ALTERNATE USES OF
SUGARCANE FOR DEVELOPMENT IN PUERTO RICO

PROCEEDINGS OF

a symposium sponsored by

THE CENTER FOR ENERGY AND ENVIRONMENT RESEARCH

in collaboration with

THE INSTITUTE OF CHEMICAL ENGINEERS

and the

THE ASSOCIATION OF SUGARCANE TECHNOLOGISTS

MARCH 26-27, 1979

CARIBE HILTON HOTEL, SAN JUAN, P.R.

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TABLE OF CONTENTS

WELCOMING STATEMENT

Dr. Ismael Almodóvar,
President of the
University of Puerto Rico

WELCOMING STATEMENT

Dr. Ismael Almodóvar, President of the
University of Puerto Rico

It gives me great pleasure to be here today, and to welcome you all to this Symposium dedicated to the search for alternate uses of sugarcane.

The sugar industry began in Puerto Rico during the sixteenth century, in the same manner that many new industries are being developed today—with a government loan. Fomento is, therefore, much older in Puerto rico than generally thought.

By the middle of the present century, four centuries after its birth, our sugarcane industry had become by far our main industry. Its efficiency was higher than that reached in Hawaii, Louisiana, or any foreign country. It was producing over a million tons of sugar annually, employing some 150,000 persons, and receiving Federal subsidies and import duties protection.

Puerto Rico had become sugar. It was generally said, and nobody dared deny it, that it was the natural industry for Puerto Rico. We had here in our own land all necessary raw materials for making sugar, which, taken together with a year-round input from the sun, would give to us more sucrose than to any other place on earth.

Then, suddenly, the clear reality and beautiful dreams were torn to pieces, and now the former giant is reduced to one fifth of what it was and only the Government can absorb its losses.

What happened?

The global answer is very simple. Scientific research was not on a par with the labor, production, and marketing problems that new local and world conditions brought upon us.

Research did not give us the proper answers. But we should not blame the researchers. They were not called in on time, or in sufficient numbers, or with the proper resources.

The industry rapidly found itself with less and less benefits and less money to discover solutions for its problems. In this connection, we must remember that the industry knew the value of research.

The President of the University of Puerto Rico now has his offices and residence at the Río Piedras Experimental Station which was established in 1911 with a gift of the Sugar Producers Association. The Association donated some 240 acres of land on the condition that they would be devoted to experiments with sugarcane and the development of more productive plant varieties.

Research done by Carlos Chardón, you will recall, saved the industry when it was affected by the so-called mosaic disease. Research also gave us hybrid varieties that raised dramatically the production of sugar per acre.

The Sugar Producers Association, in the last years of its existence, helped the Station financially to develop harvesting machines adapted to our terrain and planting systems. The sugar industry knows, therefore, by experience, the blessings that good research can give and the shortcomings from a lack of proper and timely research.

We have to look for new ways to make the land and the sun, of which we were so proud in the days of splendor in our sugar industry, productive again. We have to search for alternatives.

Let me recall that Central Igualdad, in Mayaguez, installed some years ago a plant for the production of furniture from bagasse. Beautiful furniture was made but the equipment was never used again. Something went wrong with the project, probably a matter of costs and prices, but the feasibility of manufacturing a new product was demonstrated.

If furniture can be made from bagasse, there is no doubt that several other products can be obtained from sugarcane. Many products have been suggested, especially now that oil is reaching prohibitive prices.

In the old days, the fuel used by our sugar mills consisted of its own bagasse. There is energy in bagasse. There is energy in the end product—sugar. And there is energy in the whole process. It is a matter of converting it to the best possible uses. It is a matter of approaching the whole process from new angles in search of new products more in line with present needs and conditions.

We are living now the petroleum era, but we should remember what happened to our own sugar era. The petroleum era will not last much longer. All the world's reserves of oil will be exhausted in a few decades.

Substitutes for oil will be needed. They are needed even now because of the prices that oil is commanding. The idea of substituting gasoline with alcohol is very old and has shown its worth in several countries.

It is not necessary to make sugar to make alcohol. At this moment, alcohol could give us more profits than sugar. Automobiles can guzzle more alcohol than habitual drinkers. We should go back to the old faith that we had a native raw material that can be turned into gold. What we need is research, organized research. The Experimental Station, founded for sugarcane research, should be useful. For all could be useful.

That gentleman, by the name of Mr. Castellón, who founded the first sugar mill in Añasco in the first half of the 16th century, and set rolling an industry that helped very significantly our development for the next four centuries, can be emulated now. Individually or collectively, we need the new Castellóns, the new visionaries, that can set the cane industry rolling again, rolling in new directions, in new ways, with new products.

The mere holding of this meeting shows a new spirit, a new wish for a new endeavor. You may be launching here today a new purpose, a new faith in the sugarcane industry.

Gentlemen, I hail you as a new hope of the people of Puerto Rico.

OPENING REMARKS

Dr. Juan A. Bonnet, Jr., Director,
UPR Center for Energy and Environment Research

OPENING REMARKS

Dr. Juan A. Bonnet, Jr., Director,
UPR Center for Energy and Environment Research

On behalf of the Center for Energy and Environment Research, and our co-sponsors, the ICHE and the Association of Sugarcane Technologists, I extend a warm welcome to all of you. We are delighted that you found it possible to join us today.

One of the purposes of the Center is to inform the public on the true dimensions of our energy problem, which is much more serious than most people realize, and to point the way toward solutions based on the research being done here and in other places that has applicability to our particular situation.

This symposium is eminently an educational experience for us in the Center as well as for those of you who may not be engaged in energy research. We are focusing today on sugarcane as just one of many partial solutions to our energy problem. Everything we have been able to learn about the energy problem tells us that there is no one unique solution. We look to sugarcane and other kinds of biomass. We look to Ocean Thermal Energy Conversion (OTEC), to concentrating solar collectors, to energy conservation, to wind energy, to solar photovoltaics, to cogeneration, to fossil fuels including coal, and to nuclear power.

But today we are concentrating on sugarcane, something which has been familiar to Puerto Rico since the first years of the colonization, but which we have always viewed as primarily a source of sugar and molasses. It is time in Puerto Rico that we look at sugarcane as a source of energy and chemical feedstocks. Already Brazil is producing alcohol from sugarcane, and the Island of Hawaii produces 40% of its electric power burning bagasse and fiber.

It is interesting to note that in Puerto Rico we have used sugarcane fiber as a source of fuel for operating our sugar mills and sometimes for producing electricity to be fed into the Island's electric power grid, but only to a very limited extent.

I had the pleasure of talking recently with Don Luis Ferré, former Governor of Puerto Rico and now President of the Senate of Puerto Rico, about this possibility. He was deeply interested because he is an engineer and his family has been involved in the sugar industry for many, many years. He regretted not being able to attend this seminar because of previous commitments. But he told me this subject had come to his attention long ago. He delved into his files and brought out a copy of a paper he had written on bagasse as a fuel, and on the redesign of a sugar factory to take advantage of waste heat—what we now call cogeneration—to increase its efficiency and also to produce surplus power for sale to the Island electric power grid. He was talking of new techniques and materials that made it possible to use higher temperatures and consequently increase the boiler efficiency and also contribute to an increasing number of heat recovery processes. He mentioned that the sugar industry in Puerto Rico should consider burning bagasse and fiber to produce electricity for our electric power grid.

I find it fascinating that he presented this paper to the Colegio de Agricultura y Artes Mecánicas de Mayaguez in 1935—yes, let me repeat—in 1935.

Today, however, we are going far beyond bagasse as a fuel for direct combustion. We will be looking at the remarkable attributes and potential uses of sugarcane from almost every conceivable angle. Let us remember that, in these difficult economic times, the countries that develop new industrial processes and technologies are the ones that succeed. In Puerto Rico we have the know-how to orient our sugar industry for better and more fruitfull days.

I consider it significant that *The DORVILLIER Newsletter*, the most authoritative newsletter on economic and business trends in Puerto Rico, which is read by top executives in literally hundreds of blue chip industries in the United States, bases the lead article of its latest issue (dated March 24) on this symposium.

The Dorvillier letter mentions that the documentation prepared for this meeting is the most penetrating analysis made so far of Puerto Rico's sugar industry and the most convincing case yet presented for revitalizing it on a radically different basis.

And now it is my pleasure to introduce our next speaker, Mr. Frank Castellón, Director of the Office of Energy of Puerto Rico, who will present his address on an: *"Overview of Sugarcane in Puerto Rico's Food and Energy Scenario."*

OVERVIEW OF SUGARCANE IN PUERTO RICO's FOOD AND ENERGY SCENARIO

Frank Castellón
Director, P.R. Office of Energy

OVERVIEW OF SUGARCANE IN PUERTO RICO'S FOOD AND ENERGY SCENARIO

Frank Castellón
Director, PR Office of Energy

There is a diversity of ways to look at sugarcane viewed against the background of Puerto Rico's Food and Energy Scenario. In a way, the topic reminds me of Monet's paintings. Monet, one of France's best painters of the 19th century, was able to paint the same object many times using different shades of light which accentuated the times of the day and seasons of the year making the paintings to look different. In a way our attitude toward the problems we need to face is dictated by the different perspectives and insights we have gained which reflect our different approaches to the problems and the background against which we examine them.

