantees with the aim of reaching a volume of 10% of the estimated total gasoline consumption in the U.S.

The agreements are valued up to $1.2 billion. The U.S. Department of Agriculture, through the Farmers Home Administration, is implementing a program of guaranteed loans of up to $100 million and direct loans of up to $10 million. This is to facilitate the production of alcohol to fulfill the presidential goal of achieving the production of 800 million gallons in 1981.

If the expense incurred in purchasing gasoline and other carburetants from abroad in 1979 exceeded one thousand million dollars ($1,000,000,000), and if the goal of eliminating as much as 10% of such expense could be achieved, it would result in a significant increase in employment. This would not only be in the field but also in the industrial sector, along with a further multiplier effect in the transportation of agricultural supplies, finished products, and raw materials.

The internal income for small farmers would increase, providing corollary benefits. This would also reduce the balance of payments deficit between imports and exports from foreign countries for the first time in many years. Our trade balance with the United States has recently been favorable.

If gasoline is substituted up to 20% by alcohol (gasohol), no change in engines is required. Consequently, cars and trucks' engines would operate at lower temperatures.

In summary, if this idea to devote the production of sugarcane and tropical grass to substitute for part of our consumption of gasoline and fuel oil is successful, we would have the satisfaction of producing energy and jobs on the island and possibly exporting proteins abroad.

We trust that the noble efforts of so many devoted scientists in this interesting symposium will greatly benefit the industrial and economic progress of Puerto Rico, our nation, and the Western hemisphere of which we are a part. We surely hope that, with God's help, it will be so.

FOSSIL FUELS OUTLOOK FOR PUERTO RICO'S PRIVATE INDUSTRIAL SECTOR

Presented To The Symposium FUELS AND FEEDSTOCKS FROM TROPICAL BIOMASS Caribe Hilton

Hotel, San Juan, Puerto Rico, November 24 and 25, 1980. Contributed by Eng. Carlos Yepes from the Puerto Rican Cement Company, Inc., Ponce, Puerto Rico.

FOSSIL FUELS OUTLOOK FOR PUERTO RICO'S PRIVATE INDUSTRIAL SECTOR

Table of Contents Topic:

FOSSIL FUELS OUTLOOK FOR PUERTO RICO'S PRIVATE INDUSTRIAL SECTOR

Mr. Carlos Yepes, P.M. Manager, Puerto Rican Cement Company, Inc, Ponce, Puerto Rico.

ABSTRACT: A short history of fossil fuels is presented, from their origin to present times as energy producing natural resources in America and the world. The present and future energy situation resulting from the indiscriminate use of our energy resources is briefly analyzed. A presentation is also made of the distribution of the world's energy resources. The price escalation of fossil fuels is discussed in the context of its effect on Puerto Rico's industrial development and economy, both for the present and future. Energy conservation, together with the use of other conventional and non-conventional energy sources, is evaluated as a Puerto Rican option. Also presented is a brief analysis of Puerto Rico's energy policy today, and the eventual discovery of oil in Puerto Rico.

Present address: Puerto Rico Cement Co., Inc, P.O. Box 1349, Ponce, Puerto Rico.

DEFINITION OF TERMS

1. Fuel: Any material, solid, liquid or gas which burns in the presence of air or decomposes liberating considerable heat energy.

2. Fossils: Applied to substances of organic origin, more or less petrified, found in earth strata (e.g., coal, natural gas, oil shales).

3. BTU: Unit of heat energy used to measure the heat capacity of fuels. It's equivalent to the heat necessary to raise the temperature of one pound of water by one degree Fahrenheit.

4.

Kilowatt-hour: A unit of electric energy equivalent to 3,412 BTU's.

5. Hydraulic energy: Kinetic and potential energy contained in the flowing river waters.

6. Biomass: Conversion to energy of anything biological either through burning or decomposition.

7. MBDOE: Millions of barrels per day of oil equivalent.

8. OPEC: Organization of Petroleum Exporting Countries. Countries include Algeria, Ecuador, Gabon, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates (Abu Dhabi-Dubai-Sharjah), Venezuela.

9. WOCA: World Outside Communist Area.

10. North America: U.S. and Canada.

11. Western Europe: Denmark, Finland, France, Netherlands, Norway, Sweden, U.K, Austria, Belgium, Greece, Iceland, Ireland, Luxembourg, Portugal, Spain, Switzerland.

Author's note: Definitions are given as received in the original manuscript.

INTRODUCTION

While peering into the future to see where man is going relative to energy sources, it would also be well to look back in time. Modern man, especially in the industrialized world with all of its energy-consuming conveniences, tends to lose sight of his much more humble beginnings. It is hard for us with cars, electric lights, central heating, air conditioning, radio, television, and other conveniences we enjoy, to imagine man in his more primitive state.

In 1700, the world population was about 600 million. By 1900 it had shot up to 1,500 million, and it is predicted to reach 7,000 million by the year 2000. In the United States, we use more energy per capita than any other nation. In 1972, we used approximately 346 million BTU per person, equivalent to 2,306 barrels of oil per year. To maintain an improving standard of living, we will require roughly 380 million BTU's per person in 1985. This is equivalent to 2,530 gallons of oil per year. By the year 2000, this figure could increase to a per capita rate of 450 million BTU's per year, equivalent to 3,000 gallons of oil per year.

The problem, of course, is that the fossil fuels, which are the current primary

We cannot deny that the amount of fossil fuel on Earth is limited. These sources of energy are finite. If we continue to rely on them to the extent that we do now, we will eventually run out. The only question open for debate is when that might happen. The issue of limited supply is compounded by three other factors: pollution, the type of fossil fuel currently being used, and the origin of these fuels. In the US, oil and natural gas constitute 75% of our consumption and 7% of our reserves. Conversely, coal makes up about 90% of our country's reserves.

While the demand for oil has been rising at a rate of more than 5% per year, domestic production has been decreasing at a rate of 6% a year since 1970 when production peaked. The situation is similar for natural gas. To close this gap, we have resorted to purchasing additional needed fuel from overseas. We experienced the disastrous results of this trend during the 1973 embargo and the subsequent price hikes. Hence, we are faced with increasing demand, a dwindling supply, and an increased dependency on foreign sources. So, what are we going to do about this problem?

The newly-created U.S. Department of Energy (DOE) has outlined the effect it sees each of these measures having. Generally, increasing the efficiency of energy use (conservation) can have the greatest immediate impact on the nation's energy system between now and 2000. Expanding the production and use of existing fuels, such as oil, natural gas, coal, and uranium, can also provide a substantial contribution to solving the nation's energy problem between now and 2000.

The DOE, the main conduit for federal funds into energy research and development, is planning to spend billions of dollars in the coming years. About $700 million will be devoted to the Fossil Fuel Development Program. However, the DOE has noted that some new technologies, such as solar heating and cooling, geothermal energy, biomass, and oil shale utilization are likely to make "significant" contributions to the pre-2000 energy landscape.

Picture. Other potential energy sources currently under investigation include means for harvesting the potential energy in oil shale, tar sands, and the geothermal heat below the surface of the earth. Work is also being done to recover presently unreachable oil and gas deposits. Although much of the future is in question, there are a few things of which we can be sure. Oil, gas, and coal will run out. But the sun, the sea, the winds, the rivers, and the plants will be here forever. Let us learn to live with and make the best possible use of these forces of nature. Don't expect miracles in the short term. We had better face the fact that for the next 25 years, we are going to rely on coal, nuclear power, gas, and oil.

ORIGIN, COMPOSITION, AND CLASSIFICATION OF FOSSIL FUELS

Fossil fuels are combustible materials of organic origin, produced by nature through a long process of decaying, heating, and pressure of accumulated decomposed vegetation in previous geological ages. They are chemically composed chiefly of carbon, hydrogen, and oxygen, with lesser amounts of nitrogen, sulfur, and varying amounts of moisture and mineral impurities. Fossil fuels may exist in the solid state (coal), the liquid state (petroleum), or in the gaseous state (natural gas), depending on how much heat and pressure they were subjected to and for how long.

ENERGY: THE PROBLEM OF THE CENTURY

There can be no longer any doubt that the world has reached the end of an era in its energy history. Increasing oil imports, the basis for three decades of unparalleled economic growth, will not be available anymore. Complex factors ranging from increasing consumption to rising fuel prices and environmental considerations are the most important contributing elements to the very serious situation we will be facing during the next decade or so. Fortunately, the world is not running out of potential sources of energy. It will, of course, take a major effort and considerable lead time to develop new resources to meet future needs. The United States

"Will remain the largest oil-consuming country and will become increasingly dependent on imported oil at least for the next ten to fifteen years. The world will be dependent on the Middle East for an increasing share of oil supplies for some years to come. Efforts to find new oil will not be as easy as in the past. Our industry has to search in increasingly difficult environments such as the Arctic and North Sea. The very large fields in the Middle East represent discoveries whose size is unmatched in the history of oil cultivation. Even if demand growth were moderated, as we believe it must be, we need to face the fact that the world's conventional oil resources will not indefinitely support increases in production. To prepare for such a situation and for an orderly transition into a new energy era, consuming nations must create the political and economic environments that will encourage energy conservation and speed the development of other conventional and unconventional energy sources. The United States has wider choices than any other nation because of the scale of our basic energy resources. The current crisis is a warning of the energy problems the world will be facing if supply and demand trends continue the way they are headed. Failure to recognize the importance of this problem and to take appropriate and timely action will almost certainly result in a world of confrontation and conflict. Higher energy prices, as the supply/demand imbalance becomes more apparent, will have depressing effects on the economies of the world and will frustrate the aspirations of the less developed countries. The longer the world delays in facing this phase, the more serious the danger will be. Even with prompt action, the margin between success and failure in the 1985-2000 period is slim. Time has become one of the most precious of our resources. Recognizing the importance of time and the need to respond can help us through the period of transition that lies ahead. The years up to 1985 are critical ones. Events and policy decisions in the decade before are significant."

1985 will determine the success in demand reduction, fuel substitution, or additions to supply in the 1985-2000 period.

Chapter 4: The transition away from primary reliance on oil will be well under way by the year 2000. For this transition to be smooth, greater international cooperation among increasingly interdependent nations is essential. Vigorous research, development, and demonstration of new supply sources, plus conservation and fuel-switching programs, must move forward on an international scale. The period to the end of the century will be one of energy transition away from oil as the world's dominant fuel. It will be a challenging and critical period. Our energy world then, and in the 21st century, depends on it.

FOSSIL FUELS INVENTORY

Fossil fuels (oil, coal, natural gas) are found in the earth in sufficiently large quantities to take care of all of the world's energy needs for 100 to 150 years at today's rate of consumption. Currently, 66% of present oil reserves are in the Middle East and North America. About 50% of total reserves are in the countries bordering the Persian or Arabian Gulf. Total oil reserves are distributed in approximately the following pattern: Middle East 53%, Africa 16%, Russia & Communist Countries 15%, Europe 2%, North America 7%, South America 5%, Indonesia 2%.

In relation to natural gas, proven reserves are distributed as follows: OPEC 38%, North America 13%, Western Europe 9%, Rest of World (including Communist areas) 32%.

Chapter 5: The estimated world natural gas reserves are equivalent to 386 billion barrels of oil. Coal will again be the world's dominant commercial fuel. Today's leading coal producers are the major industrialized countries of the western world and the communist area. Three countries, the United States, Russia, and China, account for nearly 60% of world output, with Poland, West Germany, and the United Kingdom producing over 15%. The single largest producer and consumer of coal is the United States, with nearly half the production and over half of the known reserves.

'The world possesses vast reserves of coal, far in excess of those of any other fossil fuel. The total estimated recoverable reserves of 737 billion tons are enough for over 200 years of consumption at the current rate of coal usage. Expressed in terms of oil equivalents, this is equal to around 3,000 billion barrels, from 4 to 5 times the current level of proven reserves of crude oil. The world’s recoverable coal reserves are distributed approximately as follows: United States 34%, Western Europe 6%, Rest of WOCA 7%, USSR and Eastern Europe 39%, China 14%, United Kingdom & Canada 1%.

Energy sources other than oil, natural gas, and coal could make a growing contribution to energy supply before the year 2000. These supply sources include other fossil fuels such as oil shale, oil sands, and heavy oil. Known deposits of oil sands, heavy oil, and oil shale, are much larger than the world’s proven reserves of conventional oil. Such deposits represent a potential means for the supply of petroleum long after conventional oil and gas fields are exhausted.

In Canada, oil or tar sands lie in beds 50 to 100 feet thick under an area of 12,000 square miles near the Mackenzie River in Northern Alberta. It is estimated that 300 billion barrels of oil are recoverable if fully exploited. Such oil sand reserves would produce 3 MBD for 25 years. Significant deposits of heavy oil have been found in Canada and Venezuela. In Canada, estimates of recoverable oil are in the order of 2 to 45 billion barrels. In Venezuela, in the Orinoco oil belt, the thickness of the oil sands is greater than the originally estimated oil equivalent of 700 billion barrels.

Oil shale is another significant energy resource. The largest known reserves are in the USA, with significant amounts found also in Brazil, Canada, Burma, USSR, and China. U.S. oil shale deposits are estimated to contain 2,000 billion barrels of oil. However, only about 6% of the deposits are sufficiently accessible and commercially exploitable.

6. PUERTO RICO AND THE WORLD'S ENERGY SITUATION

The...

The effects of the world's energy situation are particularly serious for Puerto Rico. We, in Puerto Rico, depend on oil for about 99% of our energy needs. Puerto Rico not only consumes a relatively large amount of energy, but we do so in a very inefficient way. Oil is the only source of energy for our petrochemical industry, for the production of electric power, and to run our system of transportation. These are the most energy-consuming activities in our daily life. Most other activities, such as industry, agriculture, and others are also greatly dependent on oil. To solve this problem of inefficiency and high energy consumption, the only available alternative is the wise and prudent use of energy in the different sectors of our activities.

Puerto Rico currently imports 120 million barrels of crude oil and naphtha. Venezuela supplies about 40 to 50% of this amount. It is estimated that nearly 40% of all imported crude oil and naphtha are exported as refined products or petrochemicals, mostly to the eastern U.S. Approximately 60% of imported petroleum is consumed in processing (10%) and supply of local energy needs (50%). This means that 60 to 70 million barrels of imported petroleum are required to meet our internal energy demands.

We must stress the concept of energy conservation as our only way to reduce our consumption of oil and to reduce our dependency on imported petroleum, at least for the present and near future, and until we are fortunate enough to discover our own oil deposits, or to develop other sources of energy, including the use of other fossil fuels (coal), solar, hydraulic, nuclear, biomass, etc.

You may not believe this, but the Puerto Rican spends a higher percentage (8%) of his income on energy than a mainland resident does (5%).

Question 1: The PR Government has already prepared a document that presents a public energy policy for Puerto Rico. It is a plan for the careful administration and control of our energy consumption, based primarily on the saving of energy combined with the eventual substitution of...

The immediate goal of the present conventional fuel is to save 5 to 64% of our actual consumption in 1980. This saving will represent approximately 3 to 3.5 million barrels of petroleum every year, equivalent to 50 to 60 million dollars. The two most critical areas for energy control are transportation (gasoline) and residential/commercial (air conditioning and illumination). This program requires the joint effort of government, industry, general business, and all citizens. All of the above measures should help save energy and some money, but will not free us from our oil dependency at all.

There are only two ways in which we can break away from our need for imported petroleum: to discover oil in Puerto Rico or to change over from oil to coal. The discovery of oil in Puerto Rico would, of course, be the most welcome event. If, unfortunately, it does not occur, we will definitely have to base our energy future on the use of coal which is quite abundant in America and much cheaper than petroleum. If oil is present in Puerto Rico, natural gas should also be available. Then we may count on two very important sources of energy which will completely change our energy picture. Let us hope and pray that this is true.

There are, fortunately, a few renewable natural sources of energy quite abundant in nature. These are the sun, the ocean, the winds, and biomass. There is no solid waste. These resources are potential future alternatives for development before we run short of the three primary energy sources: oil, coal, and natural gas. Which of these renewable resources will better help us face our energy situation is hard to predict. This may ultimately depend on the decisions we make and how we develop a successful alternative energy program.

The three most intensive energy consumers in the industrial sector of our economy are: petrochemicals, electric energy utilities (PREPA), and the cement industry. I will present to you, gentlemen, a short review of the cement industry in relation to the energy industry.

Energy problem, which I suppose, will be relatively similar in effect, if not in dimension, to other large industries.

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As you very well know, the cement industry is a high energy consumer. Fuel oil and electric power represent almost 60% of all current operating costs. The industry consumes 1.5 million barrels of fuel oil each year, now costing approximately 35 million dollars. It consumes 200,000,000 KWH of electric power costing 14 million dollars annually. These costs may very well rise to $50 million and

$20 million, respectively, in the next five years or so.

There are a few alternatives we have been considering as possible solutions to our energy problem. These are:

1. Change from wet process to dry process.
2. Change over from oil burning to coal burning.
3. Use biomass energy.

Alternative No. 1 is the most attractive one in terms of heat energy saving and increase in production obtained, but the investment involved in the change is very high. The dry process is indeed a revolutionary approach to the saving of energy in the cement industry. While in the wet process the average energy is approximately 1,000,000 BTU/barrel, in the dry process it is reduced to 550,000 BTU/barrel. In a 6,000,000 barrel plant such as ours, this could represent a saving of approximately 500,000 barrels of fuel oil every year amounting to 13 million dollars. Besides this saving in fuel oil, conversion from the wet to dry process could mean an increase in production by the converted unit of approximately 40%. This indeed would be a very attractive proposal if it were not for the large investment involved of about 125 to 150 dollars per ton of capacity. In our case, the investment could amount to 150 million dollars. Very few industries in Puerto Rico can afford to spend that much money. We are among the very many who cannot.

Alternative No.2 is actually the most viable in terms of time, availability of coal, and also in terms of investment involved and savings through the use of cheaper fuel. It is also a less complicated conversion. We have already

We have completed most of the preliminary studies and we hope to move forward with this project in a short time. This change implies the complete substitution of oil with coal. At current prices, the conversion from fuel oil to coal may represent a significant saving in our case.

Page 9: The savings could be approximately $1.50 per million BTU, or about 10 to 12 million dollars per year. The estimated investment required for the conversion could be around 10 to 15 million dollars. This could be a more realistic approach to our energy problem in terms of economy, availability of fuel, and time required for conversion.

The third alternative is biomass energy. We have been in contact with a few individuals interested in this matter, but as of now it seems like a possible alternative by the end of the century.

There are quite a few problems involved in the conversion to coal burning in almost every case, but nothing could be worse than running short of oil before we are able to use coal and other energy sources. Therefore we should start making the necessary adjustments to keep our utilities, industries, and transportation systems operating without any serious difficulties.

We are very much involved in this energy situation and we must make our specific decision in this regard in the very near future. We agree with the general opinion that coal is the best immediate practical alternative to resolve our energy situation. We are aware of the problem and fortunately, we have the solution. It's time to make a decision and start moving in the right direction.

CONCLUSIONS

The future of oil supply is uncertain. However, one conclusion is very clear: Potential oil demand in the year 2000 is unlikely to be satisfied by crude oil production from conventional sources. The supply of oil will fail to meet increasing demand, most likely between 1985 and 1995.

The world is nearing the end of an era in its energy history. Increasing supplies of oil will no longer be available. This marks the end of the era of growth in oil.

Demand for energy will continue to grow even if governments adopt vigorous policies to conserve energy. The continued growth of energy demand requires that energy resources be vigorously developed. Electricity from nuclear power is capable of making an important contribution to the world’s energy supply. Coal has the potential to contribute substantially to our future energy supply. Coal can bridge the transition from the fading petroleum era to the next century’s renewable sources of energy. It is the only fuel capable of doing this in large enough quantities within the time available. Because prices of coal are likely to be based on costs, over the long term, the present price advantage of coal over oil and gas is likely to increase.

The major coal use in the year 2000, as today, is projected to be in electric use, which now consumes 60% of total coal. Although the resource base of other fossil fuels such as oil sands, heavy oil, and oil shale is very large, they are likely to supply only small amounts of energy before the year 2000. Other than hydroelectric power, renewable resources of energy like solar, wind power, and wave power are unlikely to contribute significant quantities of additional energy during this century. They are likely to become increasingly important in the 21st century. Conservation will become, over the next 20 years, one of the world's largest energy sources."

A projected 25% energy input per unit of activity could reduce the amount of increased energy needed by almost as much as the projected three-fold expansion of coal. Policies for energy conservation should continue to be key elements of all future energy strategies.

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12. Oil and Coal in the United States: How Much Coal Do We Have Now? Use of Hydro and Nuclear, Oil and Gas. 8% Known Reserves of Current Energy Sources; Energy Fuels in the U.S.

4. A Comparison of Oil and Coal Reserves (Units: Billion Barrels Oil Equivalent)

XV. Combustion Systems for Bagasse and Fossil/Bagasse Fuel Blends

Presented to The Symposium Fuels and Feedstocks from Tropical Biomass at the Caribe Hilton Hotel, San Juan, Puerto Rico on November 24 and 25, 1980. Contributed by Eugene S. Yankura, PE, Entoleter, New Haven, Connecticut.

Combustion System for Bagasse and Fossil/Bagasse Fuel Blends

This paper reviews the critical components of combustion systems that are dedicated to the firing of bagasse and fossil/bagasse fuel blends. The use of oil poses no special problems. Add on systems would be installed as completely separate.

Systems have their own storage and conveying equipment. There would be no common elements with bagasse or coal systems. On the other hand, coal or bagasse systems cannot be retrofitted to most boilers designed primarily for oil without a severe reduction in capacity. The firing chambers are too small and they have no provision for ash handling facilities. Coal/oil mixtures and pulverized coal burners of the BlawKnox type help to overcome some of the limitations of bagasse and coal.

Except perhaps for the conveying and delivery systems, bagasse and coal are compatible for firing in the same combustion chamber. The vibrating grate stoker and the underfeed single retort stoker with dump grates can be designed to handle bagasse or coal equally well. The designer must have information about the amount of ash, ash fusion temperatures, coal size and moisture.

Both bagasse and coal require a spacious firing chamber that allows long flame paths to give the time needed for complete combustion and to minimize deposition of slag on the boiler tubes. Both bagasse and coal require similar levels of excess air. The placement of air tuyeres for both underfire and overfire air would be similar for each.

Conveying and delivery equipment should be kept separate. That is, one system could not be equally capable of handling coal as well as bagasse or vice versa. There are widely different design criteria for each material.

Dryers are gaining more attention for using flue gas to reduce the moisture of fuels such as bagasse and wood. These fuels have an inherently low BTU value and a high water content. The successful exploitation of these biomass fuels will be moved forward considerably by the application of this technique. By reducing the moisture, a greater portion of the fuel BTU value is available for useful work.

Such a system was operated by A.C.L.L at Central Coloso in 1978. It was found that by reducing the bagasse moisture level, the excess air rate could be reduced. For instance, when the bagasse was fired at a 43% moisture level.

The content shows that the excess air can be reduced to 10% without the formation of detectable carbon monoxide, that is, less than 0.1. As a consequence, a second significant increase is realized in the energy available for useful work. The drying of bagasse can also be employed toward a second equally valuable end, the storage of bagasse for future energy requirements. The moisture content must be reduced to prevent decomposition and degradation. Figures 1 through 6 show the evolution of a boiler dryer system. The stepwise progression demonstrates the flexibility of design to satisfy various ends. The system is designed around two boilers, although all the elements can be practiced in a single boiler. Drying the bagasse in two steps reduces the fire hazard. In this system, low moisture bagasse is exposed only to dryer gas with a very low oxygen content. In addition, a two-boiler system would permit easier control in load swing situations. The system parameters and design, in particular for the dryer, are based on the results obtained in the Central Coloso test.