Allow me to start my presentation by making a general statement about Puerto Rico. In my opinion, there is no place in the world where the existing problems are more intertwined that in Puerto Rico. If you take a worldwide problem like population growth you will quickly realize that in Puerto Rico this problem is closely related to land use, housing, transportation, education, food production, power generation, and crime, Puerto Rico offers a greatly interrelated problem-crisis matrix. In a worldwide sense, food production is closely related to energy availability, but there is probably no other place in the world where the solution of the food problem is in conflict with one of the proposed solutions to the energy problem to the extent that we find it in Puerto Rico. Since approximately 1950 Puerto Rico has become more dependent on imported fuels. Since approximately 1930, when Puerto Rico stopped using wood as a major source of energy, the Island became largely dependent on imported fuels and hydroelectric power to satisfy its energy needs. Today, 99% of all the energy consumed in Puerto Rico is obtained from fossil fuels. A very small amount of energy is obtained from food and animal power.

A very simplified version of Puerto Rico's interrelated food and energy problem can be expressed as the dilemma between the following choices:

(a) Should we produce locally, and with a minimum of imports, as much as possible of the energy that we need and import from outside most of the food that we need? or

(b) Should we produce most of the food that we need and import most of the fuel that we need from mainland U.S.A.? or

(c) Should we seek to combine both of these two extremes in order to maximize a given utility function? or

(d) Should we do nothing, in the hope that world forces can be neutralized by local inertia?

I call your attention to the fact that I have labeled the above statements as a SIMPLIFIED version of Pueto Rico's interrelated food and energy problem; emphasis on "SIMPLIFIED."

In Puerto Rico there are essentially two principal schools of thought which deal with this dilemma. One school maintains that we should produce as much as possible of the energy that we need and the other maintains that we should produce most of the food that we need. During this conference we will have the opportunity to receive information which will help us make individual analyses.

For choice (a) one must demonstrate the following:

1. That in our situation fuels are more critical than food for our economic well being.
2. That a food crisis is less probable than a fuel crisis.
3. That the relative economic value of the fuel-dependent sectors of our economy is greater than the economic value of food imports.
4. That food production efficiency in mainland U.S.A. is superior to food production from biomass in Puerto Rico.
5. That fuel production efficiency in Puerto Rico will be more efficient than fuel production from biomass in mainland U.S.A.
6. That there is a linear trade off between the ratios of the above-mentioned efficiencies.

For the selection of choice (b):

1. It needs to be demonstrated that one can classify the foodstuffs that we can produce in Puerto Rico in terms of those which can be marketed locally at a price that is lower than any available market price.
2. It needs to be demonstrated that the savings obtainable from eliminating food imports will more than balance the outlays for imported fuels.

3. It needs to be demonstrated that even if the food bill in the short run would compare favorably with the fuel bill, still the inflation rate of food will be higher than the inflation rate for fuel.
4. It needs to be demonstrated that the transition from imports to local production of food will not disrupt the marketing environment and that the final price structure will be stable.
5. It needs to be demonstrated that the specific objectives of a food program are consistent with our general economic objectives, which have been mostly attentive to industrialization.
6. It needs to be demonstrated that total employment levels, both in agriculture and in manufacturing, will be higher than can be provided by a biomass program.

As things stand now, I would discard the first as a short term solution. We would be gaining a partial independence from imported fuels at the cost of a greater dependence on imported foods.

I doubt that we can do the third given the potential growing acreage and topological constraints.

We cannot afford to do nothing, and we may in fact be late already in making up our minds. But we still do not know if growing food is really the "best" choice.

Yet we realize that biomass is one of our few domestic renewable resources, with good technical experience available, and the basic physical infrastructure on hand. We also recognize the local production of alcohol as one of the few ways available to lower gasoline imports. Our main difficulties are really in the areas of information generation. Which alternatives bring more jobs, need less capital, mean "more" to the economy? We must rely on our academic and scientific community, already overtaxed with the burdens of their main research efforts, to help us find the coefficients, measure the impacts and assess the benefits to our social system, in order to make a rational choice.

While searching for the answers to these questions I recommend strongly to follow the advice given by the great philosopher Alfred North Whitehead: "Seek simplicity and then distrust it." Many of us look for simplicity in the solutions of our problems but forget to distrust it.

SUGAR AND ENERGY ATTRIBUTES OF THE GENUS *SACCHARUM*

AN OVERVIEW

Presented To

A SYMPOSIUM ON ALTERNATE USES OF SUGARCANE FOR DEVELOPMENT IN PUERTO RICO

Caribe Hilton Hotel, San Juan, Puerto Rico
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Contributed By

The University of Puerto Rico, Center for Energy and Environment
Research, and UPR Agricultural Experiment Station
Río Piedras, P. R.

SUGAR AND ENERGY ATTRIBUTES OF THE GENUS *SACCHARUM*

Table of Contents

Topic **Page**

ABSTRACT

Sugar And Energy Attributes Of The Genus *Saccharum*; An Overview

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ABSTRACT

SUGARCANE is a living collector of solar energy which functions on a year-round basis to store this energy in forms of fermentable solids and fiber. For centuries the plant has been grown in tropical regions as a source of sucrose and molasses while its fibrous components received little attention. Today, fiber is increasingly valued as a boiler fuel and as a potential feedstock for conversion to liquid and gaseous fuels. Within this context, other members of the genus *Saccharum* having little aptitude for storing sucrose are seen to have an important new role as sources of cellulose. The role of *Saccharum* as an energy resource is further emphasized by changing trends in the petrochemical and chemical-sweetener industries, by the rising costs of planting sucrose, and by a growing need of tropical societies to use their land and water resources for food production. This paper presents an overview of *Saccharum* sugar and energy potentials within the framework of Puerto Rico's rapidly worsening energy scenario.

1/ Principal Investigator and Acting Head, CEER-UPR biomass energy program, Agricultural Experiment Station, Río Piedras, P. R. 00928.

SUGAR AND ENERGY ATTRIBUTES OF THE GENUS *SACCHARUM*; AN OVERVIEW

HISTORICAL BACKGROUND OF *SACCHARUM*

SUGARCANE is the world's finest living collector of solar energy. More than any other plant, the hybrid sugarcanes of commerce have perfected the art of converting sunlight to chemical energy and storing it in forms of sugar and fiber. Without question, the sugarcane breeder has done much to intensify these attributes in the interspecific hybrids of today's sugar industry, but the potentials themselves originated among divergent members of the genus as an evolutionary process spanning many millions of years.

In evaluating the genus *Saccharum* as a future source of sugar and biomass, one must recognize that its special attributes evolved long before the concepts of sugar and energy production were matters of concern to anything but the plant itself. Perhaps more important, the task of harnessing these attributes for the benefit of mankind, that is, of thoroughly tapping the vast germplasm pool of this genus for the production of superior new hybrids, has just barely begun.

1. Origin of *Saccharum* Species

To an important degree *Saccharum* species are products of extensive phytogeologic transformations in the region of present-day Malaysia. These changes date from the early Cretaceous epoch, the last geologic period of the Mesozoic era, which began roughly 200 million years ago (1, 2). During that period (11), the continents of Asia and Australia were connected by an extensive land mass (Fig. 1). This supports the view that an intermingling occurred of many plant genera which today are common to Africa, India, southeast Asia, and the southwest Pacific (1). It is believed that the earliest form of *Saccharum* evolved on this land bridge and eventually occupied an area extending roughly from present-day Brisbane to Bombay. Probably a diploid plant with little of the robust growth habit of its modern descendents, the original *Saccharum* prototype has either become extinct or has introgressed with other genera (3, 2).

Through most of the Cretaceous epoch the land mass joining the Asiatic-Australian continent experienced periodic inundations followed by reappearance of the land bridge (1, 11). For the continent's flora, this provided a kind of botanical cauldron favoring evolutionary diversity through repeated mixing and separation of potential parental forms. Ultimately, during the late Createaceous or Eocene, a permanent break-up of the land bridge occurred. Permanent deep-sea conditions developed on the north-south axis in the region east of the Philippine archipelago, Borneo, and Java. Plant forms continued to evolve independently both east and west of the deep-sea area. Today, an arbitrary boundry known as "Wallace's Line" can be traced along the western edge of the break-up area which roughly separates the distinctly Australian and Asiatic plant groups (1).

As noted above, *Saccharum* species were among the more ancient plant forms which preceded the continental break-up and hence continued to evolve on both sides of Wallace's Line. The early *Saccharum* species must have been as promiscuous then as their descendents are today, for totally distinct intra- and interspecific forms of *Saccharum* emerged in southeast Asia and India on one hand and in the region of New Guinea on the other (9, 10). In particular, divergent forms of *Saccharum spontaneum* developed in India through a series of natural hybrid crosses. They are so distinct, in fact, from the *S. spontaneum* clones of other regions that some authorities felt they must have evolved independently from a totally different original ancestor (2). A high proportion of the still-untested *Saccharum* genetic material needed for production of new, high-energy sugarcanes resides within the Indian *S. spontaneum* germplasm pool.