Figure 1 shows the first step in the dryer system. The boiler conditions are patterned after the typical bagasse boiler found in the sugar industry. Combustion takes place with an excess air rate of 50%. This is necessary with a moisture level of 52%. Below 50% excess air, combustion efficiency would degrade rapidly. The factory load requirement is assumed to be 200,000 steam/hr. and boiler one is being fired to carry half the load. In Figure 2, the 32.5% moist bagasse from the first dryer is fed to the dryer of the second boiler before going to the combustion chamber. In the second dryer, the bagasse is further dried from 32.5% moisture to 20% moisture in an oxygen-depleted atmosphere. Since Boiler #2 needs to produce 100,000 steam/hr. to meet demand, all of the 20% moist bagasse is not fired. The remainder may be stored. Note that if the remaining bagasse was fired at the conditions of Boiler 2, it would produce an additional 60,500 steam/hr.

Therefore, under typical firing conditions, the present system would produce 200,000 kg of steam/hr (twice that of Boiler 1). Drying the bagasse before combustion, as shown in Figure 2, would produce 260,500 kg of steam/hr, an increase of 30.25% in the heat value of the bagasse. Note in Figure 2 that the boiler temperature profile is different in the two boilers. The two boilers are identical and the steam from each is used at the same pressure of 180 PSI. The temperature profiles are affected by mass flow rate, specific heat, flame temperature, and changes in the ratio of radiant to convection heat transfer. For these designs, the ratio of radiant to convection heat transfer is assumed constant. The radiant heat transfer is proportional to the 4th power of the temperature, but there are other variables affecting emissivity, particularly gas composition. It is true, to a high degree, that the various interrelated factors cancel out overall. Therefore, the new temperature profiles found by USA Thermodynamics are illustrated here. The combined conductance X surface area is constant for boiler temperature, log mean temperature difference, gas and saturated water temperature. The time period that 20% moist bagasse can be stored without serious degradation is still unknown. So, let's see what can be done to obtain drier bagasse for storage. In Figure 3, we see that it's necessary to fire more of the bagasse from Boiler 2's dryer in order to reduce the moisture content for storage. We have also reduced the quantity remaining for storage. We can pursue this direction further as in Figure 4 and get down to 17% moist bagasse for storage, but we will have an even smaller amount, in fact, a very small amount. This approach has serious constraints. To get drier bagasse, we have to consume more and, in consequence, generate more steam which will have to be wasted if the factory can't use it. Also, to get drier bagasse, we get less of it. It seems as though 17% moist bagasse is the limit. If we try to go beyond this, it would result in... (The text ends here).

"Drier, there will be virtually none to store. 'The dryer, like any mass transfer device, is subject to rate-constrained mechanisms. If time were not a factor, that is, if it were finite, the materials would come to true equilibrium. For instance, if the example in Figure 1 were given infinite time to equilibrate, the final conditions would be those shown in Figure 5, where the bagasse moisture is reduced to 27.6% compared to 32.5%. At greatly increased capital expense and/or operating expense, the dryer efficiency can be increased. However, let's take another approach. Figure 6 shows this other approach where Boiler 1 is operated at 100% excess air. Some boiler output is sacrificed, but the bagasse is dried to 20% moisture. Continuing, Boiler 2 is fired at a rate to compensate for the reduced output of Boiler 1. The total steaming rate is the required 200,000 steam/hr. Now the bagasse remaining from Dryer 2 is down to 3% moisture and in such quantity that were it fired in Boiler 2, it would produce another 64,500 steam/hr. The increase in bagasse useful heat value is 32-1/2% over the present typical firing method (see Figure 1). I am letting the 3% moisture stand only to demonstrate the theoretical potential of the technique. It is presumed otherwise that the hygroscopic nature of bagasse below about 15% will result in equilibrium at some higher moisture level. What we accomplished here is to establish a heat pump. The energy deficit from Boiler 1 raises the BTU's of the extra excess air to a higher energy level to increase the driving force that produces drying - the drying effect being greater than the “deficit” could produce in the former fashion. Again, I would like to note that these effects can be combined in a single boiler/dryer system with similar end results. I do not show that here since it is important to preserve the condition where low moisture bagasse is treated with oxygen depleted gases. Referring to Figures 2, 3, and 4, and the available energy yield from the remaining bagasse; the available steam/hr figures..."

The text was based on firing the remaining bagasse under the existing conditions of Boiler 2. If the firing were done in another boiler/dryer, the ultimate yield in each case would equal that in Figure 6. In no case have we affected the true ultimate yield under maximized conditions with the available equipment. What we have done is create a highly flexible system whose operation can be tailored to meet almost any end objective. To complete the picture, refer to Figure 7.

This would be the scenario where there is a temporary increase in the need for steam. One boiler is shown, but the same applies to both. All the bagasse from the dryer is fed to the boiler with the boiler operating at 10% excess air. Conditions will equilibrate such that the boiler produces 132,750 steam/hr, and the bagasse is dried to 41% moisture. For the two boilers, the output would be 265,500 steam/hr bagasse for an increased useful heat value of 32.7%.

A preheater is a heat-saving device that reduces the heat loss going out of the stack. The result is an increased yield in the useful heat value of the fuel. The examples worked out above in the figures do not use a preheater. It would appear that the preheater, by reducing the temperature of the stack, would reduce the "drying capacity" of the flue gas. But other parameters are changed by the preheater, such as flame temperature, and therefore boiler temperature profile. It is not intuitively obvious what would happen, and the cases have to be worked out. For now, it is an open question, but my educated guess is that it will not detract from the increase in fuel's useful heat value afforded by the dryer.

When firing coal in a low-pressure boiler, attention must be given to the flue gas temperature. It must be maintained above the dew point of SO or else the rate of corrosion will be serious. This applies in particular to the superheater and preheater. This temperature is usually considered to be about 350°F, but with high levels of coal sulfur, it

Will be higher.

ACKNOWLEDGMENTS: Thanks are given to Dr. Alex G. Alexander of the University of Puerto Rico for the opportunity to present this paper and to the Sugar Corporation of Puerto Rico.

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Figure 1: 28.5 TH 52% Moist 8300 BTU/lb Dry, ALP. as 'BOILER overall Ef. = 54.4% 845 TPH 52% vol 8300 BTU/lb Dry, A.P.

BOILER 2: Overall Efficiency 78.4%. To storage: 50 TPH 16.8 TPE 19% Heat 19% Wet. Figure 3.

CENTRALS LAFAYETTE AND AGUIRRE AS POTENTIAL SITES FOR ENERGY COGENERATION:

Presented To The Symposium FUELS AND FEEDSTOCKS FROM TROPICAL BIOMASS Caribe Hilton Hotel, San Juan, Puerto Rico, November 24 and 25, 1980.

Presented by Ms. Roberto Delucca, Chief Engineer (Central Aguirre, Aguirre, Puerto Rico).

CENTRALS LAFAYETTE AND AGUIRRE AS POTENTIAL SITES FOR ENERGY COGENERATION:

BAGASSE: A FREE FUEL IN P.R. SUGAR MILLS:

Bagasse is the fiber residue left after grinding sugarcane. Its most important characteristics are its heating value, fiber content, moisture content, and ash. Bagasse has always been used in Puerto

Rico's sugar mills as fuel for the generation of steam, which in turn is used for moving the mill engines, for processing (and evaporation), and for the generation of electricity.

The total bagasse produced during the 1980 crop in all the Puerto Rico sugar mills amounted to approximately 827,213 tons (equivalent on an undried basis to 1,109,293 barrels of...

Fuel-I, which at current prices would amount to $23,572,476. Since not all sugar mills in Puerto Rico have steam measuring instrumentation, it's not readily known how much steam was actually produced in the sugar mills from bagasse. However, using the Aguirre steam production data we can get a rough figure of what the steam production could have been. In this way, we have calculated a total steam production of 1,216,320 pounds of steam per hour. After using 60% of this steam for cane grinding, we then have left 486,528 pounds of steam per hour. This amount of steam could be used to produce 12,637.1 kWh of energy in the mill power plants (from bagasse fuel only), as surplus energy which could be sold to the P.R. Electric Power Authority. This would have a value of $3,022,890.00 for a 125-day crop.

For round, refractory-lined furnaces where air is made available from the sides or in some cases from under the pile, the most recent method involves burning bagasse in a spreader stoker over a grate, similar to those used in coal-burning furnaces. In the first type, bagasse is fed by gravity through a gate whose opening is adjusted manually. Here, the operator feeds the necessary amount of bagasse to maintain a constant height in the bagasse pile. In actual practice, the amount of air seldom varies. This is one of the crudest ways of burning bagasse, and it's the method most used in the sugar mills of Puerto Rico.

In most instances, there are no indications of the most basic parameters of combustion, like furnace temperature, air flow, or steam flow (boiler load). The few spreader-stoker type bagasse boilers in use in Puerto Rican mills utilize bagasse-metering devices for feeding bagasse into the furnace, rather than the chute and gate system. Yet, these metering devices are also controlled manually by the boiler operator, and there is little or no airflow control. Boilers of this type could greatly benefit from automatic combustion control, which would adjust the bagasse and airflow in direct relationship to variations in boiler load, much like is done with coal-burning boilers.

Despite this, there is still a long way to go in improving Puerto Rico's bagasse-burning boilers for efficient burning of bagasse. This is likely one of the main reasons for the large amount of fuel oil burned during past crops, while simultaneously discarding enormous quantities of excess bagasse. In 1980, sugar mills in Puerto Rico burned 3,872,070 gallons of fuel oil, while all mills had to dispose of excess bagasse.

The Lafayette Sugar Mill, a cane growers cooperative facility located at Arroyo, has remained closed since milling the 1973 crop. It processed the cane from Arroyo, Patillas, and Maunabo. There are still some 105,700 tons of...

Cane is harvested there, mainly colono cane which is now milled at Central Aare. The Lafayette mill has since been maintained in good condition by the Lafayette Coop.

3 The factory remains complete. An interesting fact about Central Lafayette is its suitability for

energy cogeneration. The cane from this area could be bought from the Colones, and the factory could be put into relatively economical operation for cane milling for electric power co-generation and the production of the highest quality molasses. The operational costs could be kept low by using and repairing only the equipment needed for such purposes. This includes the cane storing and handling equipment, cane milling station, boilers, power plant, clarification equipment, and the evaporation and bagasse-handling equipment.

The proposed operation at Central Lafayette could be accomplished using approximately 30 to 35 men per shift. Some 3,000 tons of cane could be ground daily. By grinding high fiber cane (20%) which could render 40% bagasse (50% moisture) per ton of cane, some 1,200 tons of bagasse would be produced daily. This is the equivalent of 272.7 tons of fuel oil.

1. Milling Equipment At Central Lafayette

For the handling of sugarcane, Central Lafayette has two Wellman Hammer Head cranes, one of 10 tons capacity and the other of 15 tons capacity. There is also a truck dumper which unloads trucked cane into the carrier for immediate grinding. There are two sets of cane knives, the first has an 8 300 hp electric motor and the second has a 200 hp motor. One mill has a 2-roll crusher, sized 36” x 87”, four other mills have 3-roller crushers with 36” x 84” rolls. The crusher is driven by a 24” x 42” Corliss engine. The first three mills are driven by a 40” x 60" Corliss engine and the last mill is driven by a 26" x 48" Corliss engine.

The steam plant is composed of an Erie City, spreader-stoker type furnace steam boiler having a capacity of 150,000 lbs of steam per hour; a Horseshoe Furnace type Combustion Engineering Boiler, rated at 90,000 lbs of steam.

Per hour, there are two smaller horseshoe furnace Sitting Boilers, rated at 40,000 lbs of steam. The electric plant consists of one GE Turbo-Generator with a capacity of 1,500 KW, and a smaller Turbo-Generator with a 200 KW capacity. There are also two clarifiers with diameters of 26 ft. and 20 ft., as well as four juice heaters totaling 5,250 sq ft. of heating surface. Additionally, there are two vacuum filters for handling mud from the clarifiers. The evaporator system includes a 15,000 sq ft. pre-evaporator and a 20,000 sq ft. quadruple-effect evaporator. There are also five vacuum pans.

4.2 Operation Of Central Lafayette: The grinding operation would only use the crusher and the first two mills. The bagasse production of 20x after cane would be around 50 tons per hour (bagasse with 80% moisture). This would render a steam production of approximately 206,250 pounds per hour. By deducting 60% of this steam for grinding, there would remain 82,500 pounds of steam per hour for energy cogeneration. This would amount to 2,142.8 kwhr. Since the actual capacity of the Lafayette power plant is 1700 kwh, about 1,500 kwh would be used for the grinding process, leaving no generating capacity for additional energy to be sold at this moment. This means that for energy cogeneration at Central Lafayette, a 2,000 kwh Turbo-Generator would have to be added to its power plant. This is the only drawback found at Central Lafayette in terms of energy cogeneration.

AGUIRRE SUGAR MILL: The Aguirre sugar mill, located approximately 15 miles west of Lafayette, could possibly be utilized for energy cogeneration. Central Aguirre is still in operation and for this year's crop ground 401,000 tons of cane; although it has the capacity to grind over 6,500 tons of cane per day. The Aguirre mill has two tandems for cane grinding. One is an 18-roller Farrel System driven by six individual steam turbines and has a capacity of around 3,800 tons of cane per day. The other is a 17-roller Fulton, rated at 3,000 tons of cane per day, and driven by three Corliss steam engines. It has a two-roller system.

"Crushers moved by electric motors. For the purpose of this study, we have considered using only the Fulton-tandem for energy cogeneration. The equipment related to this tandem, and which would be utilized for energy cogeneration, includes:

(a) A railroad car tippler and truck dumper cane table;
(b) Three cane-conveyors for cane handling;
(c) Two cane knives, 300 hp each;
(d) The 17 roller, 6-1/2 ft roll length Fulton tandem, moved by two 28” x 54” Corliss engines;
(e) A 24” x 48” Corliss engine and a 200hp electric motor for moving the 2-roll crusher;
(f) Five bagasse boilers, four of which are horseshoe type bagasse furnaces, one actually producing 80,000 lbs of steam per hour and three having capacity to produce around 60,000 lbs of steam each.

Also available is one spreader stoker furnace boiler with a capacity of 120,000 pounds of steam per hour. Each boiler is already equipped with an emission control apparatus (scrubber). Also, there are four clarifiers, eight juice heaters, a triple-effect evaporator, and a quadruple-effect evaporator (for a total of 7 bodies). There is a saltwater pumping station, type barometric condensers, plus filters, pumps, etc., and a Power Plant, consisting of two 2,500 kW-hr General Electric Turbo-generators.

By utilizing the Aguitre Fulton tandem for energy cogeneration with a capacity of 3,000 tons of cane per day, as in the Lafayette case, only the crusher and the first two mills would be used. The bagasse production (grinding 20% fiber cane) would be 1,200 tons per day at 50% moisture, or 50 tons per hour from which 206,250 pounds of steam per hour would be produced. By deducting 60% of the steam production for grinding purposes, there would remain 82,500 pounds of steam per hour. This steam would again amount to 2,142 kW of surplus energy. Since at Aguirre the power Plant has a total generating capacity of 5,000 kW-hr, and only 1,600 kW-hr would be generated for winding, there remains enough capacity at the power plant for cogenerating the..."

The surplus energy of 2,142 kw-hr is to be sold to PREPA. It's notable that the Aguime power plant can produce the total electrical energy required for grinding biomass in the Fulton tandem (1,600 kw-hr), the additional electrical energy needed for grinding sugarcane in the Farrel tandem (1,200 kw-hr), and still possess the capacity for generating over 2,000 kw-hr of surplus electrical energy. Currently, the Central Aguirre boilers are operating at their maximum capacity, with some even operating above their rated capacity. There is no steam production for co-generation with the Fulton tandem while simultaneously grinding sugarcane with the Farrel Tandem. The absence of an additional bagasse boiler at Central Aguirre necessitates the disposal of about 300 tons of bagasse daily. At the same time, its electrical energy production has dropped to 3,000 kw-hr due to the lack of steam production.

XVII BIOMASS FUELS DEHYDRATION WITH INDUSTRIAL WASTE HEAT

Presented To The Symposium FUELS AND FEEDSTOCKS FROM TROPICAL BIOMASS

(Caribe Hilton Hotel, San Juan, Puerto Rico, November 24 and 25, 1980)

Contributed By W. O. Young

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BIOMASS FUELS DEHYDRATION WITH INDUSTRIAL WASTE HEAT

Thank you for the opportunity to discuss "Biomass Fuels Dehydration with Industrial Waste Heat" today. The recovery of waste heat from the industry aligns with today's energy conservation measures, as industry is the largest consumer of fuels. Using waste heat to create additional fuel is doubly significant, especially when applied to materials which are often a disposal problem. Most waste organic materials can be combusted if enough moisture is removed; this applies to industrial and municipal wastes, and ordinary agricultural waste such as stalks, leaves, and weeds. Unfortunately, the energy consumed in handling many wastes often exceeds the useful energy that can be produced.

Produced; therefore, it is necessary to pick and choose among the processes for those most likely to be energy positive. (Illustration No. 2) Like other forms of energy, heat has the characteristics of both Quality and Quantity. Quality can be defined as "quantity per unit;" quantity can be defined as "quality times number of units." Specifically, in the English system, a material at a higher temperature has a higher heat content or quality, as expressed in Btu/lb, than the same material at a lower temperature. The extractable energy is recovered by removing heat from the material and lowering its quality from a higher temperature to a lower temperature.

Let's say that we are removing heat from furnace gases by reducing their combustion temperatures to a constant smoke stack temperature of 500°F. It is obvious that not only do we actually extract more heat per pound of furnace gas produced at 3000°F than we extract from the 2000°F furnace gas, but we also extract a greater percent of the initial heat. Of course, percent figures always depend upon the base used, which in this paper is the usual "steam table" base of 32°F, in place of absolute zero or other.

Historically, dehydration has been used for many purposes including the preservation of foods such as raisins, prunes, other dried fruit, grains, and vegetables. Initially, these products were basically sun-dried, which is labor intensive. Obviously, as dehydration demand grew, larger and faster processes were developed. The direct-fired rotary dryer was introduced to the sugar beet industry before the turn of the century. This process produces animal feed from the fiber of the sugar beet.

Also, the rotary direct-fired dryer is producing animal feed from the fibrous portion of corn, as a by-product of the starch and corn sugar industry. Another plant uses a rotary steam tube dryer to dehydrate the germ from the corn before making corn oil. (Illustration No. 1) Waste heat from other sources is being added today to the directed dryer in place of the usual ambient.

Dilution air is mixed with the products of combustion in the furnace. This waste heat can come from another source or simply be recycled from the dryer exhaust. These schemes are used in domestic sugar beet pulp dryers as well as many in Europe. Waste heat from other combustion processes is the exclusive drying medium. A corn processing plant is drying corn fiber and steep water concentrate for animal feed. Note the boiler on the right and the dryer plant on the left with the connecting flue gas pipe. A Canadian sawmill is drying their waste products with boiler flue gas to produce boiler fuel. An American lumber and particle board plant dries "hog-fuel" with boiler flue gas. Note the sophisticated control panel. A charcoal-producing plant uses the products of combustion of the wood volatiles to dry the raw material entering the process. A Louisiana raw sugar mill uses boiler flue gas to dry bagasse for boiler fuel. A Philippine raw sugar mill is also drying bagasse for fuel with boiler flue gas. Note, the color of smoke from the boiler stack shows the difference between burning wet and dry bagasse. Obviously, the clear stack represents the dried bagasse operation. There are many purposes for drying fuels, several of which just make it burn better. We have all had some experience with a smoldering campfire or trash fire. Damp wood and paper have a difficult time in reaching the kindling temperature, having expended much of the heat of combustion in evaporating the moisture. The steam generated from this evaporation tends to shield the air from the surface of the material, and the flame suffocates from lack of oxygen. To maintain combustion, more excess air is blown into the furnace, with the net result that the combustion temperature is again lowered. Until a bed of coals is established to maintain a kindling temperature, a large part of the carbon remains unburnt in the form of smoke or is discarded with the ashes. The low-temperature combustion produces a low-quality heat, as described earlier with the bar.

Cooler gases not only carry less recoverable heat per pound, but a greater heat transfer surface or volume is required to obtain this heat. This is to say that the equipment required to transfer the same amount of heat will have to be much larger in the case of the colder gases as the rate of transfer varies directly with the amount of temperature difference between the donor and receiver of the heat. The usual engineering expression for this phenomenon is -Q = UA Delta, where the amount of heat exchanged equals a constant times the equipment size times the temperature difference. (Illustration No. 5)

The actual heating value of the fuel is increased by removing its moisture. A part of the heat of combustion is used to evaporate the water, as noted before, which lowers the total heat value of the fuel as illustrated on this graph of "moisture versus net Btu/lb of bagasse". Do not make the "optimistic error" of saying that the apparent increase in Btu/lb is proportionate to the same amount of heat increase in a fixed amount of moist fuel to be dried. (Illustration No. 3)

One pound of bagasse at $1 moisture and 3300 Btu/lb becomes 78 pounds of bagasse when dried to 37% moisture with a heating value of 4750 Btu/lb. While the ratio of heating value is 4750/3300 = 1.44, the ratio of total heat content is 3705/3300 = 1.12. The 12% increase in total heat of a crop of sugarcane will produce a lot of energy.

Another common argument, against the operation of a boiler in conjunction with a waste heat fuel dryer, is that the energy used to dry the fuel could be used to heat boiler feed water or combustion air and would amount to the same overall boiler efficiency; or to say waste heat recovery in the case of the use of boiler stack gases would be identical. (Illustration No, 2)

Please recall from previous discussions that wet fuels will tend to produce lower temperature products of combustion in greater quantities because of steam generated in the furnace along with additional excess air; therefore, a lower

Percentage of recoverable heat. (Illustration No. 6) Also, the percentage of heat recoverable from the exhaust gases is higher when a small amount of hotter gases is available. A better example of the final stack loss would be illustrated by making the bar representing the colder gases wider to show increased quantity and defining everything below the 250°F line as the loss. Other reasons for drying fuel are to reduce the quantity and weight of these materials for handling and storage purposes. Also, in the case of biodegradable materials, to prevent losses as CO or spontaneous combustion. (Illustration No. 1) The usual rotary dryer looks about like this.

1. A heat source which can be a furnace or a duct from some other process.

2. A stationary feed section, which is shown here as a part of the furnace with a feed chute into the drum. This can also be a screw conveyor extended into the drum.

3. The rotating drum with carrying rollers and drive gears (or sprockets). The drum contains some type of filters to mix material being dried with the air.

4. A stationary discharge section, to receive the material and gases from the drum and either separate and discharge them individually or simply blow everything to the cyclone.

5. An induced draft fan to pull the gases through the system along with the material. (It may be before or after the dust collector.)

6. The cyclone, which separates the material from the gases or merely removes the remaining dust from the exhaust.

7. An optional recycle duct which can be used to return some exhaust gas to the furnace.

The control of the rotary dryer operation can vary to some extent depending upon the heat source and the desired product quality. In the case of beet pulp where a 9% to 11% moisture product is desired, a furnace is required to turn the heat on and off as the feed load fluctuates. The final moisture is held within these limits by controlling a set discharge gas temperature, which in turn controls the furnace firing rate. The other usual control on the rotary dryer is the rate of gas.

The flow through the drum, if too high, will blow the material through the dryer without sufficient retention time to accomplish the drying. If it's too low, it will cause the dryer to clog. This flow rate (#25) is measured by one of the following indicators: the furnace negative pressure, the pressure drop across the drum, or the fan motor load, all of which vary with the quantity of material in the drum. The controller, sensing one of the above indicators, operates a damper on the ID fan to maintain the gas flow rate.

In the case of using waste heat from another source, the gas flow rate needs some control as above but the product moisture is allowed to fluctuate to some extent with the load to the dryer. Actually, the feed rate can be varied to maintain the desired final product moisture.

The size of a dryer varies with the quantity of materials to be dried, but more specifically with the quantity of water to be evaporated. Since the gas flow rate is fairly constant, as previously described, the only reasonable way to increase the quantity of gas flow for additional evaporation is to increase the dryer drum cross section. This is to say that the capacity of a dryer will vary as the square of the diameter, within the range of gas temperature restrictions.

Controlling the gas temperature will affect the evaporation rate within the operating range as previously explained. The retention time of the material being dried determines the efficiency of the dryer, where "efficiency" is the lowest discharge gas temperature that will accomplish the desired result. Retention time can be increased by increasing the dryer length (Illustration No. 4).

A two or three pass dryer is actually one long drum with a capacity proportional to its smallest cross section. Retention can be increased by increasing the percentage of the drum filled with material. One method of doing this is to use internal baffling which holds material throughout its cross section, as opposed to dropping the material from peripheral lifters alone. Various styles... [text ends here]

Internal baffling is used for various purposes, all of which have developed from the original beet pulp dryer design. In addition to increasing the percentage of the drum filled with material, these internal baffles distribute the material across the drum, thus preventing the gases from bypassing to the dryer exhaust. The additional metal also acts as a heat transfer medium between the gases and the moisture in the material, similar to a frying pan. All these features increase the rate of heat transfer and thereby improve the dryer efficiency.

There are practical limitations on the size of a waste heat dryer as dictated by capital cost versus annual total heat recovery. As previously explained, cooler waste heat sources require larger equipment at higher costs, but offer lower percent heat recovery. Year-round operations are preferable to seasonal operations, and drying at high moisture levels (say 40% to 80%) is more economical than drying at lower moisture levels.

The use of cooler waste heat gases requires a larger dryer for two reasons: 1. A larger quantity of gases is needed to carry the required quantity of heat, 2. A larger volume of contact between the gases and the material is required to offset the smaller temperature differential (Delta T).

The above factors aren't additive, but since they are not proportional to temperature changes to the same degree, they both have to be considered in dryer sizing.

Waste heat fuel dryers are well suited for operation with steam boilers as not only does the boiler use the fuel but also produces the waste heat. The arrangement indicated in the diagram is typical of a variety of applications where the boiler and dryer are operating in a closed loop. The wet bagasse feed is the beginning of the process and the boiler stack discharge is the end of the process, with steam as the product. The boiler flue gas can go to the dryer as needed, with the surplus going directly to the stack.

Specifically at this symposium, we are concerned with "cogeneration" of electric power and process heat, especially.

As applied to the cane sugar industry, most raw sugar mills today are burning their own bagasse to generate steam and electric power for their own processing needs. Unfortunately, these systems were designed to be heat inefficient in order to more completely incinerate the waste bagasse. The counterpart beet sugar factory, which must purchase fuel, is much more conscious of heat efficiency. (Illustration No. 7)

Utilities, whose sole product is electric power, have developed the most efficient use of steam for that purpose. In these cases, high pressure boilers feed steam to condensing turbines to attain the greatest pressure drop. Compare the percent recoverable heat of the high-pressure boiler versus that of the low-pressure boiler. Again, note the percent recoverable heat where the low-pressure boiler supplies a back-pressured turbine, as used by many sugar factories. (Illustration No. 8)

Despite a sugar factory's relatively inefficient heat process - which uses only about 8.5% of the available heat from its low-pressure boiler to produce electric power, it also uses another 76.5% for process heating by condensing the exhaust steam at atmospheric pressure. The latent heat of vaporization liberated by condensation is obviously the largest portion of the available heat from a low-pressure steam process. (Illustration No. 9)

The sugar factory with its low-pressure boiler and back-pressured turbine generates all of the electricity and process steam that it needs for its own operation. If in balance, it emits little exhaust to the roof or requires little exhaust makeup. However, most sugarcane factories do not burn all of their bagasse, and would need to burn even less bagasse if they adopted some of the steam economies of the beet sugar factories. If a balanced sugar mill were to have installed a high-pressure boiler with a suitable back-pressured turbine, it could generate additional saleable power, as represented by the area above the 160 psig level on the left side of the tall bar on

The graph, if the extra bagasse were burned in a high-pressure boiler and the additional steam were run through a condensing turbine, could generate additional power as represented by the right side of the tall bar. The heavy line on the right side of the tall bar represents the additional heat available by pre-drying the bagasse (or conversely, the heat recovered from the boiler waste gases). In conclusion, the cogeneration of a large amount of saleable electric power, in conjunction with sugar production, is now a reality. The Hilo Coast Processing Company of Hawaii now operates a very efficient power generating plant with its raw sugar mill and supplies a large part of the electricity used on the island. It uses bagasse from other mills in addition to its own, and has a high-pressure boiler supplying steam to a condensing turbine; automatic extraction from the turbine supplies process steam to the sugar mill. The dehydration of the bagasse not only increases its heating value as a fuel, but more especially increases the system's total output by making it operate at higher input temperature and exhausting smaller quantities of waste heat at lower temperature.

The rest of the text appears to be a random sequence of symbols, numbers, and words, which I am unable to fix. Please provide a more coherent passage for me to assist you with.

4.00% 4,009

825°F Hg=1400 1200 psig +S.H.

a a iu Soy 5 2 § : a 2 = a & a] z 3 = & 3 x 6 < a 370°F | 160 psig Hg=1196 | Voss 275°F 30 psig Hg=

1094 100°F = a 28"V

FIG. 7 STEAM TEMPERATURE vs. RECOVERABLE HEAT

ONILWAH HOS HS7IOG AUNSSAUd MOT WOU4 G3aY3SAO00S3Y LVSH TWNOILIGGV 2 ‘Old OH Ace osisH 5isd 9 AZLZ v60L"6H 6isd of ASLE 961 L6H 618d 091 doze

825°F Hg=1400 370°F Hg=1196 275°F Hg=1094 212°F 16 HIGH PRESSURE BOILER 1200 psig +SH E GS 8 2° s 38% Sa = FOR STEAM we y CONDENSED 2 o 3° Z| 22%N os Q go e zo S$ ea 2 ge iad a G 160 psig | 30 psig 0 psig Hf-180 100°F. 28'v Hg- 870 32°F. Hf-0

FIG. 9 RECOVERABLE HEAT WITH COGENERATION

OL‘old eB.Oy>Hg wekig pnposd Av1oy | H vst pao oss0609 1M eBivypsig soul WALSAS UV JAILISOd WILSAS NOILVUVdsud TINA

UTILIZATION OF BIOMASS/OIL FUEL BLENDS IN PETROLEUM-FIRED BOILERS

Presented To The Symposium FUELS AND FEEDSTOCKS FROM TROPICAL BIOMASS

Caribe Hilton Hotel, San Juan, Puerto Rico

November 24 and 25, 1980

Contributed By COMBUSTION EQUIPMENT ASSOCIATES, INC, New York, N.Y.

UTILIZATION OF BIOMASS/OIL FUEL BLENDS IN PETROLEUM-FIRED BOILERS

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SLIDE LEGENDS FOR CEA PROCESSES

SUMMARY

FIGURES

UTILIZATION OF BIOMASS/OIL FUEL BLENDS IN PETROLEUM-FIRED BOILERS

Floyd Hasselriis and Alphonse Bellacl

Combustion Equipment Associates, Inc, New York

ABSTRACT

THE DRASTIC increase in oil prices has changed the economic value of biomass crop residues and created incentives toward increased energy recovery and power generation efficiencies. The highest efficiencies can be achieved by burning dry, powdered biomass fuels such as ECO-FUEL™ and AGRI-FUEL™ in utility boilers, Cofiring of ECO-FUEL in suspension with

Oil in Bridgeport, Connecticut has already been demonstrated to provide up to 50% of boiler heat input with highly satisfactory results. These include no loss in plant efficiency, acceptable stack emissions, and minimal tube fouling. AGRI-FUEL has been produced in a CEA pilot plant in Connecticut. Indications show that dry, powdered fuels prepared from crops and crop wastes have significant potential as a storable, transportable fuel for co-firing with oil in new and existing boilers and cement kilns.

Present addresses: Corporate Technology (P. Hasek), and Director of Corporate Market Development (Helo), COMBUSTION EQUIPMENT ASSOCIATES, INC, 838 Madison Avenue, New...

UTILIZATION OF BIOMASS/OIL FUEL BLENDS IN PETROLEUM-FIRED BOILERS.

INTRODUCTION

BIOMASS offers a renewable alternative to petroleum oils as an energy source, especially in tropical islands, offering the possibility of energy self-sufficiency. In the past, biomass, such as bagasse and crop wastes, were burned in boilers with waste disposal as the major objective, alongside generating only the thermal and mechanical energy required by the sugar mill. This dual purpose resulted in both wasteful use of heat in the sugar mill and inefficient recovery of energy from the bagasse. Attempts to extract more energy from the bagasse would result in excess energy which the plant could not use.

The export of power from sugar mills has attracted greater interest recently as the price of oil has increased manyfold. Utilities are now willing to pay for export power at rates which reflect the cost of oil, and governmental regulations are increasingly being changed to include the capital cost of new power plants in the price paid for exported power.

This new economic situation has sparked interest in areas such as: improving the efficiency of existing sugar mills to maximize the power export, and increasing the production of fuel from biomass for transport routes and industry as a means of reducing dependence on oil.

INCREASING POTENTIAL FOR BIOMASS

"As a consequence of increased revenues from the export of power, we now see an effort to use less power in the sugar mill. This is done to increase boiler efficiency, boost the thermal efficiency of power conversion in the mill, employ heat recovery devices where practical, and improve the thermal efficiency of the sugar refining process itself.

These measures have been carried out extensively in Havana, Florida, and other places where utilities are now required to show active interest. In the past, they were only offering a pittance for excess power. As power production rather than heat generation becomes the economic objective, increasing the thermal efficiency of power generation becomes important. Low-pressure boilers and turbines produce only a fraction of the power from the same heat energy as high-pressure, high superheat boilers.

Drying the bagasse before firing and using stack gas heat recovery become attractive. The recovery of stack gas heat by air preheat economizers becomes justified. We also see a shift toward molasses and alcohol production which results in different energy balances and economics.

The direct production of fuel from biomass, without the necessary association with sugar production, has become more attractive as oil prices fluctuate and continue to rise. Over the last few years, the Center for Energy and Environment Research at the University of Puerto Rico has been closely following the interesting and exciting "energy cane management" concept.

The implementation of this concept would materially increase the amount of biomass available for energy production. As sugar becomes a less rewarding crop, the same land can be converted to grow crops for energy. However, to do this, we must find the energy users who can burn this fuel as a partial or even full replacement for oil, since the sugar mill is no longer the major user.

As previously mentioned, sugar industry boilers have historically been designed as a bagasse incinerator."

The better the efficiency, the easier to dispose of all the excess bagasse. Generally, if electricity is generated with these inefficient low-pressure boilers, it would require between 15,000 and 20,000 BTUs per KW Hr. On the other hand, if electricity is generated in a modern efficient power plant, the heat rate would be in the range of about 10,000 BTUs per KW Hr. In other words, burning biomass in existing sugar mill boilers for the purpose of generating electricity, rather than for the purpose of getting rid of the biomass, would waste about 50% of the energy in the biomass. For this reason, CEA has developed a fuel from biomass which can be burned inefficient utility boilers and in general act as a direct oil replacement in cement kilns or other applications.

LIMITATIONS OF SUGAR MILL COGENERATION

While cogeneration in a sugar mill has some obvious advantages in that it serves the purpose of providing power and low-pressure steam for the mill, the sale of excess electricity to a utility is a decidedly unattractive proposition from the utility’s point of view unless such excess electricity is available in relatively large quantities at predictable and desirable times.

In the case of Puerto Rico, where the grid capacity is about 2000 MW, the task of accepting and absorbing relatively small amounts of electricity from sugar mill cogenerators presents more of a problem than it's worth. Typically, a sugar mill would have an excess of 5 to 10 MW at varying and unpredictable times and the cost of dealing with it would probably be greater than the cost of the fuel oil saved, if there are any savings of fuel oil at all.

The revised text:

Should utilities buy excess electricity from cogenerators, it would be much more desirable for excess biomass to be converted into a comparable, storable, and transportable fuel. This fuel could then be burned in more efficient applications to minimize the waste of biomass energy. You may be aware that the CEA, in conjunction with CEER-UPR, has submitted a grant application to the U.S. Department of Energy (DOE) to finance a feasibility study to explore such a biomass fuel concept. We see utilities and industries, such as the cement industry, as major consumers since they use energy consistently, unaffected by seasonal variations. However, even with industry's interest in biomass fuel, they cannot consume the full potential production, hence they may be the tail of the kite. So far, so good. We see great potential for biomass as an alternative to petroleum in power generation, particularly in efficient boilers with efficient power cycles. But what are the obstacles? Why can't biomass be burned as an alternate fuel, replacing oil?

BIOMASS CONSTRAINTS AS AN ALTERNATIVE FUEL

There are several reasons why biomass hasn't been widely utilized as a fuel source. Some of these reasons are trivial, some surmountable, and some limit the range of its application. These include:

1. Boilers designed for one type of fuel may not be able to burn fuels with different characteristics.
2. Boilers may not be able to burn two different types of fuel simultaneously.
3. The ash content of biomass fuels necessitates the use of fly ash collectors, which are not needed for petroleum firing.
4. Tube-fouling, slagging, and erosion caused by biomass fuels may not be tolerated by boilers designed for oil.
5. Furnace and superheater temperatures can be affected by the nature of the fuel, which is why the fuel affects boiler design.
6. Control of boilers burning multiple fuels can be difficult, inefficient, or ineffective, if not impossible.
7. Reliable production of power requires a dependable supply of fuel and reliable combustion. This often means that oil must be used.

"Burned whenever the biomass fuels are insufficient, whether for an instant, an hour, a day, week or month. (4) Oil can be readily stored. Biomass fuels must also be stored to assure a steady supply to follow power demand. There are obviously many problems and questions which can be raised. What proof or answers can we offer? There are many bagasse-burning plants which demonstrate that oil can be used to sustain the combustion of bagasse in sugar mill boilers. Some modern bagasse-burning boilers use high steam pressures and temperatures. There are reports that some of these boilers have experienced tube failures when operated near their ratings when oil is fired, attributed to the hotter flame produced by oil. These faults are probably correctable, but the contradiction between wet and dry fuels remains. There are reports that, with substantially improved control systems, bagasse firing with oil assist can generate reliable exportable power. There are reports that drying the bagasse before firing improves reliability and reduces the need for supplementary oil. These reports indicate oil can be co-fired with bagasse to a certain extent in sugar mill boilers associated with fairly efficient power cycles, and that this course of action will continue to progress. BIOMASS AS A PREPARED FUEL Bagasse is a prepared waste fuel. The grinding was needed to extract the sugar. The product is over 50% water and contains large fibers which are slow-burning, needing a large combustion chamber to minimize char and black particulate. It is reasonably stable. Other types of biomass would have to be ground to permit feeding to the boiler. Their variable moisture content would cause problems in firing the boiler and maintaining reliable, efficient power production. We can draw an analogy here with the urban waste-to-energy experience of recent years. Consider the following points: Municipal Solid Waste (MSW) and Refuse-Derived Fuel (RDF), are essentially biomass, albeit heavily contaminated. Experience with RDF has..."

It has been shown that moisture, ash content, and particle size cause problems in proportion to their extent in the fuel. Experience has demonstrated that dry powdered RDF (ECO-FUEL™) can be burned in a utility boiler, initially designed for coal, with beneficial results provided it has adequate emission controls such as an Electrostatic Precipitator (ESP).

Wood has been burned in bark boilers with or without assistance. Ground wood and sawdust have been fired in an industrial packaged boiler designed for oil, with and without oil assistance.

These considerations indicate that dry, powdered biomass-derived fuels can be burned in industrial packaged boilers and utility boilers much more readily than wet, unprepared fuels. The principal reasons for this are:

1. Small particles ignite quickly at low temperatures.
2. Biomass is highly volatile and burns like gas.
3. High combustion temperatures and rapid combustion allow for smaller combustion chambers.
4. The ash in biomass is fine particulate which does not cause excessive slagging, fouling, or tube erosion when properly fired.

What we see here is that highly processed biomass fuels can substitute for petroleum oil in some existing boilers and certainly in properly designed boilers. A dry powdered fuel is much more compatible with oil firing than a large-particle moist fuel.

CEA has developed processes to reduce both Municipal Solid Waste (MSW) and crop wastes such as bagasse to dry powdered fuels which are storable, transportable, and readily conveyed by conventional powder handling systems. They open up entirely new potentials for biomass-to-energy.

The following slides will illustrate these plants and processes.

Unfortunately, the rest of the text is unclear and seems to contain incomplete sentences or phrases. It might be helpful if you could provide more context or clarify what you need assistance with.

"Weinan et al. 'These slides show how much moisture and ash reduce heating value, and reduce boiler efficiency. Figure 7: Combustion Characteristics of Coal, Oil, and ECO-FUEL. This slide shows the rapid release of energy from ECO-FUEL to be similar to that of oil. Figure 8: Packaged Boiler Burning Powdered Wood. Boilers of this type, designed basically for oil firing, have been used to burn sawdust and bound wood without major modification, when equipped with double-vortex and other suitable burners. Figure 9: Fuel Preparation Plant for Wood Waste. Figure 10: Histograms of Emissions of Fuels.

SUMMARY: Past practice has been to burn crop wastes inefficiently, with minimum processing. As the cost of oil increases, economics dictate investment in more drying and size-reduction of biomass wastes and ultimately toward production of dry, powdered biomass fuels such as ECO-FUEL and AGREFUEL, which can be burned with or without oil in boilers essentially designed for oil. This new technology is still in the state of development but has already been partially demonstrated.

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Figure 48: FUEL HANDLING SYSTEM, ASH REMOVAL SYSTEM. Figure 2: The Bridgeport ECO-FUEL II Storage and Transfer System.

Figure 3: The United Illuminating Boiler.

anoss2outen “yoorquotg Paueta rertd Tand-TeO RTT

Figure 12: Comparison of Fuel Properties (in Oak Western Penn. Resid, Dry basis) Bark, Bark, Coal" eng” BoO-mumt_xontsrums_ SS Faia Volstite 72.9 76.0 a. 57.7 1 as Fixed Carbon 24:20 87 SA? 82.2, 8 15 ah 2 ss AS eld 2 ca s untisate Hydrogen 5.6 648.0 5.7 5.0 a carbon sa seg 74.2 a asa 8 ‘Sulfur 2 oe TNT "7 2 1 Nitrogen a Yo 1s 8 ote sr sss 71280 ae 9080 9420 13,810 8200 asz 8 na 7 780.7 a9 5 3300 Sea 9.9 2 or aaa - Moor 6 68 a 28 7 Ls BS 6S Ls 8.0 - 6S 12 a7 aa 29.0 Ls ag ae 5.8 0.6 60 2 - -

1s sv pus aanasion snsseq NI-THOV PUR Tand-cDe “40K “ASK 30 enTNA BuTaeeH °F SHOT"

The following text is corrected:

Though there are problems and obstacles in these alternate sources of energy, they are modest in comparison to the problems surrounding oil, both at present and in the future. Current address: Puerto Rico Electric Power Authority, Division of Planning and Engineering, G.P.O. Box 4267, San Juan, Puerto Rico 00936.

PREPA ANALYSIS OF FOSSIL, FOSSIL/BIOMASS AND BIOMASS BOILER FUEL OPTIONS

INTRODUCTION

Electricity costs have risen around 150 percent during the last six years in Puerto Rico (1). This is strictly due to the fact that 90 percent of our electricity is generated via thermoelectric power plants that use imported oil derivatives as fuel. As we all well know, the cost of these imported fuels has jumped in an unprecedented way during the last seven years. In Table 1 (2), we present the price paid, the barrels consumed, and the total cost for if used in the production of electricity during the past ten years. Our load forecasts are also predicting that by the end of this decade at least 900 megawatts of capacity will have to be added to our system to satisfy the demand for electricity on the Island (3).

ANALYSIS

1. Fossil Fuels

Given these two hard facts about our electrical energy situation, what fuel are new units going to use? The Authority had only two choices; either nuclear or coal. The nuclear alternative was discarded because, apart from the uncertainties that exist at this moment with regard to nuclear plants and especially their radioactive wastes, it would have taken too long to be put into operation (mainly because of the licensing requirements). So the only alternative we had was coal (4). Nevertheless, one has to be very careful when utilizing coal. For instance, some problems could arise if the properties and quantities of impurities are not considered in the design and operation of the generating equipment. Take for example the coal ash; if it is not properly considered in the design and operation of the boiler it can deposit not only on the furnace walls and floor, but also through the convection.

Banks. This not only reduces the heat absorbed by the unit, but also increases raft loss, corrodes pressure parts, and eventually causes irregular or unscheduled shutdown of the unit for cleaning and repairs (5). Another aspect that must be carefully considered in coal usage is that, although boilers are often designed and equipped to use a wide range of coals satisfactorily, no boiler installation will perform equally well with all types of coals. All coals have certain properties which place limitations on their most advantageous use (6). To define the limitations of various types of coal burning equipment in service, specifications covering several important properties of coal are necessary. For example, in pulverized-coal firing, which will probably be the type of firing to be used by the Authority's units, it may be necessary to specify ash-slagging and ash-fouling parameters for a dry-ash installation.

2. Fossil/Biomass Fuels

Boilers that use coal as fuel can be designed to use other fuels as backup. PREPA's units are going to be designed to use oil as backup fuel. The decision was made based on the fact that if there should be any interruption in supplies of coal (although there will be a three month coal supply storage system), the unit would be able to continue its operation (7). Oil will be stored in tanks with a capacity for 30 days usage. At this point, we could ask ourselves: should the Authority have considered other fuels such as bagasse or solid waste to use as backup for these units? Let's analyze this situation.

Assuming a need for 200 MW, and a heat of 9145.77 BTU for 7352 hours a year (or 7,352 hours divided by 24 hours, which equals 306.33 days per year), then the rate of consumption per day is 756,000 SSE divided by 306.33 days, which equals 2,467.93 tons per day. If we continue at this rate of 2,467.93 tons per day, then the heat content needed per day is: 59,23 x 109 BTU per day divided by 6 BTU per ton, (4x 108 EEE) which equals 2,467.93 tons per day.

So, how many barrels of oil will we need per day in order to replace coal? Since there are...

The text corrected:

We need to calculate 6,087 x 108 to meet a requirement of $9.23 x 109 BTU.

Next, we have 59.23 x 10? and 6.087 x 106 BTU. This equates to 9.73 x 103 barrels or 9,730 barrels. For a 30-day storage of oil, this is equivalent to: (9,730 barrels) (30 days) = 291,900 barrels of oil.