2. *Saccharum* Diversification and Migrations

From the late Cretaceous epoch onward the main objective of the evolving genus *Saccharum* must have been simple survival in an enormously intense competition with other herbaceous species. During this interval, species of the genus progressed from small, narrow-bladed, thin-stemmed, hollow-stemmed, and fibrous-stemmed clones bordering fresh and brackish water, to larger and thicker-stemmed forms having an increasing affinity for dryland plains and even semi-arid uplands (4, 5).

Several features still evident in the genus contributed to their survival (2, 7, 8). Foremost perhaps was a marked ability to make both the interspecific and intergeneric cross. This attribute is extremely rare in higher plants. A probable second factor was the operation of the C-4 pathway of photosynthesis. This pathway would have offered a more effective utilization of available light and carbon dioxide in crowded conditions heavily shaded by competing species. A third factor is the genus characteristic of depositing much of its photosynthetically-reduced carbon in the form of sucrose rather than starch. Sucrose is a mobile carbohydrate and biochemically more accessible than starch for support of growth and respiratory processes. A fourth factor is the genus preference for vegetative reproduction. The ability to produce a new plant from a viable bud at each leaf axil, sustained by sugars stored in the immediate vicinity of each bud, must have offered an important evolutionary advantage over competitor species reliant on the production of true seed.

Curiously, the ability to store sucrose in really massive quantities, as commercial cane hybrids do today, was probably not a major factor in the evolutionary survival of the genus. This attribute was a late arrival and figured mainly in the species *S. officinarum*. This species, sometimes described as the "noble canes" or "garden canes," attracted the attention of primitive man who propagated its clones in village gardens for chewing purposes (12, 4). Unknowingly, the sweet-toothed aborigines must have aided the evolutionary development of sugarcane by retaining only the sweetest, soft-stemmed, and thick-stemmed specimens. Early man also carried *S. officinarum* with him on voyages eastward to Fiji and ultimately northeastward to the Hawaiian Islands (6, 2). However the genus did not find its way to the western hemisphere until quite recently, and then it came from the east, via India, North Africa, and Spain, finally accompanying Columbus on his second voyage to the New World in 1493. The specific clone brought by Columbus, or something very close to it, is still extant in the noble cane "Creole" (2).

BOTANICAL ATTRIBUTES

1. A *Saccharum* Preference For Fiber

In a general sense, tropical grasses are living collectors of solar energy which can operate on a year-round basis to convert this energy to chemical forms and to store it as fiber and fermentable solids. Sugarcane is perhaps the leading example of this group, but even within the genus *Saccharum* there are numerous species that excel in energy conversion but which have never been cultivated as an energy resource (7).

Grasses that yield fiber as their main product will soon become candidates for intensive cultivation as energy crops for the first time. Such species have immediate value as a boiler fuel and a longer-term value as sources of liquid and gaseous fuels (15, 16). Within the *Saccharum* group alone the fiber-producing attribute has botanically dominated the genus while sugar-bearing forms have drawn the attention of modern tropical agriculture (2). All but one of the extant *Saccharum* species have a natural preference to produce fiber while having little or no aptitude for accumulating sucrose (Table 1). The principal exception is the species *S. officinarum*. But even the noble canes, and indeed even the hybrid sugarcanes of commerce, have a natural inclination to utilize their sugars in growth processes yielding fiber when water and nutrient supplies are sufficient to do so (2, 48).

2. Physiological Attributes

Saccharum species are not only an evolutionary product of the earth's mild climate zones, they are also equipped to utilize this climate in growth and development processes more efficiently than do a majority of plant species. About a decade ago the carbon-4 pathway of CO_2 assimilation was discovered in sugarcane and it was soon found to characterize the tropical grasses in general (2). Photosynthesis in these species is further characterized by exceptionally low CO_2 compensation points, a capacity to utilize both lower and higher light intensities than do temperate or Calvin-cycle plants, and a "lack" of photorespiration.

There is also spectrographic evidence suggesting that *Saccharum* species can absorb a broader region of the incoming solar spectrum than do temperate species (13), and that sucrose is a persistently dominant photosynthate throughout most of the visible light spectrum (14, Fig. 2). Further to this, *Saccharum* species have elaborate source-to-sink mechanisms which function in a manner both qualitatively and quantitatively superior to those of most plants. Moreover, their ability to form sucrose rather than starch as the primary photosynthate has been a factor of enormous consequence both in the evolution of the genus and in its impact on tropical agriculture (2, 7).

Taken together, these attributes enable tropical grasses to "harvest" sunlight and to store it in usable forms in rather massive quantities. This is not to imply that the processes and mechanisms themselves are particularly efficient; there are no really efficient photosynthetic systems operating anywhere in the plant kingdom. Nonetheless, the genus *Saccharum* does mark a kind of apex in the evolution of plant systems as converters of solar energy.

AGRONOMIC ATTRIBUTES

The author has sometimes described sugarcane as the "world's finest living collector of solar energy," and as often as not some member of the audience will hasten to point out that corn or sweet sorghum are equally proficient in energy conversion. Their reference is to the process of photosynthetic carbon assimilation, whose measured rate is ordinarily expressed as milligrams of CO_2 assimilated per unit of leaf surface per unit of time. In this they are quite correct, at least in a physiological sense, in that species from several genera do have CO_2 assimilation rates about equal to those of sugarcane. However, and this is very important, the meaningful measure to an energy planter in the field is not mg $CO_2/cm^2/hr^{-1}$, but rather the amount of solar energy striking an acre surface in a year's time that has been intercepted by the plant, converted to a useable form, and stored as harvestable dry matter. This proficiency is expressed as tons of dry matter produced/acre/year (Table 2). Many processes seemingly peripheral to photosynthesis collaborate to form dry matter, but photosynthesis remains the decisive input upon which all others depend. Dry matter yield is still the single most accurate and meaningful measure of energy-conversion potential in higher plants. In this context, sugarcane is indeed the world's finest living collector of solar energy.

1. *Growth Characteristics*

Sugarcane has several important agronomic attributes for energy conversion not enjoyed by corn, sweet sorghum, sunflower, cattail, or other plants sometimes depicted as the equal of sugarcane. These include: (a) A profuse tillering habit that yields a cluster of 10 to 40 stems/year from an original single-bud cutting; (b) a diphasic growth habit consisting of an extremely long tissue-expansion phase (up to 8 months) and an extended maturation phase for converting the succulent green tissues to fiber; (c) a "ratooning" growth habit enabling the crown to continue a vigorous stem production for about five years without replanting; and (d) a capacity to continue the solar harvest–solar storage–tissue expansion processes 24 hours per day, 365 days per year.

The ability to profusely tiller, that is, to develop a crown which sends up a continuing array of new shoots, is itself an enormous advantage over certain other tropical grasses such as corn and sweet sorghum. Field corn rarely tillers at all while sweet corn may produce one to three secondary stems. Sweet sorghum similarly has less inclination to form tillers than does sugarcane.

For the concept of year-round solar conversion potential the limiting factor is not sunlight intensity, or warm day temperatures, or a year-round mild climate as is often supposed, but rather a night temperature consistently higher than about 65°F. This enables the plant to proceed continually with the nocturnal processes of sugar translocation and storage (ie, sucrose movement from leaf to leaf-sheath to stem or "sink" tissues). Secondary sink tissues, the apical meristem and adjoining immature internodes, also receive a night input of sugars needed in direct support of growth and respiratory processes (2, 17). Without a suitable night climate the *Saccharum* source-to-sink system for solar energy conversion will not proceed at an optimal rate; in fact, at around 60°F, where certain other species retain some growth activity, sugarcane is inclined to simply sit there and mark time in an inactive state.

2. Tissue Expansion vs Maturation

As noted earlier, tropical grasses have the capability to harvest solar energy on a year-round basis, yet maximum dry matter yields will not always follow if the energy planter harvests these species only on an annual basis. There are discrete categories of tropical grasses based on the frequency of harvest required for optimal yields (Table 3). This is a result of characteristic "diphasic" growth processes, that is, an initial tissue expansion phase which is highly visible but consists mainly of water, and a tissue maturation phase in which dry matter accumulates rapidly with little outward change in the plant's appearance. The completion of both phases requires as little as 10 weeks in some species (the NK hybrids) and 12 months or more in plants such as sugarcane (18).

A case in point is the relative productivity of napier grass (*Pennisetum purpureum*) and sugarcane when harvested at 6- and 12-month intervals. Experiments performed at the AES-UPR Lajas Substation indicate that napier grass easily produces more dry matter than sugarcane for a period of six months (Table 4). However, if allowed an additional 6 months for growth and development before harvest, sugarcane yields will increase by over 100 percent while napier grass yields decline by more than 40 percent. The reason for this is that sugarcane has barely begun its maturation phase by the sixth month, while napier grass has essentially completed both its tissue expansion and maturation phases. The second six months of growth are critically important to sugarcane while napier grass simply marks time or at best produces a few weak tillers. For this reason we have arbitrarily designated napier grass as an "intermediate rotation" crop and sugarcane a "long rotation" crop in our terrestrial biomass program (18). In a larger sense, the operation of diphasic growth processes requiring 12 months for optimization has important implications for mainland sugar planters who are denied from the onset a year-long growth period.