Considering bagasse, how many tons would be needed to replace coal? Assuming that sugarcane biomass has heat content of 14.00 x 105 BTU and we need 38.23 x 109 BTU, then we calculate as follows: 59.23 x 108 + 1400 x 106 BTU equals to 4.3 x 10! or 4230 tons.

For a 30-day storage, we would need: (4,230 tons) (30 days) = 126,900 tons.

Calculating for solid waste, assuming that it has heat content of 9.28 x 108 BTU and we need 5.29 x 109 BTU, the calculation would be: 59.28 x 10? + 9.248 x 108 equals to 6.41 x 103 tons.

Maintaining the 30-day storage requirement, we would need to store: (6,410 tons) (30 days) = 192,300 tons of solid waste.

As we can observe from this analysis, if we were to use either bagasse or solid waste as a backup fuel to coal in this 300 MW capacity unit instead of oil, we would need to store 126,900 tons of bagasse or 192,300 tons of solid waste to meet the 30-day oil storage criteria (see Table 2). Both bagasse and solid waste are more complicated than oil in terms of handling, storage, transportation and preparation.

Both bagasse and solid waste have a high moisture content; therefore, drying is essential (see Table 3). The most important factor to consider is whether the boiler will be able to burn either bagasse or solid waste to replace the coal. That is, can a pulverized-coal fired boiler be designed so as to burn bagasse or solid waste as a backup fuel? Preliminary research indicates that it is possible for such a fuel backup to be used, but extensive modifications to the boiler would have to be made. These alterations to the boiler...

The original price of the boiler would substantially elevate (12). 3. Biomass Fuel: As for a strictly bagasse-burning unit, the Authority has taken its first steps in that direction by analyzing the alternatives that exist within our system to develop a plant on an experimental basis (13). Among the alternatives being considered are the former experimental nuclear power plant at Rincon, on the western part of the Island, with a turbo-generator capacity of 17 megawatts, and the San Juan Power Plant Units No.1, No.2, and No.4, each with a 20 megawatt capacity. The aspects which the analysis is considering are: (a) The available equipment; (b) the sugarcane plantation versus the unit location; (c) transportation; (d) storage of the bagasse and the fiber; and (e) heat content of the bagasse to be used in the boiler.

An important aspect to consider in this experiment is the moisture in the bagasse. Gas produced from bagasse has a high moisture content whose weight is about twice that produced from oil and one and one-half that from coal. This high gas weight causes a high draft loss and requires either extremely high stacks or large fans to obtain the required steam capacity from the boilers. A low draft boiler can alleviate these conditions (14). Bagasse drying via a mechanical dryer, or solar dried, could be a solution. Another answer might be to use the existing gases of a high-pressure boiler. This, apart from increasing the heat content of the bagasse, would reduce the amount of gases in the furnace, producing a cleaner operation in the boiler (15).

CONCLUSION: We have shown some of the problems we could encounter when shifting from oil, our traditional source of electrical energy, to other fuels such as coal and sugarcane bagasse. Nevertheless, we at the Puerto Rico Electric Power Authority think that these obstacles are small in comparison to the economic burden and supply limitation if we continue our dependence on oil. The Authority is committed to supplying the lowest price possible.

The electricity is needed to sustain the economic development of Puerto Rico. In order to do so, we will have to solve all of the problems which are limiting the use of alternative fuels at the present moment.

3. % ne a2. 3. a. as. Arias, V. 1979. Analyst for Economic and Financial Forecasts. Puerto Rico Electric Power Authority - Planning and Research Division. Sanchez, J. 1980. Supervisor, Generating System/Alternate Energy Sources Department. Puerto Rico Electric Power Authority, Planning and Research Division. Lavina, R. 1979. A Generation Expansion Plan For Puerto Rico. Puerto Rico Electric Power Authority. Planning and Research Division, September. Ibid. Steam, Its Generation and Use. Babcock & Wilcox, Copyright 1972. Ibid. Lavina, R. 1979. A Generation Expansion Plan For Puerto Rico. Puerto Rico Electric Power Authority. Planning and Research Division, September. 'Anon. 1980. Production Cost Models, Generating System/Alternate Energy Sources Department. Puerto Rico Electric Power Authority, Planning and Research Division. Steam, Its Generation And Use. Babcock & Wilcox, Copyright 1972. Alexander, A. G. 1979. Sugarcane Bagasse as a Boiler Fuel for Puerto Rico. Presented to: La Comisión de Agricultura de la Cámara de Representantes de Puerto Rico, November. 'Anon. 1975. System Analysis of Energy and Material Recovery From Solid Waste Of The San Juan Metropolitan Area. Puerto Rico Electric Power Authority. Planning and Research Division, November. Personal communication with personnel from Combustion Engineering Co. ElKoury, J. M, 1980. An Experimental Electrical

Generating Unit Using Sugarcane Bagasse Fuel. Puerto Rico Electric Power Authority, August. Steam, Its Generation And Use. Babcock & Wilcox, Copyright 1972. Reed, T. and B. Bryant. 1978. Densified Biomass: A new Form of Solid Fuel. Solar Energy Research Institute, U.S. Department of Energy, July.

Table 1 PRICES, QUANTITIES PURCHASED, AND TOTAL COSTS OF OIL, USED FOR THE PRODUCTION OF ELECTRICITY; 1970-1980 Expenditures ~

Below is the corrected version of the text:

Bad Sis Bol x 10° Total cost ($ x 10°)
1970 1.66 11.38 18.9
1971 2.27 13.78 29.9
1972 2.83 16.59 46.9
1973 3.28 20.29 66.9
1974 7.27 20.22 147.0
1975 11.09 18.22 202.2
1976 2.7 20.69 263.6
1977 13.36 22.57 301.5
1978 14.43 23.86 346.3
1979 13.79 23.99 330.8
1980 21.75 23.38 508.5

Table 2 ESTIMATED HEAT CONTENTS, DAILY CONSUMPTION, AND 30-DAY STORAGE REQUIREMENTS FOR OIL AND THREE ALTERNATIVE FUELS

Estimated Values For Fuel Heat Content Daily Consumption 30-day Storage
Oil 6.08 x 10° BD 9,730 BOL 291,900 Bbl
BL Day
Coal 24.00 x 106 BTU 2,468 Bagasse 14.00 x 108 BTU 4,230 Ton 126,900 Tons
Solid Waste 9.25 x 10° BTU 6,410 Tons 192,300 Tons

Table 3 PROXIMATE AND ULTIMATE ANALYSES FOR BAGASSE AND COAL

Fuel Coal Bagasse
Proximate:
Moisture 2.5 52.0
Volatile Matter 37.6 40.2
Fixed Carbon 52.8 NA
Ash 7.0 NA
Ultimate:
H (Hydrogen) 5.0 2.8
C (Carbon) 75.0 23.4
S (Sulfur) 2.3 Trace
N (Nitrogen) 1.5 NA

O (Oxygen) 6.7 20.0
H2O (Water) 2.5 52.0
A (Ash) 7.0 NA

Source: Steam: Its Generation And Use. Babcock & Wilcox. 1972.
2/ As fired; % by weight.
3/ Pittsburgh Seam Coal; West Virginia.

THE MOLASSES CRISIS IN THE PUERTO RICO RUM INDUSTRY

Presented To The Symposium FUELS AND FEEDSTOCKS FROM TROPICAL BIOMASS
Caribe Hilton Hotel, San Juan, Puerto Rico
November 24 and 25, 1980

Contributed By Dr. George Samuels
AGRICULTURAL RESEARCH ASSOCIATES
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THE MOLASSES CRISIS IN THE PUERTO RICO RUM INDUSTRY

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THE MOLASSES CRISIS IN THE PUERTO RICO RUM INDUSTRY

Dr. George Samuels
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ABSTRACT

IN 1978 the Puerto Rico rum industry provided 85% of the U.S. rum market, returning to the PR treasury $200 million in Federal excise taxes. The diminishing PR.

The sugar industry is currently unable to supply sufficient blackstrap molasses (BSM) to meet the needs of the expanding Puerto Rico rum industry. At present, imports from foreign suppliers make up 88% of its needs. These imports place the rum industry in jeopardy, as these suppliers can boycott Puerto Rico to protect their own rum production, or they can insist by treaty that all rums claiming geographic origin (i.e., “Puerto Rico” rum) must be distilled from molasses produced in that country.

The purpose of this paper is to present possible solutions to improve domestic molasses production to eliminate these threats. The use of high-test molasses (HTM) would answer the present and future needs of the rum industry if produced by the energy cane (or biomass) concept. This is a management concept stressing total growth potential rather than sugar. It would permit doubling cane production per acre and produce sufficient HTM on 70,000 acres for the projected rum industry requirements.

Considerations of HTM production show that problems exist with the marketing price rather than in the field or factory. The economics of HTM pricing will have to be worked out by the interested parties: The rum industry, the sugar industry, and the government.

Agricultural Research Associates, 2001 Glenridge Way, Winter Park, Florida 32792.

THE MOLASSES CRISIS IN THE PUERTO RICO RUM INDUSTRY

INTRODUCTION

Puerto Rico rum has become the favorite rum in the United States, capturing 85% of the rum market in 1978-79. Sales increases of 43% and 147% have been projected for 1983 and 1988, respectively (1). Rum production and exports have increased greatly in the past 15 years (Table 1).

The taxes from rum sales are an important and growing source of Puerto Rico's Government revenue. For every proof gallon of rum produced in Puerto Rico and shipped to the mainland, there is a return of the U.S. $10.50 excise tax to the Puerto Rico Treasury Department. For each proof gallon sold in Puerto Rico, there is a local tax payment of $9.50. The Federal excise tax

"Returns for 1978-79 were about $200 million, and Puerto Rico's tax was about $34 million. The total of $234 million returned to General Fund revenues amounted to 14.4% of the total revenues received by the Puerto Rico Treasury. This means that of every seven dollars going into the Puerto Rico Treasury, the rum industry contributed one dollar.

The Puerto Rico rum industry is threatened by a problem which jeopardizes its future. This threat is posed by the lack of sufficient domestic molasses, the basic raw material for rum production. A declining Puerto Rico sugar industry has failed to meet rum industry demands for molasses since 1972. This deficit has been made up by importing molasses from other parts of the world. For 1980, the rum industry will have to import 87% of the molasses it uses. The cost of importing molasses from foreign sources adds to the Island's balance of payments deficit.

Dependence on imported molasses leaves the rum industry at the mercy of foreign rum producers, who, by adopting a multilateral definition of rum, can decree that rum must be distilled from molasses produced in the country of origin. This claim of geographical designation can eliminate "Puerto Rico" rum. A decision of the molasses-producing countries not to sell molasses to Puerto Rico would destroy most of the Puerto Rico rum industry.

The local production of sufficient molasses for the Puerto Rico rum industry can eliminate the "foreign threat" and reduce the balance of payments deficit. It is the purpose of this paper to present possible solutions for improving molasses production in Puerto Rico. A proof gallon of rum is defined as one gallon of rum at 100° proof (50% alcohol).

2. MOLASSES

1. The Raw Material

Sugarcane molasses is the basic raw material used in manufacturing rum. It is the end product of either raw sugar manufacture or refining. It is usually designated as "final" or "blackstrap" molasses (BSM). It is the heavy, viscous liquid separated from the final, low-grade massecuite from which no further sugar can be efficiently extracted."

Further sugar can be crystallized by the usual methods. The chemical composition of BSM varies with sugarcane varieties, weather, soil condition, harvesting methods, and processing conditions in the sugar factory. The main BSM constituents are water (17-25%), total solids (77-84%), Brix (85-92%), suerote (30-40%), total reducing substances (10-25%), other carbohydrates (2-5%), and ash (as carbonates, 7-15%).

One BSM gallon contains about 6.75 pounds of sugar, and it will produce about 0.75 proof gallons of rum. One ton of cane will produce about 6 BSM gallons. For Puerto Rico, this varied from 5.9 gallons per ton of cane in 1954 to 6.4 gallons in 1980.

"High Test Molasses" (HTM) is the name given to clear, light brown, heavy, partially-inverted cane syrup having 85° Brix. The term HTM is a misnomer because it is made directly from the concentrated, clarified cane juice, and no sugar is removed. The term "molasses" is generally used to designate material from which sugar has been removed by crystallization. However, HTM will be used herein as it is the term used in the sugar industry.

Milling, clarification, and evaporation for HTM follow the same steps as in raw sugar production. The syrup is inverted and then evaporated to 85° Brix. A typical HTM analysis shows 85° Brix, 27% sucrose, 50% reducing sugars, 2.25% ash, and 5.5% water. There are about 9.8 pounds of sugar per HTM gallon (the range being from 9.4 to 10.2), and 17.6 HTM gallons per ton of cane (the range being from 13.3 to 21.8).

Some confusion exists in the designation of sugar in HTM, as it contains sucrose and reducing sugars which combine to form the fermentable solids, or "sugars in HTM". One gallon of HTM is equivalent in sugar to about 1.5 BSM gallons. A HTM gallon will yield about 1.20 proof gallons of rum.

The Puerto Rican sugar industry was the major molasses supplier for Puerto Rican rum producers until 1971 (Table 2) when the increased needs of the booming rum industry surpassed the declining molasses supply. From 1971 onwards, the supply has been in decline.

From this point onward, rum producers were forced to import molasses to offset the dwindling supply of domestic Blackstrap Molasses (BSM). Imports have come from the Dominican Republic (major supplier), Haiti, Jamaica, Guyana, Brazil, Colombia, Panama, Mexico, and South Africa. In 1972, approximately 16% of the rum distiller's BSM was imported. By 1979, this figure had increased to an estimated 88%. Thanks to research, quality control, and advertising, the Puerto Rico rum industry has captured 85% of the U.S. rum market. Beginning with 296,300 proof gallons shipped to the U.S. in 1936, Puerto Rico rum shipments increased to 20.1 million proof gallons in 1979. Projections indicate that about 50 million proof gallons will be produced in Puerto Rico by 1985. This output will require about 75 million gallons of blackstrap molasses.

The storage and transportation of domestic High Test Molasses (HTM) for the rum industry will present certain problems. Storing HTM at extremely high temperatures will result in sugar losses. Experiments indicate that 100°F results in sugar losses. Since 1972, when BSM was first imported into Puerto Rico, a specific pattern of shipments has been followed to maintain a steady supply throughout the year and to minimize storage. Molasses is received from local sugar mills, the Dominican Republic, and other Caribbean areas from January to June. Shipments are received from Brazil, Colombia, and other sources in the July to December period when these countries are harvesting sugarcane.

Increased storage capacity will be needed to store the domestic HTM for the offseason when mills are not grinding. Usually, cane is harvested from January to June in Puerto Rico. The adoption of the energy cane concept proposed by CEERUPR scientists would enable the grinding season to be extended to about 8 months, i.e., from December through July. Thus, HTM storage would be reduced to a 4-month period.

Transportation is a factor that must be considered with domestic HTM production. The principal rum distillers, which produce over 88% of the Puerto Rican rum, must take this into account.

Rico Rum, located on the north coast, produces 72%. Bacardi, located in Catano, and Puerto Rico Distillers, in Arecibo, produce 168%. The remaining distillery, Distilera Seralés in Ponce, on the south coast, produces 12%. A significant portion of the future HTM production will likely be on the south coast. However, transporting the HTM by truck would be too expensive. It currently costs approximately 1.2 cents per gallon per mile to transport imported BSM from the dock in San Juan to the Bacardi plant in Catano, which is about 9 miles away. The most affordable method would be to transport the HTM by barge. Dock facilities are available in San Juan and Ponce for this purpose.

POSSIBLE SOLUTIONS

Several potential solutions could eliminate Puerto Rico's dependence on foreign molasses. This section will present these solutions from a technical standpoint. A future publication will tackle the economic feasibility of addressing the molasses issue.

1. Produce Sugar and BSM: The usual routine of sugar and BSM production, as currently practiced

by the Puerto Rico sugar industry, yielded only 14 million BSM gallons in 1980, or about 12% of rum industry needs. It's estimated that 62 million BSM gallons will be required by the rum distillers in 1981. The sugar industry would need about 359,000 acres of cane to produce this volume of BSM, based on current yields of 6.4 BSM gallons per ton of cane and 27 tons of cane per acre. Even energy cane, yielding 80 tons per acre, would require about 77,500 acres. These increased acreages would conflict with the proposed agricultural needs for food production. Thus, BSM is not a suitable molasses source to meet the demands of the Puerto Rico rum industry.

2. Maintain the current sugar industry and produce HTM: The production of molasses for rum can be increased fourfold by diverting all sugarcane production to HTM instead of sugar and BSM. For 1981, about 41.5 million HTM gallons could potentially be produced (equivalent to 62.2 million BSM gallons) on 87,300 acres of cane.

Acres yielding 27 tons of cane per acre (Table 3). This would meet the rum industry's needs projected for 1981, but it would only meet 83% of the 1985 estimated needs of 75 million BSM gallons. It would not be possible to supply sufficient molasses by this means for the expanding rum industry.

3. Develop the "Modern Agricultural Plan" for the Sugar Industry, Producing HTM Instead of Sugar and BSM.

The Puerto Rico Department of Agriculture, in its "modern" agriculture plan for the Island, has designated 70,000 acres for sugarcane, yielding an average of 3 tons of sugar per acre (6). This plan calls for a yearly production of 200,000 tons of sugar to supply the local market. If implemented, this plan could provide 43 million HTM gallons, equivalent to 64.7 BSM gallons, which would satisfy the 1981 rum industry needs. By 1988, the rum industry requirements (based on a 5% yearly growth) would climb to about 90 million BSM gallons. A deficit of about 28% in molasses production would be anticipated with this plan.

4. Develop the Energy Cane Concept and Produce HTM and Boiler Fuel.

A research project proposal entitled "Energy Cane Management for Boiler Fuel and Molasses" was submitted on November 4, 1979 to the Office of the Governor, Commonwealth of Puerto Rico. It was prepared by scientists of the CEER-UPR Biomass Energy Program, and was based on sugarcane research data obtained under the sponsorship of the U.S. Department of Energy (7). The basic concept of the proposal is a pilot-scale demonstration of sugarcane's value as an energy crop and source of HTM. By applying modern agronomic techniques based on sugarcane's real growth potential rather than sugar, viable cane yields in excess of 80 tons per acre per year were demonstrated (4). Juice quality data indicated that over 1700 HTM gallons per acre could be recovered from this cane. Critics of this project, and of the energy cane concept in general, have been reluctant to believe that sugarcane production can be increased by a factor of three as claimed. It is difficult.

For people who have dealt with Puerto Rico's sugarcane all their lives, it might be hard to accept the production of 80 tons of millable cane per acre, even on experimental plots. Actually, even when managed for sugar rather than biomass, sugarcane has often produced more than 60 tons per acre on the fertile, irrigated, and well-managed soils of Puerto Rico's south coast. By selecting high-tonnage varieties and managing them for maximum growth, yields in the order of 80 tons per acre per year are not at all exceptional. The quantity of molasses produced on 70,000 acres, about 9 million gallons, would supply the fermentable solids needed by the rum industry in 1981. For future molasses needs of the rum industry, various combinations of HTM, and lower quality HTM, could be produced while simultaneously accommodating some sugar production during periods of high sugar values. From 70,000 acres of energy cane, a HTM yield of 99 million gallons (equivalent to 148 million gallons of BSM) could be obtained. The use of 40,000 acres of irrigated cane lands on the south coast, yielding about 80 tons of energy cane per year, could provide about 56 million HTM gallons. This is approximately 85 million BSM gallons (Table 3, solution 44).

CONCLUSION

The use of energy cane methodology to produce HTM on 70,000 acres can supply more than enough molasses to meet the needs of the Puerto Rico rum industry. This cannot be accomplished by present sugar industry methods aimed at raw sugar and BMI. There could exist a pricing problem for HTM as regards the use of current sugar values or BSM equivalent prices. The economics of HTM pricing will have to be worked out by the interested parties: The Puerto Rico rum producers, the HTM producer (Puerto Rico's sugar industry), and the Puerto Rico Government. Cooperation by all parties is needed to resolve the pending crisis in the Puerto Rico rum industry.

ACKNOWLEDGEMENTS

Thanks are given to Prof. William Alison, Head, Department of Agricultural Engineering, University of Puerto Rico at

Mayagüez, and Mr. Mariano A. Romaguera, Puerto Rico Sugar Corporation, Mayagüez, for supplying opinions and data on HTM composition and production. Thanks are also expressed to Mr. René F. Rodriguez, Caribbean Industrial Molasses Company, San Juan, for data concerning BSM and HTM pricing, and to Mr. Carlos L. Yordan, Puerto Rico Rum Producers Association, Inc, San Juan, for data on rum production and exports. The excess HTM capacity allows for the possibility of producing sugar as well as HTM when sugar prices are favorable.

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TABLE 1. Puerto Rico rum production, sales, and taxes 1965-79
Production Sales (FG x 106) Taxes ($ x 108)
Year PR (x 108) US PR Federal PR
1965-66 14.5 3.7 -
1966-67 13.4 28 -
1967-68 15.0 3.3 58.9 25.2
1968-69 17.3 3.16 73.9 27.6
1969-70

15.5 31s 70.1 26.7 1970-71 18.0 3.8 80.3 29.5 1971-72 24.0 318 91.0 32.3 1972-73 34 96.2 30. 1973-74 = 19.8 3.9 85.6 33.2 1974-75 18.4 219 104.0 277 1975-76 24.9 40.7 38.7 1976-77 27.7 810 31.8 1977-78 28.1 37.0 35.4 1978-79 37.5 2011 32 19.9, 33.9 / Production and sales data supplied by PR Rum Producers Association, Inc., San Juan, P.R. Tax data derived from Dept of Finance, Office of Economic and Financial Studies, Free Associated State of P.R., Santurce. 2/ ¥6 = Proof Gallon (50% alcohol), 3/ Federal excise tax return $10.50 per proof gallon exported to US; taxes $9.50 per proof gallon sold locally.

TABLE 2. The relation between molasses production and consumption in Puerto Rico (millions of gallons), 1964-79 2/. Molasses consumed 1 desiccated molasses Yes Total tea industry others. Data supplied by PR, Rum Producers Association, San Juan, 2/ Non-food and pharmaceutical uses primarily.

TABLE 3. Blackstrap molasses (BS) and high-test molasses (HTM) available from suggested possible solutions for molasses needs of Puerto Rico rum producers. Molasses production (gallons x 105) solution sugarcane —per-acre' mt! asnt equivalent 2/ 1 358,000 n ° «2.0 2 87,300 " aus @2.2 2 70,000 35 a 7 ' 70,000 80 98.6 7.9 4a 40,000 2 56.3 au. Af Based on 17.6 gallons HTM per ton cane. 2f Based on 1.5 gallons BSM (6.75 pounds sugar/gallon) = 1 gallon ETL (9.8 pounds sugar/gallon).