3. *Saccharum* Yield Potentials and the Sugarcane Breeder

The high biomass yields of commercial sugarcane hybrids is widely recognized, but until quite recently there was little demand for the fibrous residues (bagasse) produced by milling operations. Throughout the sugarcane world mill engineers saw some advantage in burning bagasse to provide process heat for sugar factory operations and the generation of electrical power; however, its use as a boiler fuel consumed only a fraction of the available supply, and no alternate uses of any appreciable magnitude were ever developed. There was some reluctance to use bagasse even as a boiler fuel so long as fuel oil could be purchased at around two dollars per barrel. The optimal tonnage potentials of sugarcane as a fuel source therefore remained an open question.

Over the years, both agronomic and breeding practices designed to maximize sucrose have acted as constraints on total biomass production. An entirely new set of agricultural inputs must be evaluated together with new breeding objectives before sugarcane will operate to capacity as an energy crop. As an example of this concept, the PR sugar industry is presently producing about nine oven-dry tons per acre year as an Island-wide average. A CEER-UPR biomass project in the Lajas Valley designed to maximize dry matter production has demonstrated yields in the order of 27 oven-dry tons per acre year with plant-crop cane (43). Higher yields are expected from the ratoon crops. It is very probable that dry matter production can be raised to 35 or 40 tons per acre year using existing varieties, but with fiber rather than sucrose as the principal objective (Table 5).

Ultimately, yields approaching 50 dry tons per acre year (200 green tons) will require major breakthroughs in the breeding technology for *Saccharum* species. It is unfortunate that a series of genetic and physiological constraints have long operated in this genus to deny breeders an access to more than a tiny fraction of the available *Saccharum* germplasm (19). However, the *Saccharum* germplasm pool is such a rich and varied source of genetic material that the eventual breaking of these constraints should lead to new recombination types that will make museum pieces of present-day varieties. At that time also *Saccharum* species having fiber as their main product will be bred and valued to a far greater extent than they are today. Moreover, the newer generations of sugarcane varieties will be superior not only in terms of sugar, fiber, and total biomass, but they will also extend into marginal lands that are too cold, too arid, too saline, too acid, too poorly drained, or too steeply contoured to sustain the present-day sugarcanes of commerce.

The past history of sugar planting tells us that the sugarcane plant must give up some of its sucrose when its growth regimes are intensively forced. This does not necessarily mean that the content of total sugars must decline. In the author's experience, the loss of sucrose attending forced growth regimes is pretty much balanced out by increases in fructose and glucose (2, 20, 21, 22, 23). While the recovery of total sugars may be hindered somewhat by increased fiber, it is not an unreasonable request of the sugarcane breeder to provide us with high-biomass varieties having a molasses yield potential which is very comparable, on a per-plant basis, to the present-day sugarcanes of commerce. Putting this another way, our projected yield increases by a factor of 3 to 5 for total dry matter should be accompanied by very large increases for molasses on a per-acre basis.

FACTORY OUTLOOK

1. Sucrose vs Ethanol and Fiber

Historically, Puerto Rico's sugarcane industry has emphasized sucrose and blackstrap molasses as its primary products while placing little value on fiber (bagasse). A future industry for which sugarcane is planted and managed for energy would emphasize high-test molasses (in which sucrose is retained) and fiber, while eliminating refined sucrose as an economically-valid objective. Such changes in emphasis would not be confined to the sugar factory; to the contrary, they would necessitate some far-reaching transformations in the industry's agricultural phase. In effect, we anticipate vastly greater mill deliveries of fibrous, high-tonnage cane having a slightly lower content of fermentable solids (total sugars). In the final analyses these changes would provide a qualitatively poor cane insofar as recoverable sucrose is concerned, while the output of molasses and bagasse would far exceed the yields to which a sucrose-oriented industry is accustomed.

There are highly valid reasons today why we should ask the genus *Saccharum* to give us more fiber and molasses, rather than sucrose, after having cajoled the genus to produce sucrose for so many years: (a) In a botanical context, *Saccharum* is overall a better producer of fiber and molasses than of sucrose; (b) Puerto Rico's needs for total fermentable solids (as sources of fuels and chemical feedstocks) are becoming far more urgent than her needs for refined sucrose; (c) Puerto Rico has a critically urgent need to find a domestic boiler fuel substitute for oil, and in this context sugarcane fiber is the Island's best available resource; and (d), new developments in alternate products and by-products from bagasse, including cellulose conversion to glucose (44, 45, 46), indicate that sugarcane fiber will become a highly valued product in its own right as a long-term source of cellulose (47).

Puerto Rico's needs for sucrose and blackstrap molasses (molasses from which much of the sucrose has been removed) remain partially valid in the sense that we need molasses for the local rum industry. We also have a growing need for molasses as a source of ethanol for motor fuel and as an industrial chemical feedstock. But we can no longer afford to produce refined sucrose; in fact, the costs of producing sucrose locally have reached disastrous proportions, amounting to about 26¢ per pound in 1978. It is far more reasonable to leave the sucrose our cane still yields in the concentrated juice, ie, to produce high-test molasses, thereby lowering milling costs and offering the rum and ethanol industries a higher-quality molasses. Again, the de-emphasis of sucrose would remove some traditional production constraints from the cane plantation manager. He would now be free to approach the higher tonnage potentials which can never be realized in production operations directed toward recoverable sucrose.

2. Long-Term Prospects; Year 2000 and Beyond

By the year 2000, and perhaps much sooner for Puerto Rico, important changes will have occurred throughout the sugar-planting world which will clarify sugarcane's role as a source of sugar and energy: (a) The need for renewable, domestic energy sources will have become sufficiently great to force government action in areas which today are the preserve of semi-academic research and politically-oriented discussion; (b), breeding constraints long operative in the genus *Saccharum* will be largely overcome, and a whole new generation of superior interspecific hybrids will be planted specifically as energy resources; (c) Puerto Rico will still require molasses for her rum industry, and domestically-propagated sugarcane will be the sole source of this molasses; (d) Puerto Rico will have an equally urgent requirement for fermentation ethanol as a motor fuel. This need will be met with local molasses or glucose syrups derived from the cellulose of bagasse and woody biomass species; (e), the use of bagasse and other biomass sources as boiler fuels for electrical power production will be on the decline, but other more sophisticated uses of plant cellulose will increase the overall demand for bagasse and other sources of fiber; and (f), woody terrestrial biomass, marine biomass, and municipal refuse will have become major sources of renewable fuels and chemical feedstocks.

The scenario described above will apply to some extent to all developed societies. As a rule of thumb, however, it would apply least to developed temperate-climate nations still possessing large reserves of fossil energy, such as the mainland U.S. and Canada, and it would apply most to industrialized, tropical, and insular societies having no reserves of fossil energy. For better or worse, the roles that sugarcane will play as a future energy source will be more applicable to Puerto Rico than virtually any other society in the world.

Within this context the best that Puerto Rico can do in the realm of biomass energy is to take a forefront position in the development of sugarcane's alternate uses. Similarly, the worst thing that we can do is to wait upon other countries in other climate zones to develop other energy alternatives, which, when at last ready to come on line, will be only partially applicable to Puerto Rico.

3. Near-Term Outlook; High-Test Molasses and Boiler Fuel

(a) *Molasses Self-Sufficiency for PR:* Puerto Rico's need to produce ethanol in one form or another appears to be a permanent feature of this Island. While one may prophesize that ethanol will be in common use as a beverage, a motor fuel, and a chemical feedstock by the year 2000, it is a matter of record that rum was in common use almost from the date of Puerto Rico's discovery.

Rum has been one of Puerto Rico's finest success stories. For many years rum production was largely a family operation with minimal consistency in production processes and quality control; however, in 1938 the UPR Agricultural Experiment Station published a treatise on rum manufacture which systematized all major steps from cane and yeast selection to the processing and aging of the final rum products (24). World War II saw increased rum production and exports accompanied by highly favorable tax rebate arrangements with the Federal government. By 1960 the rum industry was the second leading source of Island revenue (25), and present-day revenues are in the order of $300 million per year.

However, in a very real sense, Puerto Rico's rum industry is in a kind of jeopardy not unlike that imposed on Puerto Rico by her reliance on foreign fossil energy. The declining sugarcane industry does not provide enough molasses to meet local distillery needs, and as a consequence Puerto Rico must rely on foreign suppliers for about half of her annual requirement. Moreover, much of the imported molasses is of higher quality than the local product and is actually preferred by local distillers. Within this context, the redirection of Puerto Rico's sugarcane industry would have as one of its first benefits the establishment of a self sufficiency of molasses. This would be accomplished in two ways; (a) A three-to-five fold increase in total sugarcane tonnage would increase by several fold the yield of molasses; and (b), the retention of sucrose in this molasses, ie, the production of high-test molasses, would yield a higher-quality product at a lower cost than the blackstrap molasses produced today. Without question, the planting and management of Puerto Rico's sugarcane for energy rather than for sucrose, ie, for molasses and fiber, would have very significant side benefits in the form of molasses self sufficiency.

(b) *Fuel Ethanol from Sugarcane:* It appears unlikely that Puerto Rico will produce significant quantities of ethanol for motor fuel before the mid-1980's. This projection is based on the need for additional research on production costs and is not a rejection of the ethanol fuels concept *per se.* Since 1976, much controversy has persisted between advocates and opponents of fuel ethanol from plant materials (26, 27, 28, 29, 31, 32, 33, 34). The best case for ethanol has been established by a team of Battelle-Columbus investigators working with sugar crops (29, 30), and by a University of Nebraska group whose studies include engine and road performances from ethanol-gasoline (gasohol) fuel blends (26, 27, 37). The entire concept of ethanol production from plant materials for motor fuel has been criticized by Iowa workers who maintain that more energy must be expended in producing ethanol than can be recovered as fuel energy (35). Park, et al. suggest that ethanol produced from sugar crops and grains will cost at least three times as much as gasoline (36). While such reports appear less informed than those of the ethanol advocates, their position lends ammunition to everyone seriously committed to criticizing ethanol.

Ethanol cost projections range from a most favorable $1.00 to $1.25 per gallon by Battelle-Columbus workers (30) to an utterly pessimistic $3.00 plus per gallon by a government project in Costa Rica (34). Quite significantly, the studies by Lipinsky and co-workers stress a need for technological improvements, both in cane handling, milling and steam generation on one hand and in fermentation–distillation operations on the other. Critics of ethanol tend to assume that all "best process" developments are complete and can be found in textbooks. Lipinsky and co-workers further identified mill operations as the phase where about 75 percent of ethanol-production improvements can be accomplished. Toward this end they strongly support a "revolutionary" method for processing sugarcane, ie, the Tilby cane separation process (38).

Puerto Rico workers are concerned with the very large improvements that can still be made in conventional milling operations and in the distillery itself. Suggested modifications include: (a) Elimination of all but one mill from multiple-mill tandems; (b) a thorough (but inexpensive) preparation of cane before it enters the single mill; (c) use of bagasse as the sole source of distillery heat; (d) direct fermentation of raw juice; (e) elimination of one (and possibly two) distillation columns; and (f) a totally new method for dewatering ethanol (39, 40).

Puerto Rico is favored for ethanol research by her long experience with rum, the existence of both commercial distilleries and pilot-plant research facilities, and the capability to supply molasses on a year-round basis. However, very limited support has been received to date from DOE, and only in recent months have the PR Legislature and the PR Energy Office awakened to the possibilities of local research on ethanol for fuels.

(c) *Bagasse as a Near-Term Boiler Fuel:* In a PR sugar industry managed for energy rather than sucrose, the large amounts of high-test molasses described above would be accompanied by massive quantities of bagasse. This material has a large potential value as a near-term replacement for petroleum boiler fuels in electrical power generation. It is very possible, even probable, that this value will exceed that of molasses itself. In any case, bagasse would be the keystone of Puerto Rico's domestic boiler fuel industry. It would retain this position until replaced by other combustibles (woody biomass, marine biomass, and municipal refuse), or until more sophisticated technologies come on line for electrical power production (solar, OTEC, and wind).

The new emphasis on bagasse as a major boiler fuel has both agricultural and factory implications to be described in detail elsewhere (41, 42). In essence, the production of this bagasse can be performed on a 12-month basis, which is climatically possible but inadvisable for agricultural reasons, or on an eight-month basis which is a more practical alternative.

The latter option would be supported by mill modifications offering new sources of process heat in two capacities: (a) Utilization of hot flue gases for the partial drying of bagasse to increase its combustibility; and (b), utilization of flue gases for a more thorough drying of bagasse enabling it to be stored for later use as an off-season boiler fuel. A significant option also remains in the open-air drying of bagasse. If option (b) were adopted it is still probable that a bagasse shortfall would occur amounting to about a two-month gap in the annual fuel supply. This gap could be filled with alternate tropical grasses propagated as solar-dried forages (43). These grasses would be bulk-baled and stored for use as off-season fuels. They would also serve as off-season substitutes for bagasse in other fiber-based industries.

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Table 1. SACCHARUM species and biomass products

Species	Principal Products
Saccharum edule	Fiber
S. barberi	Fiber
S. sinense	Fiber
S. robustum	Fiber
S. spontaneum	Fiber
S. officinarum	Sugar & Fiber
Interspecific Hybrids [1/]	Sugar & Fiber

[1/] Commercial sugarcanes.

Table 2. Two points of view on the photosynthetic potentials of higher plants

Investigator	Assimilation parameter of greatest interest
Plant physiologist or plant biochemist	mg $CO_2/cm^2/hr^{-1}$
Energy planter	Tons DM/Acre/yr

Table 3. Categories of tropical grasses based on time requirements for optimal fiber yield and probable frequency of replanting 1/

Category	Harvest frequency (Mo)	Replanting frequency (Mo)	Candidates
Short Rotation	2-3	2-10	Sordan 70A, 77
Intermediate	4-6	6-30	Napier grass
Long rotation	12	30-60	Sugarcane hybrids
Minimum tillage	6-12	30-?	*Saccharum* species

1/ Based on findings to date from DOE contract no. ET-78-S-05-5912 (43).

Table 4. Divergent responses of sugarcane and napier grass to 6-and 12-month cropping (43)

Species	Total dry tons/acre, for — First 6 months	Second 6 months	Yield Change (%)
Sugarcane 1/	8.0	17.5	+119
Napier grass 2/	12.4	6.9	- 44

1/ Mean values for three varieties and two row spacings

2/ Mean values for one variety and two row spacings

Table 5. Projected yield potentials for sugarcane propagated as an energy source in Puerto Rico

Industry Objectives	Varieties	Production Inputs	Estimated Yield (Tons DM/Acre Year)
Sucrose, Blackstrap Molasses	Existing High Sucrose	Minimum	9 1/
Fiber, High-Test Molasses	Existing High Tonnage	Water, N, Pest Control	20
Fiber, High-Test Molasses	Existing High Tonnage	Maximized water, N, Pest Control	30-40
Fiber, High-Test Molasses	New *Saccharum* Interspecific Hybrids	Maximized water, N, Pest Control	50

1/ Present PR industry average

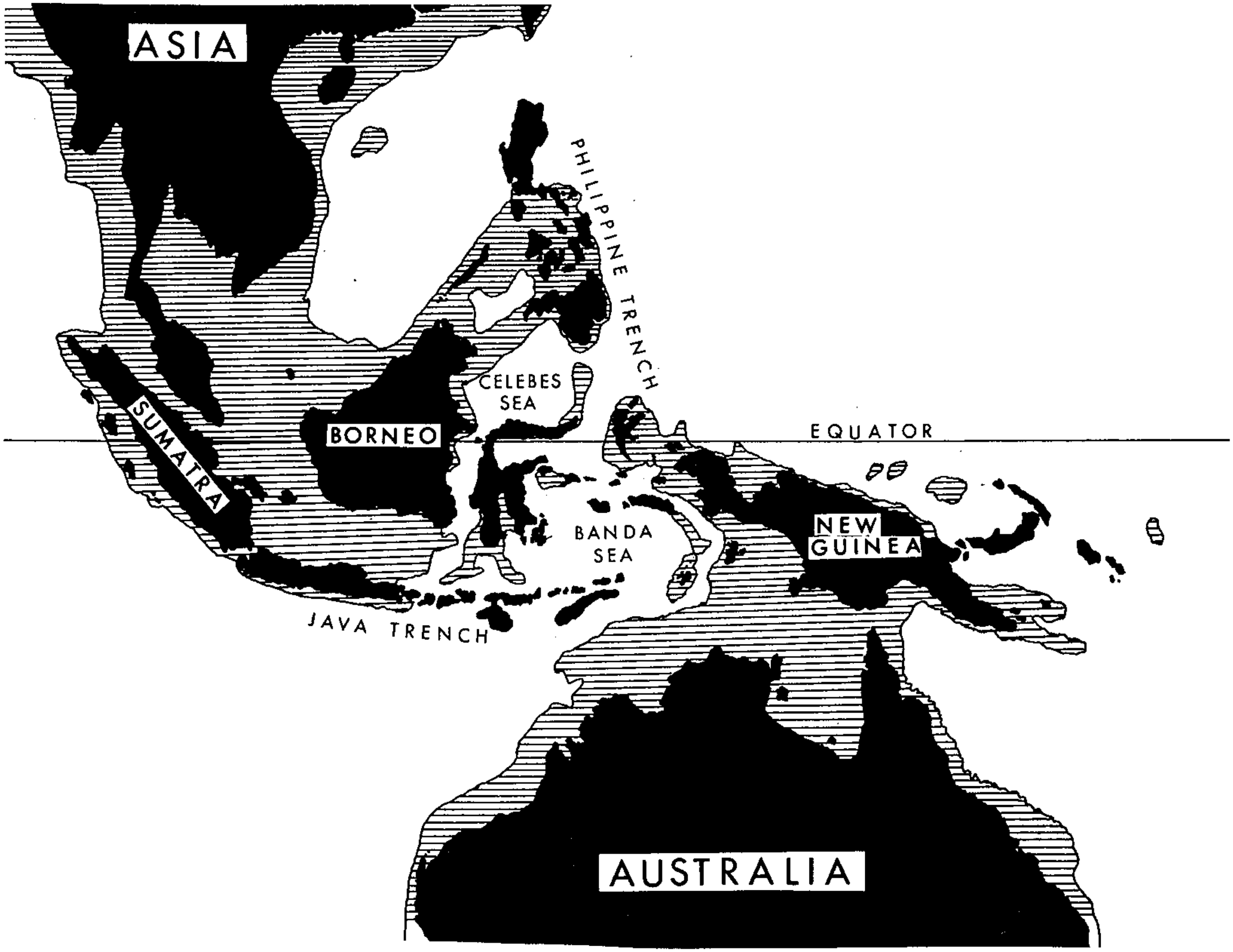

Fig. 1. Site of an Asiatic-Australian land mass where the genus Saccharum originated during the Cretaceous epoch, and evolved into complex forms during the late Cretaceous, Eocene, Pleistocene, and Tertiary eras.