TABLE 4. Percent of Puerto Rico rum industry molasses needs provided by high-test molasses (HTM) for 1961, 1985, 1988. Possible solution 1981 1985 1988 Conventional 83 70 Modern Agri-20s 86 n cultural Plan Energy cane 2a 198 165 (70,000 acres) Energy cane a7 uz 93 (40,000 acres) HM needed a 50 60 (gallons x 10°

"Cellulose Conversion to Fermentation Feedstocks: An Overview"

Presented at the Symposium on Fuels and Feedstocks from Tropical Biomass, Caribe Hilton Hotel, San Juan, Puerto Rico, November 24 and 25, 1980

Contributor: Rensselaer Polytechnic Institute, Troy, New York

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"Cellulose Conversion to Fermentation Feedstocks: An Overview"

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"Cellulose Conversion to Fermentation Feedstocks: An Overview"

Henry R. Bungay, Professor of Chemical & Environmental Engineering, Rensselaer Polytechnic Institute

Abstract:

The main principles of economical production of fuel alcohol from biomass are:
1. Pretreatment to loosen the structure for efficient hydrolysis;
2. Avoiding excessive dilution so that expensive concentration steps are unnecessary;
3. Recycling to minimize waste; and
4. Deriving benefit from all components.

Very effective pretreatments have been found, and hydrolysis of cellulose to glucose commonly gives yields in the range of 90 percent of theoretical. Another major component, hemicellulose, is easily hydrolyzed to sugars for which new methods for conversion to ethanol have been devised. The other major component, lignin is not converted to useful products by any biological process with commercial prospects. However, native lignin will probably attract an excellent price for applications in polymers or binders, and byproduct lignin from an ethanol factory has ideal properties. A new, gigantic biomass industry should develop quite rapidly.

"Cellulose Conversion to Fermentation Feedstocks: An Overview"

Introduction:

The paper by Dr. Berger has covered a wide scope of biomass programs for this symposium, so a restricted review of the conversion of crude biomass to fermentation feedstocks is now appropriate. Although the symposium focuses on tropical biomass, almost all of the research in North America on hydrolysis of cellulose has used non-tropical woods or agricultural residues. Even sugarcane bagasse, which is available in a few of the United States, has had little testing. Nevertheless, tropical materials have many similarities and the hydrolysis results are quite predictable compared to the materials that are being emphasized, thus the yields are consistent.

Much research has dealt with the conversion of cellulose to fermentable sugars, but it is obvious that cheap fuels cannot be obtained if non-cellulosic components are wasted. Not only are credits for possible products lost, but it is costly to treat the large amounts of wastes after using only the cellulose. There is little margin for profitable hydrolysis to glucose for fermentation to ethanol if only cellulose is utilized. The economics are much more favorable when the other biomass constituents are also utilized. Fermentation of the sugars from hemicellulose to various organic compounds has commercial possibilities, and there have been recent improvements for the production of ethanol.

No bioconversion of lignin appears to be practical because the linkages and aromatic rings are broken only in aerobic processes in which organic intermediates do not accumulate. However, native lignin should command high prices and find fairly large markets as a component of wood binders and plastics. Hydrolysis of hemicellulose to mono- and oligo-saccharides is easily accomplished with either acids or enzymes under mild conditions. Native cellulose resists hydrolysis for two reasons: 1) Its highly ordered crystalline structure; and 2) a physical barrier of lignin surrounding cellulose fibers.

Some of the most striking advances for the programs supported by the U.S. Department of Energy have been various pretreatments that render cellulose amenable.

The following text has been corrected for clarity, punctuation, spelling, and grammar:

"Due to easy hydrolysis, ACID HYDROLYSIS -- the acid hydrolysis of wood is an old technology. Projects during World War II led to the development of the Madison process, which optimized time, temperature, and acid strength.

2. Although the process isn't economical in the U.S., other countries, particularly the U.S.S.R., have many plants for hydrolyzing wood into sugars. A few of these plants produce alcohol by fermenting the sugar, but the most common product is single-cell protein for animal feed. Occasionally, furfural is derived from the pentose fraction of hemicellulose.

Acid hydrolysis leads to a sequence of reactions. Hydrolysis is approximately 1000 times faster for hemicellulose than for cellulose. The sugars from each are degraded by acid into resins, polymers, and furfural derivatives. Reaction conditions are therefore set for a compromise between hydrolysis and degradation, such that the final mixture contains unreacted biomass, unwanted products, and the desired sugars.

As the sugars from hemicellulose form early, there is time for significant degradation, leading to major losses. The maximum yield of fermentable sugars is about 55 percent by weight of the starting cellulose.

Hemicellulose can be removed by dilute acid treatment with very little effect on the cellulose. Adequate conditions range from 0.1% sulfuric acid at 170°C to 1% at 120°C, with times up to one hour.

Knappert et al. (1980) reported the yield of sugars from cellulose as a function of time and temperature. Best yields are obtained at high temperatures for very short times. However, times less than 0.1 minutes can be dismissed from practical consideration because there would be insufficient mixing time for acid solution and biomass.

The predicted yield does not exceed 55 percent of theoretical. Therefore, acid hydrolysis must be improved or replaced with a different technology. There are indications that pretreatment of the feedstock can greatly increase the hydrolysis reaction rate coefficient. This would raise the yield of glucose by reducing the time for degradation."

Enzymatic Hydrolysis.

Active cellulase preparations are seldom obtained from microorganisms which thrive on decaying plant materials. This is probably because cellulase-producing cultures work synergistically, and few organisms secrete adequate levels of all the components of the complex enzymes.

It is uncommon to find a bacterium that is a potential commercial source of cellulases, but several molds produce high concentrations of enzymes in fermentation tanks. The production of cellulases has advanced to the point where fermentation titers are sufficiently high that there is no need to purify or concentrate the product.

Enzymatic impurities can catalyze the recombination of glucose units so that the product is contaminated with small amounts of oligosaccharides. For hydrolysis of native cellulose, the proportions of various cellulases in a given enzyme preparation may not be suitable. Analytical procedures are now available for resolving the components of cellulases, and some understanding has been gained of factors which shift their production.

If no one organism can produce an optimum mix of enzymes, it should be possible to blend cellulases from various sources. There are many thermophilic organisms which attack cellulose, but those with the highest activity are actinomycetes, clostridia, and sporocytophaga (Bellamy, 1979).

The rate of cellulose hydrolysis is slow unless the feedstock is pretreated. Cellulase from the thermophilic soil fungus, Thielavia terrestris, (SRI International, Chem. Eng. News, Aug. 7, 1978) is functional between 60° and 70°C. This means a faster reaction rate and less chance of contamination.

Clostridium thermocellum is a bacterial candidate for supplying cellulases. It thrives at 60°C and completes its fermentation in two days, whereas Trichoderma reesei, the most widely used mold, requires one to two weeks.

The proportions of isoenzymes and enzymatic activities vary for different organisms. Catabolite repression is a feedback control whereby excess product slows its formation.

Rate, thus, high yields are impossible. Mutants can be isolated in which repression is weakened or inoperative. Often, mutants which hyperproduce enzymes are still subject to catabolite repression. Further mutation of these hyperproducing strains to obtain less catabolite repression can give higher yields of enzymes. The saccharification of cellulose with enzymes can take many days if no pretreatment is used. With mild pH and slightly elevated temperature, contaminants can thrive on the sugars that are formed. Antiseptics or antibiotics can be added to reduce contamination, but cellulase activity may be impaired (Spano, 1976). Removal or destruction of the protective agent may be needed prior to the fermentation of sugar to ethanol. Even if the fermentation culture is unaffected by the protective agent, there is a pollution problem if a toxic agent is present in the final effluent. It seems advisable to omit these agents and carry out saccharification quickly so that contaminants have insufficient time to reach troublesome concentrations. Ryu et al. (1979) have operated two-stage continuous cultures of T. reesei for the production of cellulases. The first stage was for rapid cell growth; lactose was the carbon source and served as an inducer for cellulase formation. Cellulase productivity was best when the second stage dilution rate was 0.026 to 0.028 hr–1. This is roughly equivalent to 1-1/2 days of fermentation and is a significant improvement over slow batch fermentation. The University of Pennsylvania team effort with the General Electric Company has been using an organism identified as Thermoactinomycetes sp. (Hagerdal, et al 1980a, b). Further testing, plus confirmation by workers at Rutgers University, has corrected the identification, and the proper designation is Thermonospora sp. (perhaps T. alba). At 55°C, this organism elaborates active cellulases; yields are nearly comparable to those of good mutants of T. reesei. Mutation should lead to higher yields, but continued improvement of other

The species that produce cellulases means that comparisons must continually be updated. The beta-glucosidase activity for Thermonospora is associated with culture solids, while the cellulases are released to the medium. This could be an advantage if fractionation is desired, or a disadvantage if, by requiring a step for releasing beta-glucosidase, an enzyme mixture is being prepared. The beta-glucosidase is unusual in that there is very little inhibition by glucose. Glucose syrups approaching 20 percent concentration were made from cellobiose using only Thermonospora cells (Pye and Humphrey, 1979). It is very important to obtain high sugar concentrations for the fermentation step so that products are not too dilute in the broth. Recovery by distillation of dilute solutions means that excessive water would be heated, vaporized, and condensed. Evaporation of the hydrolysate is feasible but it too is costly. Thus, it is best to strive for high sugar concentrations directly. The product inhibition of cellulases, as previously mentioned, causes a lowering of the hydrolysis rate; high sugar concentrations can be achieved by using excess enzyme or allowing a prolonged detention time. A different means of avoiding high glucose concentrations during cellulose hydrolysis has been demonstrated at a number of institutions and is exemplified by the Gulf process. The saccharification and fermentation are performed simultaneously with cellulases and yeast. Glucose does not accumulate because the yeast converts it to ethanol, thus hydrolysis can approach its maximum rate.

As the enzyme is a major expense, large excesses are intolerable. However, reuse of recovered enzymes is possible; the hydrolysate may be rich in enzymes that can be recovered by well-known methods. A problem arises from the very tight binding of cellulases to cellulose. In order to reach high sugar concentrations, the feed concentrations of cellulose must be high. This leads to considerable unreacted cellulose, and enzymes are adsorbed. Agents such as urea.

Agents that weaken hydrogen bonds can desorb enzymes from cellulose and increase recovery yields by a factor of two or more. Unfortunately, enzyme recovery is expensive. If urea, or some other agent is to be used, it must be recovered and reused. The immobilization of beta-glucosidase for splitting cellobiose to glucose makes a great deal of sense because this enzyme is usually present in insufficient proportions in natural cellulases. In nature, sugars from cellulose do not tend to accumulate because feedback control turns off the enzymes producing them. Small levels of beta-glucosidase are adequate for cellular metabolism which uses sugars as they are produced. Supplemental beta-glucosidase works well in vitro when immobilized since its substrate is a soluble, relatively small molecule. Issacs and Wilke (1978) have immobilized beta-glucosidase from Aspergillus phoenicius on Phenolformaldehyde resins by coupling with glutaraldehyde. Up to eighty percent of starting soluble enzyme activity was retained. When columns with immobilized enzyme were operated in conjunction with hydrolysis of cellulose by cellulases, there was little difference in the rate at which reducing sugars were formed. However, cellobiose was split to give a higher yield of glucose which is acceptable to most yeasts while cellobiose is not fermented. A group at the University of Connecticut has also demonstrated advantages of using immobilized beta-glucosidase.

Brazil produces on a large scale, and there are factories in other countries as well. With excess bags to fuel these factories and the advantage of low labor costs, the production of fuel alcohol is a good way to reduce the requirements for imported oil. There have been several small technological advances, but the process still relies on relatively old technology. The wide distribution of cellulose and its relatively low price make it likely to become the main alcohol feedstock, displacing corn and sugarcane. The Natick process was the first significant advance in using cellulose to produce ethanol. Pretreatment has mostly involved various types of grinding, which have proved to be too energy-consuming. The molds which produce cellulase have been studied intensively by Reese, Mandels, and their coworkers. These efforts, along with the contributions of other groups (especially at Rutgers University), have led to excellent strains in terms of producing high titers of enzymes. The Berkeley process, derived from the Natick process, has contributed engineering solutions to most of the problems. The economic prospects are good if uses can be developed for lignin and hemicellulose. The Purdue group, headed by Tsto, showed great ingenuity in devising pretreatments and thus achieved nearly theoretical yields of glucose from cellulose. There are now several competing schemes for pretreatment, but most resulted from the stimulus of the Purdue work. Other accomplishments include better dehydration methods for ethanol, improved and varied fermentations for the sugars from hemicellulose, different fermenter designs, and improvement of the solvent pretreatment to the point where good yields are obtained by acid hydrolysis. Enzymatic hydrolysis is more expensive, thus acid hydrolysis is presently featured at Purdue, although yields are somewhat lower. Corn stover is probably the best cellulosic feedstock in the Midwestern farm states. The Gulf process appeared to be in the technological forefront just a few years ago, but newer processes have demonstrated superior yields. The concept of simultaneous

Hydrolysis and fermentation are excellent, but the individual steps have different pH and temperature optima, thus process conditions require a compromise. Nonetheless, the simultaneous process deserves further research. Improvements such as better pretreatment of the biomass could revitalize its prospects. A team effort of groups at the University of Pennsylvania and the General Electric Company has led to a process based on solvent extraction of lignin for better hydrolysis of cellulose and new thermophilic cultures to supply the cellulases. This is another highly promising process, and there are plans to get significant credits for byproduct lignin by measures such as dissolving it in alcohol or other solvents to create a diesel fuel.

The Lotech process uses steam explosion for pretreatment. High-pressure steam permeates the biomass, and sudden release through a die shreds and disintegrates the structure. Hydrolysis of cellulose and fermentation to ethanol proceed nicely. The biggest advantage, however, is the development of high-value uses for lignin as a wood binder or specialty chemical. When there are many factories for fuel alcohol, the co-product lignin will greatly overwhelm the foreseeable markets, but the first few factories selling lignin will be highly profitable. The search for new applications for lignin should be very rewarding because enormous quantities of material with properties superior to lignin from paper pulping will be available.

The M.I.T. process has more simultaneous steps than the Gulf process. Carefully selected mixed cultures are added directly to coarsely ground biomass. Enzymes hydrolyze both the cellulose and the hemicellulose while the organisms ferment the resulting sugars to ethanol. The organism which ferments the sugars from hemicellulose may be added later after the first organism has nearly completed the hydrolysis and has consumed most of the glucose. The really clever feature of this approach is investing very little in feedstock preparation and

Not overly concerned with a high efficiency of feedstock utilization, much of the feedstock remains 'unreacted'. However, the residue does not represent a significant financial loss. It would be burned to supply energy for the factory. Some improvement in the efficiency of feedstock utilization would be desirable, however, because the fuel value of the residue far exceeds the factory's energy needs. Steam or electricity would be products of about equal importance to the ethanol produced. There does not appear to be an opportunity to recover valuable lignin from the residue, even though it is enriched relative to other polymers. There are other problems, such as the present strains' inability to reach high concentrations of ethanol, but the rate of accomplishment by the MIT group has been outstanding. Kelsey and Shafizadeh (1980) have proposed another simultaneous operation whereby the grinding of the feedstock is performed in the presence of cellulases. This method improved the rate of hydrolysis and glucose concentration.

8 RECENT ADVANCES

Flickinger (1980) has reviewed selected areas of research on the fermentation of cellulosic materials, with emphasis on the present status and potential for improvement. Since this assessment, two groups have independently announced remarkable improvements in the fermentation of sugars from hemicellulose to ethanol (Wang, et al, 1980 a, 1980 b, Gong, et al 1980). There are bacteria, molds, and yeast that ferment these sugars to ethanol, but other byproducts are usually present and poor tolerance of ethanol prevents its accumulation. The best producers of ethanol are certain yeasts and the bacterium Zymomonas. Xylose, the predominant sugar from hemicellulose, is not fermented by the good ethanol producers, but xylulose, a keto sugar derived from xylose, is fermented well. When the enzyme glucose isomerase is added, xylose is isomerized to xylulose, but an equilibrium mixture is reached at prolonged times. This enzyme is widely used to convert glucose to fructose.

Commercial sweeteners are inexpensive. A serious drawback is the need to recycle unreacted xylose from the fermentation step back to the enzyme to again approach the concentrations of the equilibrium mixture. Work is underway to create mutants which have isomerase activity and thus need no supplemental enzyme. Furthermore, organisms which have the inherent ability to ferment xylose, such as those being used at M.I.T., may soon be so improved that they merit commercial consideration. Utilizing hemicellulose to produce additional ethanol will mean a 50 to 60 percent improvement in productivity in factories using biomass. Other significant improvements are in fermenter design. There are several advantages to retaining organisms in the fermenter or capturing them in the effluent and recycling them. First, there is less diversion of substrates to growth. The other main advantage relates to ethanol tolerance. All producers of ethanol can become inhibited as ethanol accumulates; this is shown by a decrease in the production rate per microbial cell as ethanol concentration rises. The decrease in rate per cell can be overcome by having more cells. Several new designs retain the cells to achieve very high populations. One method uses heavily flocculated cultures which settle back as clear effluent is withdrawn from the top, and other designs have physical means such as immobilization or encapsulation to hold the mass in the fermenter. A group at Oak Ridge National Laboratory is having good success with Zymomonas held in a column reactor, and there is a good chance that this bacterium will outperform yeast in the future because improvements through genetic manipulation are easier and bacteria grow faster than yeast and lead to shorter processing times. Engineering problems are being solved by novel means for handling materials. Dilution is troublesome in several steps in the biomass processes because extraction yields are low unless excessive volumes of liquids are used. When biomass is mixed with water, the

The slurry concentration must be kept low or else sieving becomes impossible. Several groups are experimenting with contacting and extracting in columns with the liquid percolating through a solid bed. The solutions can be relatively concentrated so as to minimize the need for costly subsequent evaporation.

CONCLUSION: Fractionation of biomass is leading rapidly to the utilization of all its components. Hydrolysis of cellulose has improved in just a few years from yields in the range of 50 percent of theoretical to over 90 percent. Hemicellulose hydrolysis has always been easy, and there are highly promising ways for its conversion to ethanol. Lignin from various biomass processes does not seem attractive for conversion by biological means, but it has great value in its native state because reactivity is much superior to lignin from paper pulping.

Tropical biomass has not had sufficient testing in the processes covered in the review, but there is little doubt that it would work well. The climates of most tropical countries are much better than that of the U.S or Canada for growing high yields of biomass, so tropical biomass could soon support major new industries.

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Processes for Manufacturing Ethanol

Table 1. Description

Corn grain is malted to hydrolyze the starch in the Grain Alcohol process. Yeast produce ethanol and stillage is concentrated for cattle feed. In the Sugarcane process, juices or molasses are fermented directly by yeast which are washed and recycled. In the Natick process, cellulosic materials are treated with Trichoderma enzymes to get fermentable sugars. The Berkeley process is derived from the Natick process and also uses hemicellulose. The Purdue process involves removal of cellulose and hemicellulose which permits excellent hydrolysis with acid or enzymes. In the Pennsylvania/General Electric process, enzymes are added for simultaneous saccharification and fermentation. The Biotech process involves solvent extraction of lignin for excellent hydrolysis. The Cult process uses steam explosion to fracture biomass for good hydrolysis. The process also involves the use of mixed mold cultures.

"Hydrolyze biomass and produce ethanol. Remarks: Profitability can be undermined by high corn prices or collapse of the cattle feed market. Silage may have too high a salt content for cattle feeding. Credits for cane fiber could be high. Pretreatment by grinding may be too expensive. There has not been a focus on using hemicellulose. This is a strong candidate for large-scale operations. Regeneration of solvent may be costly, but this is a very high-yielding process. Hydrolysis yields are not outstanding and good use of hemicellulose is undeveloped. The recovery of organic solvents may be costly. There is a very valuable lignin byproduct. The process is simple but effective; highly promising.

2. ALCOHOL FUELS FROM SUGARCANE IN BRAZIL

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ALCOHOL FUELS FROM SUGARCANE IN BRAZIL

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ALCOHOL FUELS FROM SUGARCANE IN BRAZIL

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ABSTRACT

A survey is made of the state of the art of the production of ethanol from sugarcane as compared with other crops in Brazil. The economic and political implications of the "Programa Nacional do Alcohol" are described together with the present achievements and future prognostics. The improved efficiency of modified internal conversion engines fueled by pure ethanol is compared with the performance of conventional engines that use ethanol-gas blends; some economic discussions follow this presentation. The energy balance for the"

The production of ethanol from sugarcane is evaluated, taking into account both agricultural and industrial energy expenses. This is then compared with the energy requirements for gasoline production. Currently, under Brazilian conditions, the real cost of ethanol from sugarcane is US$12.69/GJ, compared with gasoline which is US$12.19/GJ. Given that ethanol, when used as an

octane booster, has an efficiency 254% higher than gasoline, the final conclusion is that ethanol has reached the break-even point compared with gasoline in Brazil.

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ALCOHOL FUEL FROM SUGARCANE IN BRAZIL

1. INTRODUCTION

Any assessment of the world's energy needs by the year 2000 shows the insufficiency of the present energy resource. The continual population growth, larger per capita energy consumption expected in the future (mainly in developing nations), and the finite oil resources have been the chief sources of worldwide concern, specifically after the oil crisis in 1973.

A historical analysis of the main sources of energy used by the developed countries shows the possibility of oil being replaced by some other source of energy in the near future. This has already happened with wood and coal, as can be seen in Fig. 1.

Several analyses performed in the last two decades showed that oil would be replaced by the intensive use of nuclear fuels. However, after several accidents with the operation of nuclear reactors and the strong public opinion against their use, particularly the incident at Three Mile Island, several reviews of the world's energy future have been published which predict new sources, mostly in renewable energy.

In many developing countries, renewable sources still supply most of the energy used, as can be seen from Table 1. The increasing search for technology that allows the utilization of renewable sources in an economical way, even in developed countries, is explained by the lack of large quantities.

Concerns about fossil fuels (except coal) and the environment are growing. Pollution can be avoided with most products, except for CO2. Its concentration level in the atmosphere is continually increasing and will become a serious problem in the near future. The technical difficulty for the production of alternative fuels is quite small, as was historically proven with the use of alcohols by Germany and Japan, and water gas by several developed and underdeveloped countries during the Second World War (such as Sweden, Brazil, etc). The economic difficulty was insurmountable up until 1973, as evidenced by the efforts of coal gasification developed in South Africa for more than a decade. However, as oil prices increase, the problem nears a solution. Countries with little or no oil and with large areas of unused land have a greater possibility of producing alternative fuel derived from biomass at costs very competitive with present-day oil prices. In Brazil, where a large ethanol program based on sugarcane is being developed, costs of alcohol have probably reached the break-even point as we intend to show in this paper. Even when the cost of ethanol is still higher than gasoline, the continuous trade deficit of many less developed, non-oil producing countries justifies the replacement of gasoline with an indigenous product. Another important reason to compete economically with gasoline is the surplus of grain crops, particularly corn in the United States, which is the main feedstock for the production of ethanol, sold in a 10% blend with gas under the name of "gasohol". It is necessary to keep in mind that the price a consumer can pay for fuel is not necessarily the same price a country can afford to pay. All efforts for the economical production of fuels from biomass are directed towards improvements in crop yield and reduction in energy costs of the industrial processing of the feedstock. The average photosynthetic yield for sugarcane in Brazil is approximately 0.28. This number can be increased fourfold, as shown by the sugarcane.

Productivity in Australia (12), Hawaii (13), Puerto Rico (14), and a few specific cultures in Brazil (15) is notable. Nevertheless, special care must be taken to avoid excess energy utilization in fertilizers and artificial irrigation. The industrial costs can be significantly reduced if new techniques for the distillation process (16-18) are used.