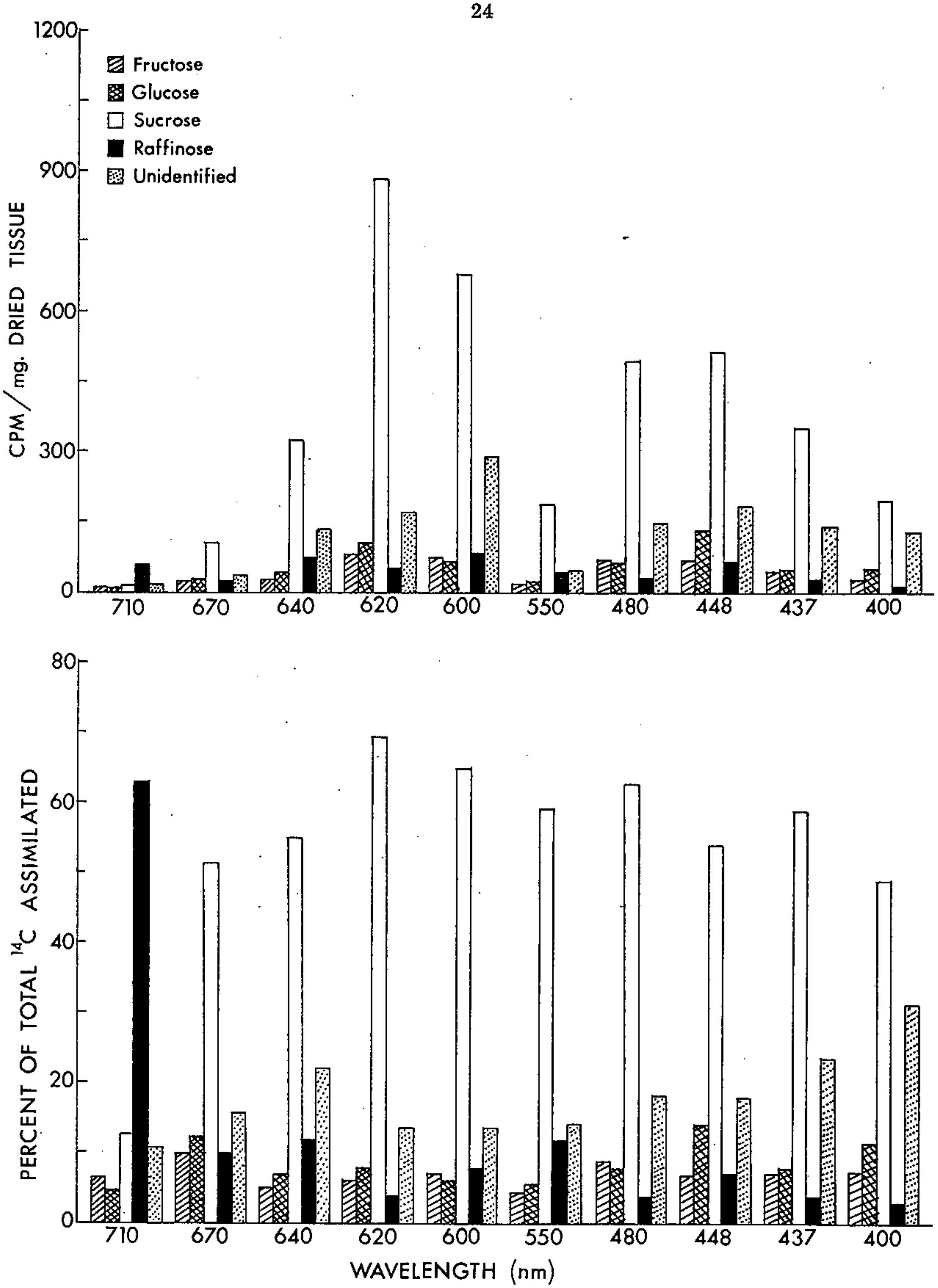

Fig. 2. ^{14}C assimilation into leaf-sugar components of sugarcane variety PR 980 illuminated with different wavelengths of the visible light spectrum. Sucrose predominates at test wavelengths of 670 nm or lower, both in terms of total ^{14}C assimilated (top) and as a percentage of the total ^{14}C assimilated (bottom).

BREEDING POTENTIALS FOR BIOMASS IN THE GENUS *SACCHARUM*

Presented To

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Mayaguez Campus, Río Piedras.

BREEDING POTENTIALS FOR BIOMASS IN THE GENUS *SACCHARUM*

Table of Contents

Breeding Potentials For Biomass in the Genus *Saccharum*

Teh-ling Chu [1]

ABSTRACT

In view of the mounting interest being directed toward sugarcane as a renewable source of energy for Puerto Rico, the breeding potential for biomass in the genus *Saccharum* is evaluated briefly in this report. The background of the Island's long-established breeding program for conventional sugarcane, which is similarly accessible to biomass breeding, is reviewed. The wild species *S. spontaneum* and *S. robustum* in the genus *Saccharum* are perceived as the most valuable sources of genetic material in developing new biomass candidates. New hybrid cane varieties emerging from the latest breeding cycle of the AES-UPR sugarcane breeding program are also regarded as superior material for use in biomass breeding. With some limited modifications, the breeding procedures and methods being employed in the existing sugarcane breeding program are similarly applicable to biomass breeding.

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INTENSIVE research on the use of plant biomass as a renewable energy source has been underway in both the US mainland and Puerto Rico since the mid-1970's. Biomass, together with solid wastes, is seen as a potential energy contributor amounting to some 10 to 12 percent of the US annual energy requirement. This is regarded by DOE as a highly significant fraction (22).

Biomass studies performed to date in Puerto Rico among tropical grasses from *Saccharum* and allied genera indicate that the hybrid forage grass Sordan 70-A is the outstanding short-rotation plant, while napier grass is a superior candidate for intermediate-rotation cropping. *Saccharum* hybrids and clones from several *Saccharum* species are regarded as outstanding long-rotation and minimum-tillage crops, respectively (2).

In view of the lack of fossil fuels in Puerto Rico, and the ability to grow sugarcane here on a year-round basis, the concept of exploring the genus *Saccharum* and related genera as a renewable energy source for Puerto Rico seems to be fully justified. However, breeding for total biomass as the key objective in the genus *Saccharum* has never before been attempted in Puerto Rico or elsewhere.

A background of Puerto Rico's long established sugarcane breeding program, together with breeding potentials for biomass in the genus *Saccharum*, is briefly presented in this paper.

CANE GROWING CONDITIONS IN PUERTO RICO

A virtually identical temperature pattern dominates the principal cane growing regions in Puerto Rico2/. However, an extensive diversity exists in the annual precipitation and soil types throughout the Island. The southern coast is generally characterized by low annual precipitation (37 inches), and irrigation is a well-established practice. The western and northern coasts are characterized by high annual precipitation in excess of 72 inches. Intermediate rainfall regimes (approximately 66 inches) are found in the east and southeast regions where irrigation is not generally practiced (19).

The cane lands in Puerto Rico embrace a wide variety of soil types. These range from fertile, highly-productive and irrigated alluvial soils on the south coast to the low-yielding and

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2/ The annual mean temperature ranges from 76° to 79° throughout the major cane growing regions (19).

poorly-drained clay soils in the north, southwest, and southeast coastal plains. Heavy and poorly drained clays with salinity problems are extensively scattered along the southwest coast, especially in the Lajas Valley.