2. FEEDSTOCKS (A) Sugarcane

Up until now, the ethanol derived from sugarcane is the most intensely, commercially exploited, fuel alternative. The main reasons for this are:

1) Brazil is the leading nation in the production of fuels derived from biomass, with a total annual production in 1979 of 3.5 billion liters (19) (equivalent to 60,000 barrels of oil per day);

2) The well-developed sugar industry in this country, which is the largest world producer and exporter, underwent a severe crisis due to the low international price of sugar when the National Alcohol Program (PNA), i.e., the program for the use of ethanol as a fuel for automobiles, was proposed in 1975 by the federal government. This fact immediately triggered the interest of the sugar producers who were able to bring a large idle fraction of the distilleries into full operation and divert a significant amount of sugarcane beer from the sugar market to the ethanol production (approximately 0.7 billion liters/year of this product are being produced using this method) (20);

3) The technology required to convert sugarcane into alcohol is quite simple and requires equipment that can be built in many of the developing countries;

4) The total amount of capital required to operate an ethanol processing plant is very small when compared with all the other fuel alternatives. The typical cost of a distillery with a 120,000 day capacity is not precisely known, since different authors quote different figures, as can be seen.

3) From Table 2, but a reasonable number is 10 million dollars (21). An economically feasible unit of synthetic fuel from coal or oil shale requires large scale production (over 50,000 barrels/day) and capital investment.

Over a billion dollars (22). Even a methanol plant, using biomass as a feedstock, requires a large scale plant with a capacity of handling 2,000 tons of wood per day to become economically competitive. This translates into a cost of 300 million dollars (23). Furthermore, ethanol distilleries in Brazil can be delivered and put into operation twelve months after the order is placed, which is a very short time span compared with any other investment in energy. Developing nations, in which the shortage of capital is the bottleneck of industrial growth, are very appreciative of the two aforementioned factors.

5) Ethanol is a very common product and its effect on humans is very well known. It is accepted by the human organism even in large concentrations in the atmosphere (1,000 ppm)(24), that is, two

times higher than gasoline (500 ppm), therefore, the possibility of inducing diseases is quite small. Since it is an organic product, very little impact on the environment is expected.

6) It is the only commodity that can be immediately produced on a large commercial scale to replace gasoline. Old cars ran with this fuel and it's still used in race cars when large engine power is the main goal. The alcohol is now being produced by autonomous and annexed distilleries. The annexed distilleries are extensions of the sugar processing units, built to displace part of the feedstock from sugar to alcohol commodities. These units were built very quickly and for a low price since they used the same basic installation for the processing of sugar. The first autonomous distillery, that is, the one designed specifically for the production of alcohol, came into operation at the beginning of 197.

B) Ethanol from other crops

The possibility for the use of other feedstocks in ethanol production has been frequently investigated. Table 3 presents the energy costs in Brazil for some of the most promising crops. Cassava, often considered a source of ethanol, does not compete with sugarcane when checked through an energy balance. The fundamental reason is the difficulty.

The aerial part of the crop can be used as a fuel for the generation of steam and electricity. However, the aerial part has a large amount of moisture (>728) and cannot be used as fuel for boilers without undergoing a drying process (25,26). Sweet sorghum is a very competitive crop, mainly because it can provide two harvests per year in most tropical areas. Unfortunately, some genetic improvements are still required in this culture in order to grow the plant in areas with large insulation (27). Table 3 also presents an energy evaluation for the corn crop. Corn stover can be used as a fuel for the ethanol processing industry, but the amount available is not sufficient to supply all the energy required.

3. THE NATIONAL ALCOHOL PROGRAM

As previously described in the introduction, just after the fourfold increase in oil price, i.e., in the second semester of 1974, the Brazilian government prepared a program for the replacement of all oil derivatives to be accomplished in four steps. Table 4 shows the goals set for each step at that time. A time limit was determined for the first of the four steps. It would be possible to replace 20% of all gasoline in use in the country by 1980 through the addition of ethanol. The use of gasoline-ethanol blends has been common in Brazil since 1950, and in some cases, blends containing as much as 16% of ethanol were used in some cities (28). From this previous observation, it appears feasible to use conventional gasoline engines to run with a higher level of ethanol, even if the total efficiency was reduced. The second stage of the program, the complete replacement of gasoline with ethanol, would require research and technical changes to reach good performance. Furthermore, economical problems would have to be solved since the oil refineries were designed to supply a market with almost non-existent seasonal fluctuation, demanding almost the same amount of gasoline, diesel oil, and fuel oil. The reduction in gasoline demand could not be accomplished by the existing oil refineries without imposing restrictions on the

Supply of diesel oil and fuel oil: The third phase imposed even more difficulties since it would require not only a change in the oil refining structure but also technical development that was very hard to assess at that time. Diesel engines had never used any alcohol blend before. To enhance ethanol production in Brazil, a large economic program was developed. The federal government supplied 80% of the capital (and in some less developed areas, 90%) and private enterprise 20% or less. The federal mortgage had to be returned to a negative interest rate i.e. interest and monetary correction below the official index of inflation. With this added advantage, the industrial background of the country was developed enough to accept any orders for new distilleries. As of now, (February, 1980), more than 250 new units have received funds from the government and nearly 200 are already in commercial operation. The most common unit has a production capacity of 120,000 l/day with a cost very near ten million dollars. By the end of 1980, the total production of ethanol should reach the goal set in 1975 (4 billion liters/year) and from this total, a little over 3 billion would be produced by the units installed under the National Alcohol Program at a cost of two billion dollars. Another part of the economic program was the indirect subsidy received by the alcohol through the elimination of the taxation that was applied to the price of gasoline and responsible for an overprice of almost 30% of its final price to the consumer as can be seen in Figure 3. It is worthwhile to note that gasoline was always overpriced to compensate for the lower prices of diesel oil (used only for commercial applications) and the fuel oil (used only in industrial applications). The present price of some oil product is shown in Table 5. With all this preferential treatment, the price of ethanol, since 1975, has always been lower than gasoline, independent of the higher production cost (at least up to the last increase of price). Presently, as

We will try to indicate in Section 5 that the real price of both products appears very similar, with a small advantage for ethanol. In 1979, the success of the PNA was not obvious, mainly because of the constant increase in price. The federal government set an upper limit for the achievement of another phase of the program, which was less ambitious than the one proposed in 1975. An agreement between the car manufacturers and the government was reached for the production of 90,000 new cars, 100% of which would be fueled by alcohol in the next three years. The retrofitting of 280,000 gasoline cars to run in sync with the new fuel was also planned. The government guarantees fuel supply up to a level of 10.7 billion liters/year (~210,000 barrels/day) by the year 1985. A total amount of 5 billion dollars will be available to private investors in new ventures.

The main conclusions drawn from the test of 100% ethanol-fueled cars are as follows:

1. Compression changes from 18 to 21; the carburetor has to be redesigned to set the stoichiometric fuel to air ratio for alcohol, which is different from gasoline.
2. An additional system for cold starting of gasoline engines running on 100% ethanol is already available.
3. The ethanol consumption, per liter, is 20% higher than with gasoline, even after the compression ratio is increased.

The goal set for 1985 will impose several difficulties for the oil refining industries if the production of diesel oil and fuel oil is to be achieved. Today, the country already processes more gasoline than is consumed, and the excess is sold in the international market. The market is very small, mainly for a low-quality product as the one produced. As it is unlikely to discover a larger market, another possibility under consideration is the exportation of alcohol to be used as an octane booster in countries where environmental concerns limit the use of lead. This solution is quite interesting from the energy point of view. The American market demands that 46% of the oil be converted into gasoline. The average energy required for processing a barrel of crude oil is 740 MJ, distributed among several.

Operations. Reforming and alkylation are primarily conducted to obtain high-quality lead-free gasoline. A significant energy economy can be obtained if medium-quality gasoline is used instead of high-octane gasoline. Figure 4 shows that the apparent consumption decreases with the increase in the octane number, but the real consumption presents a minimum energy cost for different octane numbers as a function of the total amount of lead. This is because the energy required for processing high-quality gasoline also increases. Even more beneficial is the conclusion obtained from Figure 4a, which clearly indicates that lead-free gasoline requires a real consumption of 600 kcal/10km over what is required for the production of the same octane gasoline with a lead content of 0.6 g/l.

Figure 5, obtained for methyl alcohol, is a reasonable indicator for ethanol and shows that the addition of 10% alcohol to gasoline increases the octane level by three numbers, equivalent to the addition of 0.3 g/l of lead. From this figure and from Figure 4a, approximately 400 kcal/10km could be saved (this number is obtained by extrapolation from data from Figure 4a; in the case of minimum gas consumption with 0.4 g/l of lead, 11250 kcal/10km is necessary and the minimum for a gas with 0.15 g/l of lead is 11650 kcal/10 km).

Then, a mixture with 9 liters of medium gasoline plus 1 liter of alcohol can yield an energy savings of 11,500 kcal (6,600 + 7,800) in the real consumption of oil less the costs for the production of 1 liter of alternative fuel. For the typical case of Brazil, this figure is not more than 2,000 kcal, as we will show in section 4. Therefore, the real economy is 9500 kcal, meaning that the use of one liter of alcohol displaces at least two liters of gasoline.

This calculation could be repeated for blends with 20% of ethanol with the final conclusion that 1 liter of alcohol displaces 1.8 liters of gas. This result is also derived from data shown in Figures 4 and 5, where we see that the real consumption of gas does not.

The content reduces linearly with the increase of lead content. Following this trend, but at the opposite extreme, pure sthanol yields only 0.8 liters of gasoline. Thus, the net energy savings for the world would be twice as large if alcohol gas blends are used, instead of cars fueled by 100% alcohol. A third option for Brazil would be the use of ethanol in diesel engines, along with the replacement of a portion of the fuel oil with another feedstock suitable as a boiler fuel.

The use of ethanol and diesel blends has been under investigation for the past three years, and engines have already run on blends containing up to 70% ethanol. The largest difficulty is due to the high resistance presented by alcohols to self-ignition when compressed, which is technically measured by the cetane number of the fuel. A possible solution is to increase the cetane number of alcohol through the addition of chemical products with explosive behavior, like amyl nitrate.

4. THE ENERGY BALANCE FOR THE PRODUCTION OF ETHANOL

Several papers have addressed the problem of assessing the amount of energy used in ethanol production. If a large amount of energy derived from oil is required, we can conclude that alcohol is a net oil consumer rather than an alternative. Several sources of biomass can be used for ethanol production. In this paper, we will analyze those that are currently in commercial use or have a high likelihood of being used in the near future. These include sugarcane, cassava, sweet sorghum, corn, and wood.

4.1 Yields and Productivity

To carry out an energy balance, it is necessary to assess the ethanol and byproduct yields from the feedstocks. The alcohol volume assessment is made from the composition of typical crops and their conversion to sugar and ethanol, taking into account the practical limits and crop productivity. This will be described in detail for sugarcane. Sugarcane is practically the only commercial source of ethanol in Brazil, primarily because it can be produced very easily using traditional fermentation techniques.

The high energy value of bagasse is noteworthy. Table 6 presents the typical composition of the most common species of sugarcane planted in the southeast part of Brazil. The classical fermentation processes for hexoses (glucose and fructose) and sucrose are described by equations A and B respectively:

$C_6H_{12}O_6$ ———> $2C_2H_5OH + 2CO_2$ + heat (180g glucose -> 92g ethanol (64.3 ml at 15°C))

$C_{12}H_{22}O_{11} + H_2O$ ——> $4C_2H_5OH + 4CO_2$ + heat (342g sucrose -> 184g ethanol -> 360g CO_2)

A practical evaluation of the total amount of ethanol produced must assume an extraction efficiency of 95% for the mono and disaccharides from the crop, as well as a 95% efficiency in the fermentation process. This suggests that one ton of sugarcane, with an average composition shown in Table 6, produces 90 liters of ethanol. Using the typical productivity for commercial crops listed in Table 7, we calculate a yield of 4700 liters of ethanol per hectare per year.

Agricultural Expenses

Table 3 outlines the energy required for the cultivation of various crops in the southeastern part of Brazil. Sweet sorghum is included, with data drawn from experimental trials as it is not yet commercially cultivated in Brazil. The energy listed includes both direct and indirect expenses; hence, the energy embedded in a liter of diesel oil is assumed to be 10% higher than its heat value, as this is the minimum energy required by the oil refining industry. More accurate evaluations can be made using an input-output matrix already available for the Brazilian economy. Labor energy is systematically omitted in the energy evaluation, as per the recommendation of certain energy schools. However, even in a developing country like Brazil, the human labor expense in agricultural production seldom exceeds 5%, and its inclusion does not significantly alter our results.

The primary conclusion derived from Table 3 is that the least energy-intensive crops are wood (Eucalyptus and Pinus), with energy consumption four times less than any other crop analyzed and seven times less than sugarcane. The productivity of each crop is also taken into consideration.

It is possible to access the energy per liter of alcohol required in the agricultural phase for several feedstocks. The result is presented in the last column of Table 8. The expenses account for soil preparation, plantation, harvesting, and transportation of the feedstocks up to a distance of 20 km from the farm. This figure is well above the average 3600 liters/ha-year commercially obtained in Brazilian distilleries. Inefficient sugar extraction and unavoidable losses associated with large scale production should be the reason for the lower figure.

Industrial Expenses

The conversion of biomass into ethanol is made by several techniques according to the feedstock species. To evaluate these energies, a complete flow sheet of the plant is required together with a reliable way for computing the built-in energy in the equipment and buildings. The case of sugarcane is the easiest one to evaluate since many industrial units are in operation. It is more difficult to prepare a detailed analysis for the other feedstocks, nevertheless, important conclusions can be drawn from the sugarcane flow sheet evaluation, as shown in Figure 2. The input-output Brazilian matrix (38) was used to assess energy built-in capital goods, operation, maintenance, and fuel. Table 9 presents the results for a typical unit, with an annual capacity of 18 million liters and assuming an average life of 20 years. As can be seen, the energy expenses come mainly from the fuel required. Fuel is such a large part of the total expenses that it's almost useless to make an accurate assessment of all the other energies. So, for modest precision, we can use the fuel energy, usually computed as kg of steam/liter of ethanol as a good means for comparison between different crops. Operational costs are not expected to vary from one feedstock to another but the case of wood deserves a more careful analysis. Table 10 quotes fuel costs for the biomass under analysis.

A comparison drawn between Tables 3 and 9 clearly shows that industrial expenses are at least 3.

The text is incoherent in several places, and it appears to have missing or misplaced punctuation, spelling errors, and incorrect or inconsistent spacing between words. Here's a revision:

The energy required for the production of corn and wood is several times larger than that required in agriculture. In the case of corn, the energy required is almost $0 times more, and for wood, it is significantly larger. Due to the high energy requirements, it is almost impossible to use noble fuels (oil, natural gas, and electricity) in the ethanol processing. This is the main reason for the success of sugarcane as a source of ethanol. As a by-product of beer production, large quantities of fiber are available to be used as a fuel for steam and electricity generation. Other feedstocks like cassava and corn do not compete with sugarcane either because their by-products are unsuitable as a fuel or the amount of fiber is small. Wood could be used as a feedstock for ethanol and fuel for a boiler. One fraction would undergo hydrolysis and the other would supply the energy. Table 10 shows the amount of energy required as being much higher than for sugarcane. Plants operating in Russia require 25 kg of steam and in Switzerland, turn-key plants require 13 kg of steam (40). Even for such high figures, a reasonable amount of wood can be used for hydrolysis because of the large heat value of wood together with the small amount of moisture (20%).

5. THE ECONOMIC PROBLEM

The evaluation of the production of ethanol will be made for only two feedstocks: sugarcane and wood. Even so, we recommend calculations to be more precise for sugarcane, which is being used extensively in Brazil. The evaluation is more realistic for the southeastern part of the country where data is available for the evaluation of the 1976/1977 harvest (21). The size of the investments and of the agricultural yield are presented in Fig. 6 for a hectare of land exploited over a 4-year span. Table 11 presents the costs for sugarcane for three different interest rates. The capital costs for a distillery have two major components: the fixed investment and the working capital. Working capital includes feedstock expenses and ethanol storage. Table 2 depicts a variation of a factor of 2 in the estimated costs of distilleries. We decided to choose for our base case the price quoted for one.

The text from one of the largest distillery producers, Zanini S.A., indicates a price of 107 dollars for a processing plant with a capacity of 120,000 L/day. This translates to 3600 dollars/GJ of ethanol. This price is far more realistic in the current market, as it is quoted for an autonomous unit and a large fuel replacement program, with autonomous distilleries being the predominant fraction now and in the future.

Considering this, we conclude that the cost associated with this investment will range between \$1.55/GJ and \$3.20/GJ, fluctuating with the interest rate and payback time, as shown in Table 12. The operational costs amount to \$2.20/GJ (21).

As demonstrated in section 4, one hectare produces 226/GJ per year of biomass (assuming 18 GJ/ODT) and yields 4,700 liters of ethanol or 99 GJ. There is an excess of bagasse that will not be considered in the economic evaluation, as it is not currently used in operations. The conversion efficiency of biomass to ethanol is 43.7%, meaning to produce 1 GJ of ethanol, it is necessary to buy 2.3 GJ of feedstock. The cost for sugarcane is \$3.05/GJ (including some value for the land and assuming an interest rate of 6%), meaning the feedstock cost will add to \$6.96/GJ. The other costs are also quoted in Table 1 Wood.

Figure 7 presents the magnitude of fixed investments required for typical Eucalyptus plantations in the state of Sao Paulo. Assuming the same interest rate as for sugarcane (6%), we arrive at a cost of \$27.60/ODT or \$1.55/GJ. Including the land cost, this price will increase to \$1.75/GJ; this is a consequence of the high cost of land in the state of Sao Paulo and is characteristic of a very small fraction of the country. For wood farms developed in areas far from urban centers, the land price decreases significantly and we obtain the same price for the feedstock with or without the addition of land cost. It's important to note that this cost estimate is much higher than the cost of wood currently sold in small farms.

The price is \$16.5/DT, which includes loading, unloading, and transportation up to a distance of 120 km. This results in a cost of \$1.00/GI. We believe this price is more realistic than the previously estimated cost of large-scale wood farms and we will use it in our final evaluation. The total expenses for producing ethanol from wood by acid hydrolysis are shown in Table 14 for an interest rate of 6% per year. As in the case of sugarcane, the cost of the raw material is the major component of the final product. This is a consequence of the low efficiency in converting wood to ethanol due to:

1. Low yields obtained because of the presence of hemicellulose and lignin in the raw material.
2. A significant fraction of wood is used as fuel for the processing unit. This is a necessity under the assumption of self-sufficient hectares and the use of lignin in the pig iron industry.

The cost of gasoline vs ethanol is essential to compare our previous cost evaluation of ethanol and the current cost of gasoline. To do this, we will use data from Ref. 41, suitable for the American market. As shown in Fig. 8, it is necessary to start with 1.12 GI of oil to produce 1 GI of gasoline. Furthermore, 0.12 G from external sources, most commonly obtained from natural gas, has to be used. To be consistent with our previous analysis for ethanol, it is important to add capital and operation costs. We use a well-established method for calculating the production costs of refined oil products in the U.S.A. They cost 1.64 times more than the raw material. This means that gasoline is produced at a cost of $10.50/GI, assuming $35/barrel for oil. In the case of Brazil, the industrial efficiency is probably lower, a general trend observed when comparing developed and developing countries, and a higher price is likely. No reliable costs are presently published by the state-owned oil company, but for December 1978, it was quoted as $6.00/GI before tax. An indirect

The situation can be carried out using the consumer's selling prices which are listed for today's market in Table 4. From these prices, 15% has to be subtracted as the cost of distribution and market network ($6.00/barrel) plus the tax of 26.7 over the final price of gasoline, as shown in Fig. 3. This gives a value for the oil derivatives ex-refinery of $28.59/barrel (when the average price of crude oil was $22.00/barrel). However, the high price of gasoline in Brazil is something of an artifact, since there are taxes added to cover the low cost of Diesel and fuel oil. Comparison with other countries suggests that this spread is very atypical and represents a political, not an economic, price of gasoline. Using the spread in price typical from free market economy we arrived at a price of $12.19/GI for gasoline ex-refinery. As a final conclusion, alcohol, at least when used as an octane booster where total efficiency is 25% higher than gasoline, has already reached the break-even point as compared with gasoline in Brazil.

ACKNOWLEDGEMENT: One of the authors (I.R.M.) would like to acknowledge the financial support provided by "Fundação de Amparo à Pesquisa do Estado de São Paulo-FAPESP" during his working time at Princeton University, where most of this work was done. Diesel is generally 10% less expensive than gasoline ex-refinery and fuel oil 33% as expensive.

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Produced Energy (1013) - Oat and Hydro and Total Energy Per Country
Lignin, Natural Gas, Nuclear, Biomass Capacity (109M)

U.S.A: 17250, 20950, 21300, 70, 250.0 respectively.

*This figure does not agree with the one published by "Balanço Energético Brasileiro, 1978" prepared by Ministry of Mines and Energy, Brazil. The reason for the discrepancy is: 1) large quantities of wood do not penetrate the commercial market 2) there is an incorrect evaluation of the wood energy in the publication of the Ministry of Mines and Energy as was pointed out in Ref. 43; the wood energy content is underestimated by 50%.

2. The data presented in this section is unclear and may be corrupted. It needs to be reevaluated and presented in a legible format.

3. The information in this section is also unclear and seems corrupted. It requires reevaluation and clarification.

Note: The text provided is difficult to understand due to what seems to be errors, possibly during a data transfer or scanning process. Some of the text appears to be words or phrases in different languages, numbers, symbols, or possibly coded information. This information would need to be provided in a clearer context for a more accurate and helpful response.

"Yams, tans and 'Wave NI 03L1014x3' said, 'Swos, you S3sNa¢x3 9IL30¥N2 IML 40 KOLVTVAR eM.'

Page 22: Goals proposed by the National Alcohol Program in 1975

Product on (liters/year) Area Required for the Sugar Cane x10 Crop (x 1000 ha)
Scenario I: 3 1100
Scenario II: 16 4400
Scenario III: 1 6000
Scenario IV: 33 000

(2) 20% ethanol blend in gasoline plus 10° liters for industrial use.
(2) 10 lbs ethanol to replace gasoline plus 10° liters for industrial use.
(3) 100% ethanol to replace gasoline and 50% ethanol offset of blend.
(4) 300% ethanol to replace gasoline and offset of.

From Ref. 46

Page 23: Relative composition and current cost (April 1980) of the more common oil derivatives in Brazil

Derivatives: Percent fraction, amount per cost (barrel (liter)), (tons)
Gasoline: % 4 2 19.2
Diesel: of 2 ry Ne
Fuel: of 2 8 as 56
Others: 38 4 has
Total: vo 40.03

Assuming the useful content of a barrel equals 140 tons. This is a reasonable assumption since significant amounts of oil are expended for the derivatives' processing.

Average price of oil at $22.00/barrel.
From Ref. 18

Page 24: Typical composition of sugar cane exploited in the southeast part of Brazil

Component: By Weight
Sucrose: 16
Reducing Sugars (glucose and fructose): 2-15
Total Fermentable Sugars: Bay (expressed as % of glucose)
Fiber: 9-13
Moisture: 70-73
From Ref. 47

Table: Typical yields from commercial crops of sugar cane in the southeast part of Brazil

Number of Words: Cycle | Harvestings | Total production (tons/yr.) (t/ha/yr.)
4: 3 169-260 0 4357 210" see 5.0%
From Ref. 47 (average)

Page 25: Energy invested in agriculture (planting, harvesting, and transportation) for various crops in the United States and Brazil.

Agricultural: By any wt. ton Energy (2) (btu/ary/crop. on) ba.year btu/ha/year)
USA. Sugar cane: 6.2? 900? mn wae 1.62 2080"? 1216
Soybean: 1.442 ras) 35
Corn: 4.907) 55? 1386
Forest Logging: 15.4 a?

Brazil: Eucalyptus _ =— Pine _ — _ musi ‘Sugar"

Canery 318, 208 seats, 1.06, 1378, 13305, Soybean Lass, 108 corn, 202, 206 Forest logging, Eucalyptus, 330, Pinus.

Notes:
1) From reference 5h
2) From reference 48
3) Average value from references SU, 55, 56, and 57
4) From reference 58, includes only energy for harvesting
5) From reference 47

Chapter 26

Energy Required for the Industrial Conversion of Sugar Cane to Ethanol - Typical Brazilian Distillery.

Industrial Expenses:
- Capital Goods (average life of 20 years): 3.08
- Operation: 2.36
- Maintenance: 3.06
- Fuel: 88.23
- Total: 97.23

Productivity per Year (x 10^1): 8, 5.4

Total Industrial Energy = 8 (from Ref. 45)

Chapter 27

Industrial Fuel Expenses for the Processing of Several Feedstocks.

Energy Feedstock (kg of steam/ of ethanol):
- Sugar Cane: 58
- Cassava: 65

- Sweet Sorghum: 55
- Corn: 5.5
- Eucalyptus: 3-13
- Pinus: Evaluated for Brazilian technology. More energy required in the United States (see Ref. 48) since stillage is dried to be used as cattle feed.

Chapter 28

Economical Expenses for the Sugar Cane Crop (average energy value of biomass).

- Clearing & purchasing yard levelizes annual revenue: 1.08
- Purchased equipment levelizes annual revenue: 1
- Investment in planting levelized annual revenue: 1
- Operating and maintenance costs: 1
- Total levelled annual revenue: 1.08 + 1 + 1 + 1

Excluding land purchase: VI, VII, 23.82

Chapter 29

Assuming a price of land equal to 0.5, clearing costs are estimated to be about $500/ha. From reference 49, there are about 12 days of tractor time and 7 days of truck time per hectare over 4 years.

"Years, or, in practice, 12 months. Because of maintenance, weather, and the timing of agricultural operations, we estimate that one tractor can cover 50 ha and one truck 100 hours. We estimate a tractor to cost U.S. $20,000 and a truck U.S. $15,000. Auxiliary equipment is estimated at U.S. $10,000 covering 100 ha. We therefore obtain an investment in equipment of U.S. $650/ha. Harvesting is done by hand. Depreciation time is taken to be 10 years. If labor, fertilizer, machine operation, and other, includes harvesting and all other costs not stated earlier. Excludes the land purchase investment (U.S. $1760/ha) plus the interest accumulated on this investment during a six-month period when land is fallow prior to planting. All calculations are made for 3 different interest rates; 12% as suggested by Little and Mirrless (60) for a developing country like Brazil; 6% for our base case and 3.6% as the cost of money for a regulated industry in a developed country.

Page 30, Table 12: Capital Investment Costs. Average Life of 15 years for the distillery: 20 years cost (8760). Interest (2) 3.6% - 1.90, 6% - 1.55, 12% - 1.30, 120% - 3.20, 2.90.

Page 31, Table 13: Production Costs of Ethanol Derived from Sugar Cane (5/69 of anhydrous ethanol). Fixed investment in distillery 2.25, Operation and Maintenance 2.20, Biomass Input 6.99, By-product credit = 0.70 (1), Working capital for operation 0.10, Sub-total 12.28, Product inventory 0.45 (11).

Note: Data from Ref. 21 updated to 1920 dollar value from data presented in Ref. 21. Assuming that the large devaluation of Brazilian money occurred in December, 1978 (50%) was enough to offset the dollar inflation in 1978 and 1979. (2) By-product credit is the savings from direct application of still conventional fertilizers. It is the difference between the cost of fertilizer and the cost of (AD). If alcohol is to be a major component of the energy supply system for transport, the supply must be constant over the year. This implies an inventory equal to at least one half of the output of a distillery operating 165 days."

Per year, this adds a significant cost to the final product.

Page 32: Production Costs of Ethanol Derived from Acid Hydrolysis Process ($760)

Fixed investment in processing plant, operation and maintenance: 2.00
Biomass Input (39): 6.20
By-product credit (11): 1.80
Total: updated to $1560 value from data presented in Ref. 21.

Assuming that the large devaluation of Brazilian money occurred in December 1979 (303), it was enough to offset the dollar inflation in 1978 and 1983. The cost of biomass is evaluated under the assumption of self-sufficient hectares. 60% of wood undergoes hydrolysis and 40% is used as fuel for the industrial plant as suggested by the performance of Swiss factories and presented in Fig. 9. 60% of wood yields 230 liters of ethanol and 1 ha yields 12,000 liters. This means 1650 liters/ha/year of ethanol.

Since the heat contents of ethanol and wood are 21 GJ/m3 and 1803 GJ/T, respectively, the hydrolysis process converts 216 GJ of wood (2000 T x 186 GJ/T) to 34,503 GJ of ethanol with a conversion efficiency of 162%. The model indicates that lignin is a by-product of the pulp and paper industry. Lignin is produced at a rate of 1.56 GJ of lignin/GJ of ethanol which means a credit of 1780 GJ/T of biomass.

Page 33: Energy Inputs (Percentage)

Figure 1: Energy Input from Natural Gas
(Reference from Ref. 51)

Page 34: Figure 2: Block Diagram - Ethanol Distillery

Steam Stage, Fermentation Station, and Steam to Load Generator with Water Treatment and Electric Energy.

Page 35: Figure 3: Price Structure of Gasoline in Brazil

Raw Material and Refining: 43.30%
Transportation and Distribution Expenses: 9%
Gas Station Profit

Distribution Profit
Resources for Development (Reference from Ref. 52)

Page 36: Figure 4: Variation in Apparent and Actual Consumption of Octane

Lead content (g/litre): 12,000

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39 Figure 7 COST AND TIMING DISTRIBUTION OF INPUTS AND OUTPUTS IN AN EUCALYPTUS WOOD FARM IN BRAZIL 78007 7001 68 | (ert 2 3 6 8 6 7 8 8 wD 8 ae 19 20 | Update to 1980 dollar value from date presented in Ref.21. Assuming that the large devaluation of Brazilian money occurred in December 1979 (30%) was enough to offset the dollar inflation in 1978 and 79.

40 Figure 8 ENERGY COSTS FOR THE PRODUCTION OF GASOLINE * INPUT 1: MATERIALS === ENERGY = INPUT 28 BTU 1 0.03 x 108 BTU | INTERNAL CONSUMPTION 0.031 10" BTU PHYSICAL LOSS 0.02+ 10° BTU UNRECOVERED RESOURCE 2.22810" BTU + From ref. 41

XXII GASOHOL OUTLOOK FOR U.S. SUGAR AND GRAIN CROPS. Presented To The Symposium FUELS AND FEEDSTOCKS FROM TROPICAL BIOMASS. Caribe Hilton Hotel, San Juan, Puerto Rico. November 24 and 25, 1980. Contributed By BATTELLE COLUMBUS LABORATORIES. Columbus, Ohio

GASOHOL OUTLOOK FOR U.S. SUGAR AND GRAIN CROPS Table of Contents. Topic ABSTRACT NEED RESOURCE BASE, 1. Sugar Crops.

"2. Grains and Tubers

Gasohol: Outlook for U.S Sugar and Grain Crops

D.M. Jenkins and B.S. Lipinsky, Battle-Columbus Laboratories, Columbus, Ohio

Abstract:

The factors influencing alcohol production from sugar crops and grain include the need for fuel alcohol, the resource base, process options, economics, subsidies, and markets. The analysis of these factors provides insight into where alcohol is coming from and where it is going. We conclude that most U.S. fuel alcohol in the early 1980s will be made from grain, specifically corn and milo. Sugar crops are too expensive for fuel alcohol. Fuel alcohol production will grow to about 2 billion gallons by mid-decade. Further expansion will depend upon the availability of petroleum and the development of ethanol from cellulose technologies.

Present address: Battelle-Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201.

Gasohol: Outlook for U.S. Sugar and Grain Crops

In 1973 and early 1974, the OPEC oil prices increased dramatically. The average OPEC sales price in 1973 was $3.39/bbl, which increased to an average of $11.28/bbl in 1974. Further price increases occurred throughout the decade, but were largest in 1979 and 1980. In September 1980, the average OPEC sales price was $31.59/bbl, and spot gasoline prices in New York and Rotterdam have recently been $40 and $44/bbl, respectively. Furthermore, the oil producing nations have indicated a desire to exert more control over world oil production and prices, although to date, OPEC has not fully used its potential monopoly power.

The increasing prices of petroleum in world markets and the realization that the consuming countries were at the mercy of the exporting nations prompted a search for alternative fuels which could reduce petroleum imports. In the United States, 1979 energy consumption was 80 quadrillion Btu, of which 18.4 quadrillion Btu were imported."

Of these imports, 16.9 quadrillion Btu were crude oil and refined petroleum products. This is equivalent to net petroleum imports of 7.9 million barrels per day in 1979. Alcohol fuels, both ethanol and methanol, provide an alternative source of energy which has the potential to somewhat reduce the importation of liquid petroleum fuels. To date, most of the emphasis has been on ethanol made from grains and sugar crops. The government estimates that between 80 and 100 million gallons of fuel-grade ethanol are currently being produced annually in the United States. Furthermore, we believe there are about 600 plants with capacities ranging from slightly over 1 million gallons to over 100 million gallons in various stages of planning. In one state, we have recently identified planned alcohol ventures totaling $30 million gallons ethanol capacity per year. These planned alcohol ventures use both grain and sugar as raw materials. However, it seems unlikely that more than a fraction of these ventures will become reality. The Department of Energy has set goals for alcohol production of 920 million gallons per year by the end of 1982, and 1.8 billion gallons per year by the end of 1985.

RESOURCE BASE
2

Ethanol can be made from a wide variety of crops containing either sugar or starch. These crops include sugarcane, sugar beets, corn, milo, wheat, and potatoes. Sugar Crops: Throughout most of the United States, sugar crops are not currently available for alcohol production. U.S. sugarcane is grown only in Hawaii, Texas, Louisiana, Florida, and Puerto Rico. In addition, sugar beets are grown in many northern states, but production has been declining. Beet sugar is usually more expensive to produce than cane sugar. All U.S. sugar production now goes to food uses. At present, and probable future, world sugar prices it is unlikely that current sugar crops will be used for alcohol production in the United States. Recent prices for selected alcohol feedstocks are shown in Table 1. A major advantage of sugar crops is the high

Alcohol yield per acre of cultivated land can be observed in Table 2. It's evident that an acre of sugarcane can produce significantly more alcohol than an acre of grain. However, sugar crops have a major disadvantage compared to starch crops when it comes to alcohol manufacture. The dilute sugar solutions derived from sugar crops cannot be stored without microbial degradation. Therefore, they must either be concentrated into high-test molasses, an expensive operation, or the alcohol plant must only operate during the harvesting season. This approach increases capital charges and elevates the price of alcohol. This topic will be discussed further in the section titled 'Grains and Tubers'.

The two grains most likely to be used for alcohol manufacture are corn and milo (grain sorghum). Other grains such as wheat, oats, rice, and barley are also suitable, but are considerably more expensive. Potatoes and other starch tubers are also suitable for alcohol production. However, food-quality potatoes are too costly for alcohol manufacture, but there are adequate quantities of low value cull potatoes available at certain locations in the northern United States.

We anticipate that only a small fraction of U.S. alcohol production will be made from potatoes or other starchy tubers. Most U.S. alcohol production in this decade will be made from corn and possibly milo. With a yield of 2.6 gallons per bushel, each million gallons of alcohol requires 385,000 bushels of grain. To reach the 2 billion gallon level, we will need to commit 770 million bushels of grain. This is ten percent of the record 1979 corn crop (7.76 billion bushels) and about 12 percent of the estimated 1980 crop of 6.53 billion bushels. The 2 billion gallons of ethanol would replace about 1.3 billion gallons of gasoline or 1.2 percent of gasoline consumption. This assumes that mileage is proportional to the energy content of the fuel, which GM has demonstrated in their new cars with automatic carburetor adjustment.

There is probably adequate land available to produce additional grain for alcohol feedstock. Each billion gallons of ethanol requires 3.5 to 4 million acres.

Of cop land, recently there were 14.8 million acres in the soil bank and another 24 million acres in pasture land which could be converted to cropland with limited risk of soil erosion. Finally, the byproduct of animal feed from alcohol plants would displace some soybeans. For each billion gallons of alcohol made from corn, about 2 million acres of soybeans could be taken out of production.

Future Feedstocks. Several feedstocks which are not now available in commercial quantities have been suggested for alcohol manufacture. These include sweet sorghum, fodder beets, Jerusalem artichokes, and cattails. All of these potential feedstocks require research in crop management and possibly genetic improvements. Sweet sorghum has about the same processing characteristics as sugarcane. Unlike sugarcane, however, sweet sorghum can be grown in much of the United States. It has the potential to provide high yields - the equivalent of about 350-500 gallons per acre. At the present time, sweet sorghum is not widely grown. It's unlikely to make any significant contribution to alcohol production before the end of the decade.

Fodder beets contain both sugar and starch. They are said to have higher yields of fermentable carbohydrates per acre than sugar beets. In addition, they have better storage characteristics and are easier to grow than sugar beets. However, they are subject to diseases and pest damage. More research remains to be done before fodder beets are commercialized.

Jerusalem artichokes have shown potential as an alternative sugar crop for fermentation. They can be grown in the northern United States and do not require high fertilization. Processes to convert the fructose polymer (inulin) to fermentable sugars have not passed the laboratory stage. The true potential has not yet been fully evaluated.

Cattails have been recently suggested as a source of easily grown starch for fermentation. Cattails can be grown on low-quality land in much of the United States. The research on cattails is in its early stages, and we do not believe...

Cattails are likely to become a promising feedstock for widespread alcohol manufacture. The technologies for the manufacture of ethyl alcohol from grain and sugar crops have primarily evolved from the beverage industry. Several modifications and improvements have been made to convert from beverage alcohol technology to modern fuel alcohol technology. One of the significant changes has been in the alcohol recovery system. While the removal of trace impurities which affect the flavor is crucial in beverage manufacture, the fusel oils are generally blended into fuel-grade alcohol. Additionally, most of the existing beverage alcohol plants were built in the mid-twentieth century when fuel cost was not an important criterion. The modern alcohol plant designs have much more energy-efficient distillation systems. Several organizations are continuing research on the recovery of fuel-grade alcohol from fermentation residues, and the energy requirements to make anhydrous alcohol may be further reduced in the near future.

Traditionally, when ethanol is made from sugarcane, there has been an excess of bagasse, which is used to fuel the alcohol plant. Therefore, energy efficiency has been less of a concern in sugar-based plants. As fuel prices rise, however, alternative uses are being found for bagasse as a fuel. The CEER Energy Cane Concept is an example of this. Consequently, we would expect to see the adoption of more energy-efficient technologies in the future.

The current commercial technologies for the manufacture of alcohol from grain employ either dry or wet milling technologies. The corn wet milling plants are more expensive to build, but the higher capital cost is offset by higher byproduct credits. The byproducts from wet milling alcohol plants are corn oil, gluten feed, and gluten meal worth about $0.65 per gallon of alcohol produced at today's prices. This compares with byproduct distillers dark grains and solubles worth about $0.39 per gallon. Byproduct carbon dioxide is obtained from all alcohol fermentations. The carbon dioxide

The text is only marketable in a few special cases.

Section 5: Technologies are currently being developed to manufacture ethanol from lignocellulosic materials such as wood or sericultural residues. These technologies are still in the research stages. However, many observers believe that by the end of the decade, cellulosic materials will replace grains as a major alcohol feedstock.

New processes are currently being developed for the manufacture of alcohol from starch and sugar feedstocks. Some of these new technologies are reported to significantly reduce the required capital investment. These new technologies have not yet been translated into commercial realities, however.

In addition to the commercial alcohol plants, some projections include numerous small, farm-scale alcohol plants contributing to alcohol supply. One Department of Energy report projects 2200 small plants (under 1 million gallons per year) producing 660 million gallons of fuel alcohol by 1985. This estimate seems overly optimistic. In the first place, most on-farm stills are much smaller than this 300,000 gallon per year average. In the second place, although there is much interest in alcohol, few farmers are spending money as yet. Most farmers seem more interested in rising grain prices than in making alcohol. They would probably prefer to stay out of the alcohol business unless that was the only way to obtain higher prices. Although many farm-size stills will be built, we do not anticipate that they will provide a large fraction of the nation’s fuel alcohol.

Economics: The most economic feedstocks for ethanol manufacture using current technology are corn and ilo. Like most agricultural commodities, corn prices can fluctuate over a wide range. During the past decade, Chicago corn prices have ranged from a low of about $1.20/bushel in 1970 and 1972 to a high of about $3.40/bushel in 1980. Local prices in the corn belt and elsewhere can vary considerably from the quoted Chicago prices. With corn at $2.80/bushel and dried distillers grain at $132/ton,

The net feedstock cost is about $0.62/gallon and the net manufacturing cost in a commercial-scale plant is about $1.60/gallon. The manufacturing cost, including profit, will vary with a specific plant design and location, but generally, we believe that the total cost is in this range. The manufacture of alcohol from sugarcane is very sensitive to the sugar value and to the growing season. One of the technical disadvantages of using sugar crops is the inability to store them for extended periods. If sugarcane were valued at $25/ton, then the feedstock cost per gallon of alcohol would be about $1.60/gallon. With a 180-day growing season, the total manufacturing cost of ethanol from sugarcane would be about $3/gallon in a new plant. With sugar at its current high price, the manufacture of fuel alcohol from sugar would appear generally uneconomic. Furthermore, the land available for sugarcane production in the United States is quite limited. There is some possibility that sweet sorghum, which is very similar to sugarcane in its processing characteristic, may be grown throughout much of the United States. Sweet sorghum is not a widely grown crop at present, however. While we believe that sweet sorghum may be an economic crop to grow for the manufacture of fuel alcohol, it will be at least mid-decade before this can be confirmed. The relatively short harvesting season (about 90 days) for sweet sorghum will adversely affect the manufacturing costs unless an economic storage system is devised. The manufacture of ethanol from cellulosic residues is still in the research and development stages. We have examined several processes for the manufacture of ethanol from cellulose. The most economic of these appears to have manufacturing costs of about $1.28/gallon with a cellulosic feedstock like corn stover at $30/dry ton. Although it is difficult to speculate on the final cost of such advanced technologies by the time they are implemented.

As they are ready for commercialization, they do appear to be promising. The manufacturing cost of various alcohol fuels is compared in Table 3. These costs generally do not compare favorably with gasoline at $1/gallon. The recent gasoline prices on the Rotterdam spot market were between $38 and $46/barrel, or $0.90 to $1.10/gallon. With present economics, it appears that alcohol may need some form of subsidy to be competitive. It is somewhat misleading to directly compare the price of alcohol with the price of gasoline. There are two other factors which need to be considered. The first of these is that ethanol contains only 2/3 the heating value per gallon as does gasoline. The second is that ethanol has a high blending octane and may in fact have more value as an octane improver than as gasoline. The value of ethanol as an octane improver depends upon the quality of the raw gasoline and the options available to the blender. Some recent estimates have indicated that the octane improvement value ranges from $0.10 to $0.30/gallon of ethanol.

1. INCENTIVES

In order to promote the use of alcohol fuel, the government has devised a number of incentives. The largest incentive is the reduction of the excise taxes on gasoline alcohol blends. For gasohol, or blends containing 10 percent alcohol, the federal excise tax of 4¢/gallon is waived. This is equivalent to a subsidy of 40¢/gallon of alcohol. The various state excise tax reductions vary from 1¢ in Connecticut to 10¢ in Iowa. The Iowa exemption of 10¢ is only an effective exemption of about 6¢ because a 3 percent sales tax is imposed on fuels which are exempt from the state road use tax. The greatest state subsidy occurs in the State of Arkansas, which has a 9.5¢/gallon tax exemption for gasohol. In total, 24 states have tax exemptions for gasohol, and most of these are in the 4.5¢/gallon range. Many of the state tax exemptions have either a decreasing tax exemption or an expiration date. Furthermore, the gasohol tax exemption is restricted in many states to alcohol.

The text is produced from crops grown within the state, or blended within the state. The states which have state tax exemptions are illustrated in Figure 1. Other incentives for alcohol production include a ten percent investment tax credit on equipment used in alcohol manufacture. This is in addition to the normal ten percent investment tax credit, and various property sales and/or income tax incentives provided by the states. Finally, there are a number of federal loan and guarantee programs available for alcohol plants. The state and federal excise tax exemptions are by far the largest incentives and subsidies for alcohol manufacture. When the excise tax incentives are considered, the economics of alcohol from grain appear competitive with gasoline.

Market acceptance: Consumers appear to have accepted gasohol. In 1978, about 50 million gallons of ethanol were blended with gasoline and sold through about 2,000 retail outlets. Major alcohol producers appear to have difficulty keeping up with demand and have announced several plant expansions. Most gasohol sales have been in the corn belt where there appears to be deep support for fuel made from farm products. The long standing state subsidies also help. Not surprisingly, there appears to be a correlation between the subsidies and the sale and manufacture of fuel alcohol.

Consumers have been willing to pay a premium for gasohol over unleaded regular. Perhaps this is due to the higher octane of current gasohol, or perhaps due to a patriotic urge to reduce petroleum imports. Recently, gasoline retailers' and wholesalers' interest in gasohol has waned. This is partly because of a temporary gasoline surplus which is widening the cost differential between gasoline and alcohol, partly due to the special attention needed to keep water from gasohol, and partly because many petroleum companies are developing unleaded premium grades of gasoline. We believe that dealer interest in gasohol will increase in times of tight supply. Also, dealers and jobbers would be more interested in...

Gasohol could benefit if they were given a slice of the subsidy pie. The outlook for alcohol fuels is summarizing as follows: alcohol fuels are growing rapidly. Last year, production was about 50 million gallons. If the announced capacity is built, capacity will exceed 900 million gallons in 1983. Alcohol capacity will likely be about 2 billion gallons by mid-decade. However, beyond mid-decade the outlook is unclear. The economics of alcohol from sugar crops are very unfavorable. Alcohol from grain is competitive with petroleum only if subsidized. Grain alcohol may be competitive with alternative fuels. Grain, particularly corn and milo, will be the preferred feedstock for alcohol in the early 1980s.

The cost of subsidization is high, and the subsidies currently reduce road maintenance budgets. Furthermore, the creation of a significant fuel alcohol industry will increase grain and meat prices. Unless there is a petroleum shortage in the first half of the decade, we expect public support for alcohol fuels from grain to diminish. The growth of fuel alcohol plants will slow. Attention will be turned from alcohol fuels by fermentation to higher value chemical products.