BREEDING OBJECTIVES FOR BIOMASS vs SUGAR

The CEER-UPR biomass energy program is evaluating sugarcane as an energy source in two capacities: (a) Production of sugarcane and its related species solely as fiber; and (b), production of fermentable solids to be converted to ethanol (2). On the basis of these two goals, the distinctive features between sugar and biomass breeding are quite obvious. In the conventional breeding of sugarcane, the primary objective for a given variety has been a high sucrose content and a reasonably high cane tonnage yield per acre year. To the contrary, the critical factor for a biomass candidate ought to be total biomass tonnage per acre year, with emphasis directed toward a high fiber content rather than sucrose. An equally valid objective is the high tonnage variety having a high brix value (total soluble solids) even though its purity values may be low. In this instance a satisfactory yield of total fermentable solids can be expected in spite of a poor yield of sucrose.

In addition to these two key criteria, a candidate for plant biomass should possess most of the following features: (a) Good germination; (b), rapid initial growth; (c), a strong tillering capability with rapid closure of the canopy; (d), a strong ratooning ability; (e), resistance to major diseases, such as mosaic, rust, ratoon stunting and smut (not present on the Island at the moment); (f), drought and salinity tolerance; (g), waterlogging tolerance; and (h), suitability for mechanized harvest.

Owing to Puerto Rico's population pressures coupled with limited agricultural land, it is reasonable to assume that a considerable portion of the land diverted to future large-scale biomass production would be marginal land characterized by low productivity. In addition, minimum tillage-cropping would be stressed under conditions such that modest or low biomass yields can be obtained at very low cost. Under such conditions the most suitable biomass candidate may be a more primitive *Saccharum* form accustomed to survival within highly-stressed growth regimes.

BREEDING HISTORY AND VARIETAL CHANGE

Although the sugarcane breeding program in Puerto Rico was initiated in 1910, only a few island-bred varieties, such as M 28, M 285, M 336, and M 341[3/] had been planted on a commercial scale prior to 1950. The sugarcane breeding policy in Puerto Rico can be best described as one of recurrent selection. In the beginning, a few noble canes and noble-cane hybrids were the primary commercial varieties and breeding stocks used in Puerto Rico. Owing to their low disease resistance, a severe outbreak of mosaic occurred from 1918 to 1925. From that time onward, a series of mosaic-resistant varieties produced by nobilization and by interspecific hybridization were introduced from Java and India. From these imports, the variety POJ 2878[4/], a third generation hybrid of *S. spontaneum* Java, soon became the predominant commercial variety in Puerto Rico. In the meantime, our local breeding objectives specifically emphasized the development of new varieties combining mosaic resistance with other desirable agronomic characters. This was accomplished by use of POJ and Co varieties and their PR hybrids. From this first breeding effort (1946 to 1962) a number of superior PR canes emerged, including PR 980, PR 1028, PR 1059, and many others widely used in Island plantations. The variety PR 980 (Co 281 x POJ 2878)[5/] has been a predominant commercial variety since 1965. It accounted for 20.44% of the 1960 crop and peaked at 62.60% of the total cane acreage for the 1969 crop (14). More recently-developed varieties, such as PR 1152 (Co 281 x POJ 2878) and PR 62-258 (PR 980 x M 336), have steadily increased in planted acreage during recent years.

However, due to the recurrent selection policy applied by the sugarcane breeding program, a serious lack of genetic variability in the available germplasm pool became apparent. This lack was clearly manifested in seedling populations developed during the early 1960's. In view of the urgent industry demands for high-sucrose and high-yielding canes suited to mechanized harvesting, the needed broadening of the genetic base was attempted by use of conventional breeding lines instead

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[3/] Among these four varieties, only M 336 had attained as much as 13 percent of the Island cane acreage by 1960 (14).

[4/] POJ 2878 comprised 65.4% of the 1949 acreage (14).

[5/] Co 281 is a tri-hybrid of *S. officinarum, S. barberi,* and *S. spontaneum* India.

of by new and untried wild clones from the *Saccharum* germplasm pool. A total of 250 elite breeding lines and commercial varieties from throughout the world were introduced and incorporated into the cane breeding collection maintained at the AES-Gurabo Substation. A number of excellent new varieties have emerged from this genetic pool (Table 1; 11, 23). These include PR 64-1618 and PR 66-2281, which are increasingly planted in the Humacao, Yabucoa, and Aguirre areas.

However, improvements in commercial sugarcane varieties throughout the world was accomplished by use of only limited amounts of original source material (4). Such a narrow genetic base must eventually constrain the varietal gains that can be made via breeding processes. For this reason, from 1974 to 1976, some eighty basic breeding lines structured with new clones of *S. spontaneum*, *S. robustum*, and *S. officinarum* were introduced into Puerto Rico from USDA sugarcane collections at Houma, Louisiana, and from Beltsville, Maryland. To date, more than twenty of these lines have been incorporated into our breeding program. Some 25,000 seedlings have been obtained from this effort. These progeny provide a range of genetic diversity for the further broadening of the *Saccharum* genetic base. It is expected that new, high-yielding clones having disease resistance and tolerance to adverse growing conditions will emerge from the third improvement cycle which is now in progress. It is further believed that many of the new clones emerging from this breeding cycle will have major roles to play as renewable energy sources for Puerto Rico.

BREEDING MATERIALS AND INITIAL ATTEMPTS FOR BIOMASS

With the key breeding objectives for the biomass candidates in mind, two wild *Saccharum* species, *S. spontaneum* L. and *S. robustum* Grassel, appear to be the most valuable source of genetic material for biomass breeding. The potential value of *S. spontaneum* L. in the breeding of conventional sugarcanes has been widely confirmed. As general features, this species transmits vigor, hardiness, tillering proficiency, resistance to mosaic and downy mildew, and tolerance to saline and drought conditions (5, 6, 13, 18, 20). Each of these traits is of major importance to biomass candidates. In fact, the clones SES 231 and Tainan *(S. spontaneum)*, (Table 2) have already been evaluated as long-rotation candidates for biomass production in preliminary studies by the CEER-UPR and AES-UPR biomass program (3).

S. robustum has been used for years as a source of breeding stock in Taiwan, Hawaii, and Australia (6, 18). The clone 28 NG 251 was extensively used in Taiwan in the hope of developing high yielding, erect, and wind-resistant varieties (6). However, none of the *S. robustum* hybrids in Taiwan have reached the level of commercial varieties owing mainly to their high fiber content and poor juice quality. However, these same features from *S. robustum*, intensified in new hybrid progeny, would be highly desirable for biomass production.

A recent study on the fiber and sucrose contents of some 72 *S. spontaneum, S. officinarum,* and *S. rubustum* clones was highly revealing as to the suitability of these species for the breeding of biomass and sugar attributes (Fig. 1). The results indicated that first-generation hybrids (F_1) of *S. spontaneum* produced the highest fiber and lowest sucrose contents. Second-generation hybrids (BC_1) of *S. spontaneum* lost fiber and increased sucrose. For *S. robustum* clones, fiber content was similarly high, but sucrose was lower even than in the *S. spontaneum* F_1 generation (only 0.6 percent). As expected, the *S. officinarum* clones had markedly lower fiber values and higher sucrose values than either *S. spontaneum* or *S. robustum.*

These findings indicate that, for breeding biomass solely for fiber, the first-generation hybrids of *S. spontaneum* offer a better source of candidates than the second-generation hybrids. When breeding both for biomass and fermentable solids, the superior candidates should appear among the second-generation hybrids.

A study was conducted in Taiwan on the sucrose and fiber contents of some 137 clones of *S. spontaneum* (21). Fiber values varied from 22 to 42 percent, while sucrose values were exceedingly low. Some 114 of the clones had a sucrose content less than 1.0 percent. None had a sucrose content higher than four percent. Based on the above information, the most logical approach toward breeding *Saccharum* for biomass would be to cross clones of *S. spontaneum* (or its F_1 hybrids) with clones of *S. robustum* (or its F_1 hybrids).

A limited effort has been made to breed *Saccharum* for biomass as a contribution to the CEER-UPR and AES-UPR biomass energy program. During December of 1977 a number of *Saccharum* clones in mainland USDA collections were evaluated for subsequent screening as biomass resources. A total of 73 clones were imported into Puerto Rico for this purpose. Some of these were intergeneric and interspecific hybrids representing parental material from the genera *Saccharum Eccoilopus, Sorgo, Sclerostachya, Miscanthus, Erianthus,* and *Ripidium* (Table 4). Several clones, including US 67-22-2 (a BC_1 *S. spontaneum*) and B 70701 (an F_1 Noble cane x *S. spontaneum*) have already shown excellent promise as biomass producers. They were therefore used as parents in crosses with a number of varieties from the AES-UPR sugarcane breeding program. It was possible to make these crosses through the use of "cut back" (3) and leaf removal (9) techniques, which in essence delay the flowering of early-tasseling varieties sufficiently long for synchronization with later-tasseling parents. Some 5,000 seedlings obtained from these crosses will be evaluated at the AES-Gurabo and AES-Lajas substations.