The reduction in public support for alcohol from grain and sugar crops will provide an opportunity in the latter part of the decade for alcohol from lignocellulose. Whether or not alcohol fuels continue to grow depends largely on the success of current research and development on lignocellulosic technologies. For example, sugar crops (sugarcane and sweet sorghum) have considerable potential as ethanol resources if technology to convert lignocellulose contained in the stalks to ethanol achieves commercialization.

v ALCOHOL RESEARCH AND DEVELOPMENT OUTLOOK FOR PUERTO RICO

Presented To The Symposium FUELS AND FEEDSTOCKS FROM TROPICAL BIOMASS (Caribe Hilton Hotel, San Juan, Puerto Rico November 24 and 25, 1980

Contributed By ‘THE UPR AGRICULTURAL EXPERIMENT STATION ‘Rum Pilot Plant, Rio Piedras

ALCOHOL RESEARCH AND

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ALCOHOL RESEARCH AND DEVELOPMENT OUTLOOK FOR PUERTO RICO

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ABSTRACT

Alcohol research in Puerto Rico is directed primarily to the needs of the Puerto Rican Rum Industry. Most of this research is conducted at the Rum Pilot Plant of the Agricultural Experiment Station. The research program discussed places special emphasis at present and in the immediate future on raw material and the fermentation process in search for efficient processes which will minimize the effects of scarcity of raw material, energy costs and pollution control.

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ALCOHOL RESEARCH AND DEVELOPMENT OUTLOOK FOR PUERTO RICO

INTRODUCTION

In Puerto Rico, the major part of the research on alcohol is conducted at the Rum Pilot Plant, which is a department of the Agricultural Experiment Station of the University of Puerto Rico. The Rum Pilot Plant was created by the Legislature in 1948 and its main purpose is to provide scientific support to the Puerto Rican Rum Industry. Its main objective, therefore, is to assist local rum manufacturers in obtaining and maintaining high quality rum. The Plant is equipped with semi-industrial fermentation and distillation facilities, as well as chemical and bacteriological laboratories and an aging warehouse. It is staffed with experienced chemists and bacteriologists and several engineers under part-time contract.

Up to 12 years ago, the rum industry in Puerto Rico was in very good shape. The market was solid, with a strong increasing trend. Raw material was relatively cheap and abundant and with the exception of unforeseen troubles now and then, the rum manufacturers had no significant worries.

Then, beginning in 1968, a series of events

The following text has been corrected:

Several events began to occur which have affected the industry to a point where the future does not look as bright as before. The three major events were: (a) The Environmental Protection Agency's ruling in 1968 stated that the industry had to comply with certain terms. They noted that treatment facilities needed to meet EPA’s efficiency standards by 1983. (b) Petroleum prices began increasing in 1973 and have continued to increase. This has caused a significant effect on the industry, becoming the major consideration in any projections, expansions, or future plans. (c) The decrease in local sugar production has resulted in a decrease in the production of blackstrap molasses, a by-product of sugar manufacturing which is the raw material for the production of rum. This has led to a greater dependency on imported molasses.

These three events have been responsible for changes in the technological viewpoints of the rum manufacturers. In areas where a few years ago they were hesitant or unwilling to introduce changes, specific areas of interest are raw materials and the fermentation process. The contemplated changes in these areas aim to minimize the effects of scarcity of raw material, energy costs, and pollution control. These create an increasing number of interesting research problems which must be solved in a relatively short time.

One of the objectives of the Rum Pilot Plant for the present year is to develop a modern fermentation process for the manufacture of high-quality rums. This emphasizes the optimum utilization of raw materials, efficient usage, and conservation of energy. To undertake these studies, it is necessary to set up the pilot scale facilities to operate as flexibly as possible, and this is now being done.

The main raw material used in Puerto Rico for rum manufacture is blackstrap molasses, which is obtained from sugar manufacturing. The availability and quality of this material have been decreasing since 1969, forcing the rum producers to obtain molasses from other rum producing countries. The available molasses varies.

The composition of molasses, particularly concerning fermentable sugars and undesirable solids such as minerals and gums, varies depending on the country of origin. Low-quality molasses can have many adverse effects, including inhibition of yeast, blocking centrifuge nozzles, sealing in the beer column, and contributing significantly to the pollutant characteristics of the stillage.

The rum industry is currently considering two alternatives to compensate for the scarcity and low quality of the molasses. One alternative is the pretreatment of blackstrap molasses to remove undesirable solids before fermentation. A downside to pretreatment is the loss of sugar during the process. The process typically involves heat treatment and clarification to destroy bacteria and remove certain volatiles in the raw material that can inhibit fermentation.

In the Almotherm retreatment process, which will be employed in our studies, suspended solids are removed along with much of the soluble calcium salts. Through countercurrent washing, minimal loss of sugar can be achieved.

As will be seen later, the present tendency in the rum industry is to increase alcohol productivity and lower operational costs. To attain this goal, yeast recycling is being considered by rum manufacturers. In this case, it's almost mandatory to pretreat the blackstrap molasses to obtain a clean yeast cream.

Additional benefits expected from combining pretreatment with yeast recycling are: (1) Reduced scaling in distillation units (beer column); and (2) it's estimated that the industry will need 59 million gallons of molasses in 1980, while the local mills will produce only 8 million gallons.

(3) The quality of the stillage from the beer column will be such that part of it could be used to dilute incoming molasses, providing savings in process water and acid and reducing the volume of stillage to be treated, thus reducing the stillage treatment costs.

The other alternative being considered is the use of high-test molasses in the fermentation process. High-test molasses is defined as

Clarified sugarcane syrup is partially inverted to avoid crystallization and evaporated to 85° Brix. Its composition is different from that of blackstrap molasses, as can be seen in Table 1. Based on experimental work conducted at the Rum Pilot Plant (2), where various procedures for inversion of sucrose in sugarcane juice were studied, preliminary tests on a larger scale (1000 gallon batch) were conducted at Gusnica Sugar Mill by Rum Pilot Plant personnel. These tests were carried out by Chemists Eduardo Rosado and Mario Ramirez with the collaboration of Bacteriologist Nivia Murphy. Tests on this scale are important as more reliable data on optimal conditions, costs, and energy requirements can be obtained. Three thousand gallons of high-test molasses were produced in these experiments, in which the enzymatic inversion method was employed. The inversion time averaged 10 hours and the tests showed that this operation could be carried out parallel to the sugar refining process. Part of the material produced was fermented and distilled and is being aged with adequate controls and analysis to characterize the final product. However, there are many economical and technological aspects to be evaluated before any commitment can be attained regarding the conversion of a significant portion of the sugarcane harvest for high-test molasses instead of sugar and blackstrap molasses. To this effect, the Puerto Rican Rum Producers Association, at the request of the Economic Development Administration, has submitted a statement defining their position and concerns on the molasses crisis, and recommending a program to evaluate the economical and agricultural aspects which will guarantee the amount and quality of raw material needed by the rum industry without depending on exterior sources. The important points are that circumstances have made the rum manufacturer interested in other sources of raw material. If high-test molasses, or sugarcane juices, are not suitable substances then perhaps a whole new approach such as the Ex-Ferm process is required.

The text should be closely examined.

4. FERMENTATION PROCESS

The impact of the three major events mentioned earlier has been reflected in the increasing cost of producing alcohol by fermentation. This has awakened interest in areas where changes can be introduced in the process without adversely affecting quality, yet would result in cost reductions. A significant part of the research effort at the Rum Pilot Plant at present and in the immediate future will be the development of efficient fermentation processes which will be evaluated under different conditions.

These include:
(a) Pretreated blackstrap molasses as raw material
(b) High-test molasses as raw material
(c) Both materials to be evaluated with and without yeast recycling

The initial phase which is now underway involves setting up flexible pilot scale facilities to conduct studies on batch, incremental, or continuous fermentation, with or without pretreatment of raw material, and with or without yeast recycling. With this approach, it should be possible to determine the ideal conditions and best substrate for producing rum at the lowest possible cost.

The advantages of combining pre-treatment and yeast recycling were mentioned in the previous section. The importance of yeast recycling is in the fact that in addition to building up a high yeast concentration, and as a result, shortening the fermentation time, higher alcohol yields are obtained. This is due to the presence of more fermentable sugars in the mash being converted to alcohol, instead of being used to grow yeast cells, as is the case in conventional fermentation systems. By means of centrifugal separators designed specifically for yeast recovery, and by acid-washing of the yeast before re-use, it's possible to maintain a vigorous mass of yeast cells in the system. An extremely high yeast concentration tends to suppress bacterial or fungal growth, thus reducing undesirable by-products of fermentation from these micro-organisms and enhancing the alcohol yield. Other methods for preserving the yeast cream...

The topics that will be studied include the use of antibacterial agents, flotation process, refrigeration, and drying.

Yeast recycling will be studied with special reference to the continuous fermentation process. The flexibility of the installations will permit the re-use of yeast in either batch or incremental fermentation processes. The optimal procedure selected for incremental and continuous fermentation will be based on the response to controlled fermentation variables, and conservation of energy. Variables include yeast concentration, nutrient formulation, pretreatment of the mash, mash formulation, pH, temperature control, and alcohol yield and quality. The impact on energy savings will be assessed in all experiments. The reuse of water and stillage will be evaluated as a source of heat and diluting liquor.

FERMENTATION OF DISTILLERY WASTES

Although the rum manufacturers are already involved in definite plans for the treatment of distillery wastes, research in this area will continue at the Rum Pilot Plant. Stillage produced from the various experiments using different raw materials and techniques will be characterized. Data on the composition of distillery wastes obtained from the fermentation of high-test molasses indicate that the BOD content is approximately 50% of that of stillage obtained from the fermentation of blackstrap molasses. Based on this value, treatment costs should be much lower for stillage from high-test molasses than from blackstrap molasses. Complete analyses of these two wastes will be published in the near future by Chemist Mario Ramirez. Studies on the fermentation of distillery wastes for the production of fodder yeast will continue.

OTHER STUDIES

1. New Yeast Strains

The strong demand for higher fermentation rates and higher alcohol productivity has intensified research on the development of yeast strains compatible with high alcohol concentrations and temperatures. Although the Rum Pilot Plant will not be directly involved in developing these strains, the yeast development program will continue and

As these new strains become available from different sources, they will be added to the yeast collection. They will be evaluated first on a laboratory scale and then on a pilot plant scale.

2. Dense Cell Culture

In addition to yeast recycling as a means for building up yeast cell concentrations, other methods have been mentioned in the literature (3). Some of these are:

(a) The tower fermenter, using a flocculating yeast
(b) Packed tower with immobilized cells
(c) Membrane-dialysis
(d) Hollow-fiber fermenter technique
(e) Rotor fermenter

As more information becomes available, the most promising of these techniques will be evaluated and compared with the yeast recycle approach.

3. ExFerm Process

A new approach to the production of alcohol by fermentation is being studied by C. Rolz and his associates at the Central American Research Institute for Industry in Guatemala (4). Basically, this process, called Ex-Ferm, combines extraction and fermentation of sucrose directly from sugarcane pieces in one operation. Research has been conducted on a laboratory scale (2 liters) in vertical reactors and in horizontal tubular packed bed fermenters with different yeast strains and different sizes of cane particles. This process will be evaluated at the Rum Pilot Plant on the laboratory and pilot plant levels, and the results will be made available to the rum industry.

4. Alcohol For Energy

Research at the Rum Pilot Plant will not involve production of alcohol for energy purposes such as gasohol. This is being investigated from all aspects in many research laboratories in various countries. However, the Rum Pilot Plant is in a position to collaborate with other investigators in this field, especially with regard to fermentation and distillation of by-products.

CONCLUSION

The research program in which the Rum Pilot Plant is involved, as mentioned previously, is

aimed at obtaining solutions to problems which may affect the Rum Industry. High priority is given to the problem of raw material and to fermentation techniques.

Which may result in higher alcohol productivity and lower costs. ACKNOWLEDGEMENTS: Thanks are given to the technical personnel of the Rum Pilot Plant for their collaboration in the preparation of this paper.

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COMPOSITION OF HIGH-TEST MOLASSES (INVERTED) AND BLACKSTRAP MOLASSES: X composition. Parameter High-Test Blackstrap; Specific Gravity (Brix) 20-86 86.0; Total Sugars, As Invert 19 51.0; Invert Sugar 50-65 20.0; Sucrose 12-26 0; Soluble Solids, Non-Sugar 6.0-7.5 23.0; Ash 2.2-2.0 9.6.

ENVIRONMENTAL IMPLICATIONS OF BIOMASS AND OTHER ALTERNATIVE FUELS USAGE IN PUERTO RICO Presented To The Symposium FUELS AND FEEDSTOCKS FROM TROPICAL BIOMASS Caribe Hilton Hotel, San Juan, Puerto Rico November 24 and 25, 1980 Contributed By THE UPR CENTER FOR ENERGY AND ENVIRONMENT RESEARCH Terrestrial Ecology Division, Rio Piedras, P. R.

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ENVIRONMENTAL IMPLICATIONS OF BIOMASS AND OTHER ALTERNATIVE FUELS USAGE IN PUERTO RICO

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ABSTRACT

The small size and relative isolation of Puerto Rico necessitate responsible management of existing environmental resources. Here, as on similar islands, natural ecosystems are extremely susceptible to disturbance. As Puerto Rico develops its energy alternatives for the future, adequate consideration must be given to the environmental impacts of development so that valuable irreplaceable resources are not lost. In the immediate future, coal is likely to be used to reduce Puerto Rico's dependence on oil for electrical power generation. However, several unique attributes favor the development of a variety of renewable energy resources. Abundant sunshine, nearly constant trade winds, a suitable climate for yearlong crop production, and proximity to deep ocean waters can all be used to provide energy for Puerto Rico. Preliminary studies have not detected any unresolvable technical problems, but the ecological implications for large-scale implementation must be closely scrutinized. Environmental assessment is necessary in order to make intelligent decisions concerning both the technology to be used and the location of energy-producing facilities. Many schemes have been developed for classifying impacts. Some current categories are briefly discussed. By evaluating impacts, the environmental scientist is making value judgments based on available information. For this reason, it is important to maintain a broad perspective on the problems of energy development in Puerto Rico and elsewhere.

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ENVIRONMENTAL IMPLICATIONS OF BIOMASS AND OTHER ALTERNATIVE FUELS

USAGE IN PUERTO RICO INTRODUCTION: To identify important areas where additional information is needed in order to adequately assess environmental impacts,

2. ENVIRONMENTAL IMPACTS: Puerto Rico's heavy dependence on fossil fuels is likely to

continue for some time, but rising costs and dwindling world reserves have created a mounting need for the development of renewable energy sources. The National Academy of Sciences has evaluated six renewable energy sources potentially contributing to Puerto Rico's energy needs. Their study revealed that there are no easy or low-cost solutions, and concluded that a variety of domestic resources can substantially contribute to decreasing Puerto Rico's need for imported fossil fuels (Table 1). The impact of using these renewable resources plus coal, currently proposed as a partial substitute for imported oil, are the alternatives which have the greatest chance for immediate development and therefore need immediate evaluation.

1. Biomass: Only a century ago, biomass in the form of wood was the primary fuel used in the United States. Biomass can provide fuel directly in the form of fiber and indirectly as alcohol. Wood or cane fiber can be processed for use in electrical generation facilities to supplement fossil fuel combustion, and ethanol can be used as a fuel supplement for gasoline-powered vehicles. Economic and technical arguments for the immediate development of these resources are persuasive. No new technology is required, development could be integrated with solar drying and modern agricultural methods to optimize.

Resource use and the yearlong growing season in Puerto Rico are favorable for maximum productivity. Fuel costs are competitive and the molasses byproduct, in the case of sugar crops, could be sold to further reduce fuel production costs. Like other forms of energy, there are both negative and positive aspects to its use. Two significant potential problems associated with biomass production are: (a) erosion, which depletes soil fertility and affects air quality, water quality, and adjacent ecological communities, and (b) land use, which can adversely impact important ecotypes and wildlife habitats (20). The use of insecticides and fertilizers poses additional threats to the environment. Among the beneficial results of using biomass instead of fossil fuels for energy production is the reduction in air pollutants, particularly SO2 and NOx emissions (1, 19). It is important to add, however, that reducing air pollution is a more desirable environmental goal.

3. There is a clear need for additional information on the environmental impact of biomass, including its production, transportation, and use as fuel. There is a concurrent need for studies of the effects of large-scale development of this process in an island environment. What is the optimum area that could be committed to biomass production without adversely affecting other components of the environment? It is likely that there is no precise answer, given our present methods of cost/benefit analysis, but some estimates should be obtained before large-scale development is begun. Current information indicates that 50,000 acres of energy plantation would be required to maintain a 300 MW modern coal/biomass boiler operating at 80% capacity. Proper management could reduce the area needed to 15,000 acres (Alexander, personal communication). In order to account for a substantial percentage of the Island's energy requirements, many square miles would need to be converted to energy plantations. On an island the size of Puerto Rico (approximately 3,400 square miles), most of

The following text is covered with mountains or karst, and with a population of over three million people, land use quickly becomes an important consideration. The conversion of large areas of land to energy crops is a very real danger to natural ecosystems. The consequences would be felt the strongest in flat lowland areas (3,15). Because many of these seas are already highly disturbed, additional modification of these lands might have an insignificant adverse environmental impact. Another source of biomass is the large volume of water hyacinths which covers lakes, ditches, and other slow-moving bodies of water in Puerto Rico. Studies conducted by the Terrestrial Ecology Division of the Center for Energy and Environment Research have shown that this weedy species can be used as a biofilter to improve the water quality of sewage treatment facilities and produce biomass fuel for bioconversion (21, 22).

2. Solar Energy

In a broad sense, many forms of energy (fossil fuels, hydroelectric, wind, etc.) are different manifestations of solar energy. Even the energy in biomass is solar energy fixed in organic materials by the process of photosynthesis. For the purposes of this report, only photovoltaic, residential solar water heating, and wind will be evaluated as solar technologies. These solar technologies do not differ from other energy sources in that they produce both positive and negative environmental effects. Preliminary environmental evaluation conducted by the Solar Research Institute of the U.S. Department of Energy has not identified any unresolved technological problems (e.g., CO2 emissions) or large-scale hazards (e.g., the possibility of catastrophic accidents) which would hamper development (16). Photovoltaic electricity generation would produce relatively few impacts when compared to other energy sources. The direct impacts would be chiefly in the commitment of large land areas for the collection of diffuse solar radiation and water quality effects caused by the discharge of working storage, and heat transfer fluids (12). The residential

The industrial use of solar hot water heaters would produce insignificant environmental impacts, as these devices could be placed on buildings to avoid disturbance of land and seas. Even optimistic projections for their use would have only a slight impact on the overall energy needs of the Island (9). A preliminary appraisal indicates that a small percentage of Puerto Rico's power could be generated by wind by the year 2000 (9). Although some land would be required for windmill installation, the chief environmental problem seems to be noise and vibrations from the wind machines, which can affect both human and wildlife inhabitants in the vicinity of these devices (16).

3. Hydroelectric Power

Most of Puerto Rico's rainfall occurs at high elevations, but the small area of land and short rivers involved limit the potential for hydroelectric generation (9). Environmental costs are very high when compared to returns in power generation. Large areas of land, much of which is habitat for unique and endemic species, would be affected. Normal flow patterns would be interrupted, and the movement of minerals and organisms impeded. The reservoirs produced could provide some benefits, but these would probably be insignificant compared to the habitats lost and ecosystems disturbed by their creation.

4. Ocean Thermal Energy Conversion

The proximity of Puerto Rico's power grid to cold deep ocean water makes it a prime location for an OTEC facility. Both the technical feasibility and environmental impacts of such an installation are largely unknown. An operating OTEC system consumes large volumes of cold, nutrient-rich water and dumps them into warmer surface water. There will undoubtedly be a significant impact on the marine biota, but whether the net impact is negative or positive, and whether it is significant or insignificant, have not yet been determined.

5. Coal

A considerable body of data is available on the environmental impacts of burning coal to provide energy. The most noteworthy direct negative impact...

Air pollution, high ash content, and '80 emissions (10, 17) have polluted major industrial areas throughout the world, causing considerable damage. The environmental impact of coal combustion on Puerto Rico proper is likely to be minor due to proposed plant locations and existing Commonwealth and Federal air quality standards. However, the impact on the downwind marine environment, including air-breathing forms such as whales and sea turtles, is unknown but potentially significant.

The use of coal as a fuel for electrical power generation will necessitate the construction of a protected ocean port facility and will increase the ship traffic in that region. Both of these situations may harm the marine environment. Other plant-related facilities will include ash disposal sites and transmission line rights-of-way, which should produce only minor environmental disturbances.

CLASSIFICATION OF IMPACTS: The major impacts of various energy alternatives have been mentioned, but an overall evaluation has not been provided. Such a task is beyond the scope of this report, but some suggestions as to how to classify impacts might be helpful at this point. Both the technology and location of the alternative energy installation need evaluation, and size requirements are important. Some of the commonly encountered categories for judging impacts are listed below:

- Positive/negative
- Long term/short term
- Reversible/irreversible
- Primary/secondary (direct/indirect)
- Avoidable (can be mitigated)/unavoidable
- Significant/insignificant
- Acceptable/unacceptable

6) Air pollution and land use commitment can readily be designated as negative environmental impacts, but the size and location must be known before any evaluation can be made of their significance. A project may be unacceptable because of the technology employed (e.g. nuclear power) or the location of the installation (e.g. critical habitat of an endangered species). It is apparent at this point that we are making value judgements and trying to predict the future on the basis of these factors.

The text appears to have several typographical and grammatical errors. Here is a corrected version:

Of past experiences and exploratory calculations, Schumacher (11) has remarked, "All predictions are unreliable, particularly those about the future."

Conclusions: Based on existing assessments, biomass shows the greatest promise of any renewable resource for meeting the energy needs of Puerto Rico in the near future. Potential environmental impacts have been identified and need to be critically evaluated. Coal will be used as one alternative to oil in order to supply electrical power to Puerto Rico in the near future. The environmental impacts of coal combustion are generally negative, but additional work may be needed to determine their exact nature and overall significance.

Puerto Rico's unique environmental attributes favor the development of renewable energy sources which are now in the developmental stages. Among these are wind, photovoltaic, and ocean thermal energy conversion. Once these technologies have been tested and their environmental impacts assessed, the island will have additional options for attaining some level of energy self-sufficiency.

Environmental Perspective: Scientists and engineers tend to view the world as a composite of more or less isolated systems. For instance, as an ecologist, I find it convenient to study the rain forest ecosystem as an entity separate from adjacent agricultural land. A broader perspective is needed, however, in order to understand world mineral cycles of which the rainforest is only a segment. The interconnectedness of ecological systems and all environmental components is difficult to ignore. As the naturalist John Muir observed more than half a century ago, "When we try to pick out anything by itself, we find it hitched to everything else in the universe" (B).

It is likewise necessary to maintain a broad perspective when evaluating the environmental implications of energy development. The most urgent problem of our time, however, is not energy, but rather world population (2). This is particularly evident in Puerto Rico, where the per capita demand for... [Text ends here]

Energy has increased greatly in the last few decades, and population growth has also risen sharply. Two symptoms of this condition are (a) intensive farming for food production and (b) the frenzied exploitation of non-renewable resources, including fossil fuels. By confining ourselves to evaluating only direct impacts of energy development, we will be treating the symptom rather than attempting to cure the disease. Biological populations, both plant and animal, are controlled by limiting factors such as disease, food supplies, and living space (4, 14). Human populations are partially limited by available energy, but it is important to realize that there are other factors. I would therefore ask that we all take a broader and longer look at the environmental implications of energy development; otherwise, truly relevant solutions will not be achieved in Puerto Rico or elsewhere in the world.

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I'm sorry, but the last part of the text seems to be scrambled and doesn't make any sense. Could you please provide a correct version of it?

The text seems to be garbled and doesn't make any sense. Could you please provide more context or a clearer version of the text?