IMPROVED BREEDING METHODS FOR SUGAR AND BIOMASS

Flowering Synchronization

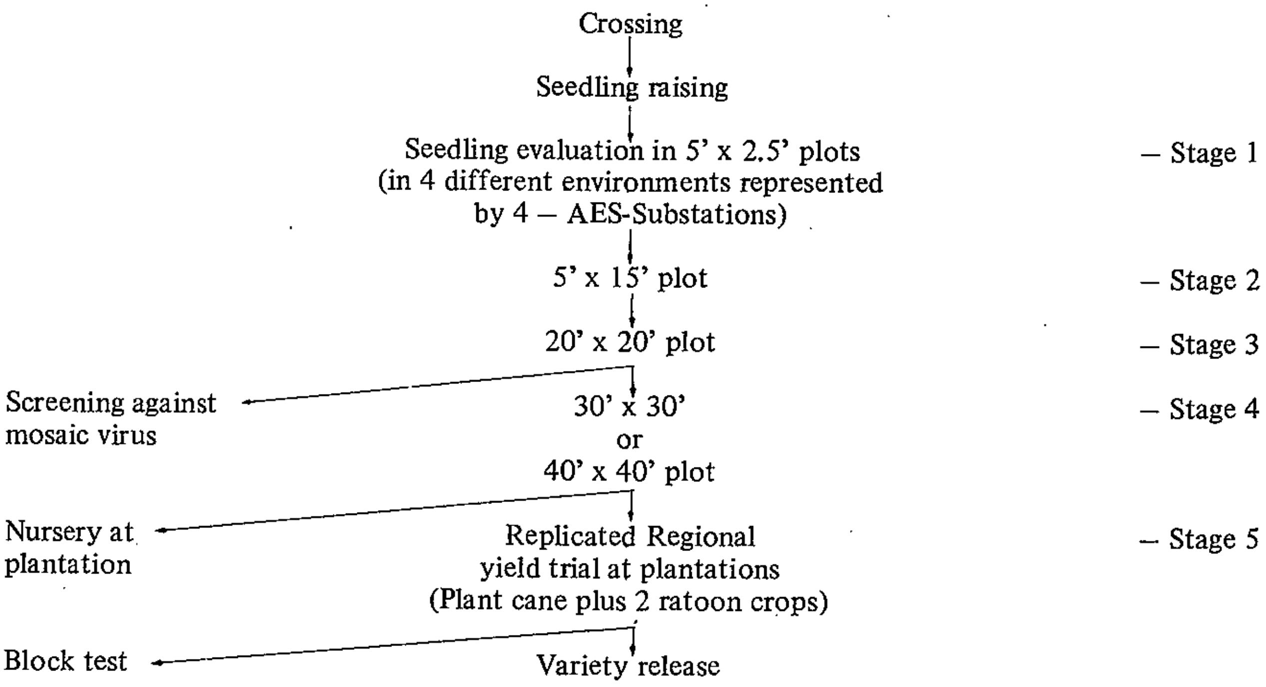
It is widely recognized that the *Saccharum* genetic base actually available for sugarcane breeding is limited by physiological constraints and by genetic constraints incident to excessively high polyploidy (4). The species *S. spontaneum* and *S. officinarum* in particular experience wide differences in their flowering periods, with *S. spontaneum* clones tending to flower many weeks earlier than *S. officinarum* clones. In recent years, largely as a result of controlled photoperiod research (12, 15, 16), studies on leaf removal for critical leaf ranks (7, 8, 9), and other treatments, substantial progress has been made toward synchronizing the flowering periods of divergent *Saccharum* species.

An example of such synchronization is found in "leaf-trimming" experiments performed with the variety NCo 310 at the AES-UPR Gurabo Substation (9). It was found that the absence of leaf ranks −1 and −2 for about 10 days following the initiation of floral primordia produced tasseling delays in the order of four to six weeks duration. Similar treatments administered to the early-flowering *S. spontaneum* hybrid US 67-22-2 produced tasseling delays of up to six weeks duration. In the latter instance, it now became possible for the first time to use this *S. spontaneum* hybrid in crosses designed to intensify both the sugar-and biomass-yielding attributes in new hybrid progeny (Table 3).

Breeding Procedures

At present, a collection of approximately 500 sugarcane breeding lines are maintained at the AES-Gurabo substation as germplasm sources for both conventional and biomass breeding purposes. The collection has been continually renewed and new clone introductions have been added with a view toward maintaining a broad and viable germplasm base for Puerto Rico's breeding needs. A quarantine greenhouse is also available to accommodate the newly-arrived plant introductions.

The breeding procedures which have been in use in Puerto Rico since the mid-1960's are summarized in the following outline:



Crossing: The dilute acid crossing technique, as developed in Hawaii, has been used extensively in Puerto Rico since 1963. Although the stems of some varieties tend to die prematurely when standing in the weak acid, a majority survive for long periods of time. Two methods of crossing are used, the *polycross* and the *biparental* cross. Approximately 100, 000 seedlings are presently produced each year.

Selection and Testing: Seedling selection and testing procedures are performed in five stages. In the first stage, all original seedlings (germinated in flats in a greenhouse) are transplanted in field plots with 2.5 x 5.0 foot spacings, and at eight to 10 months of age are screened on the basis of hand-refractometer and visible-character comparisons with standard varieties. Subsequent stages involve progressively more severe screening, increased replications, evaluation at AES regional substations, and finally field-scale evaluations at commercial sugarcane plantations.

The author believes that the breeding and progeny-evaluation procedures herein described for conventional sugarcane can also be employed, with some limited modifications, for biomass breeding.

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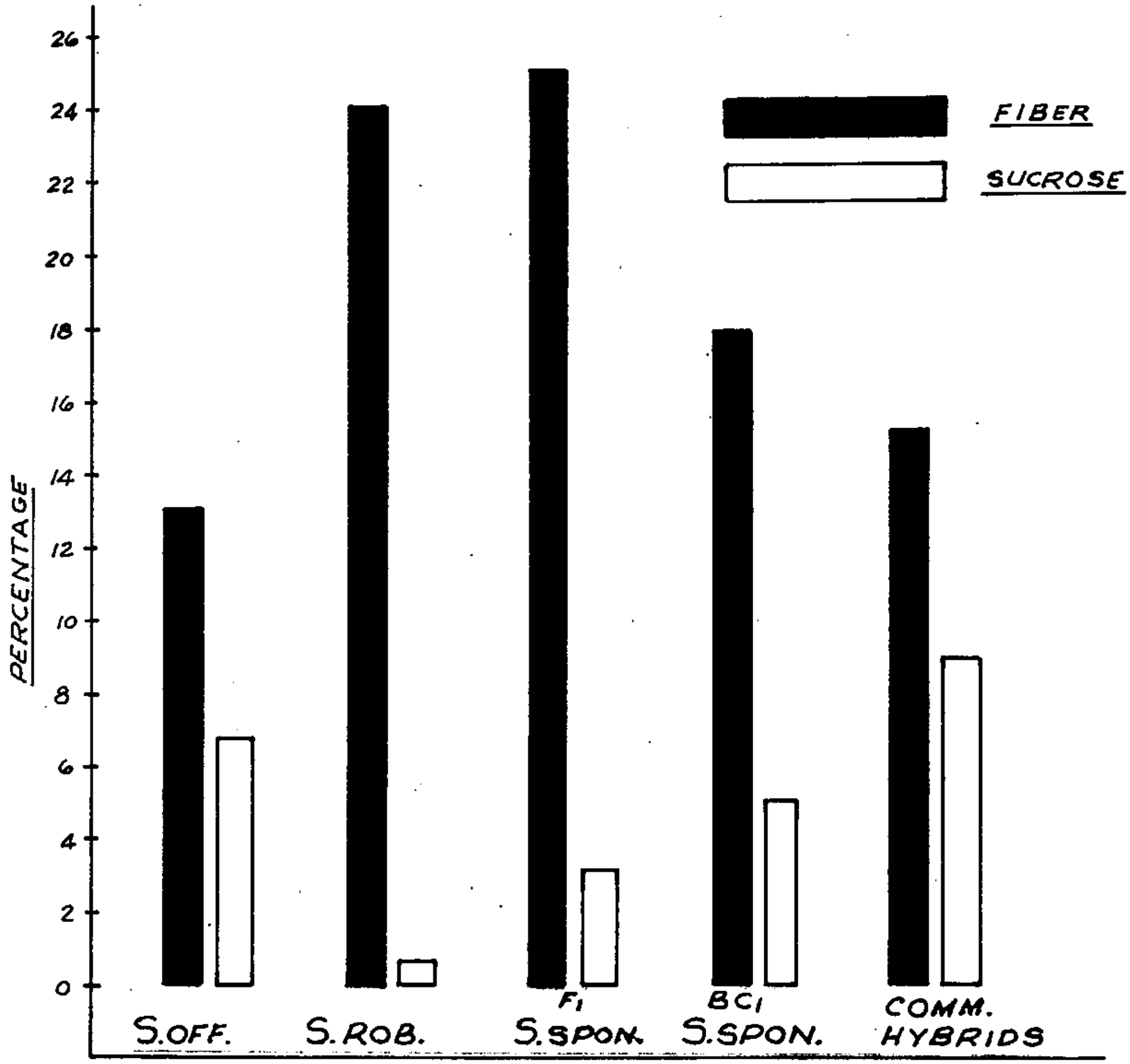

Fig. 1.-Fiber and sucrose contents of Saccharum clones harvested at nine months of age.

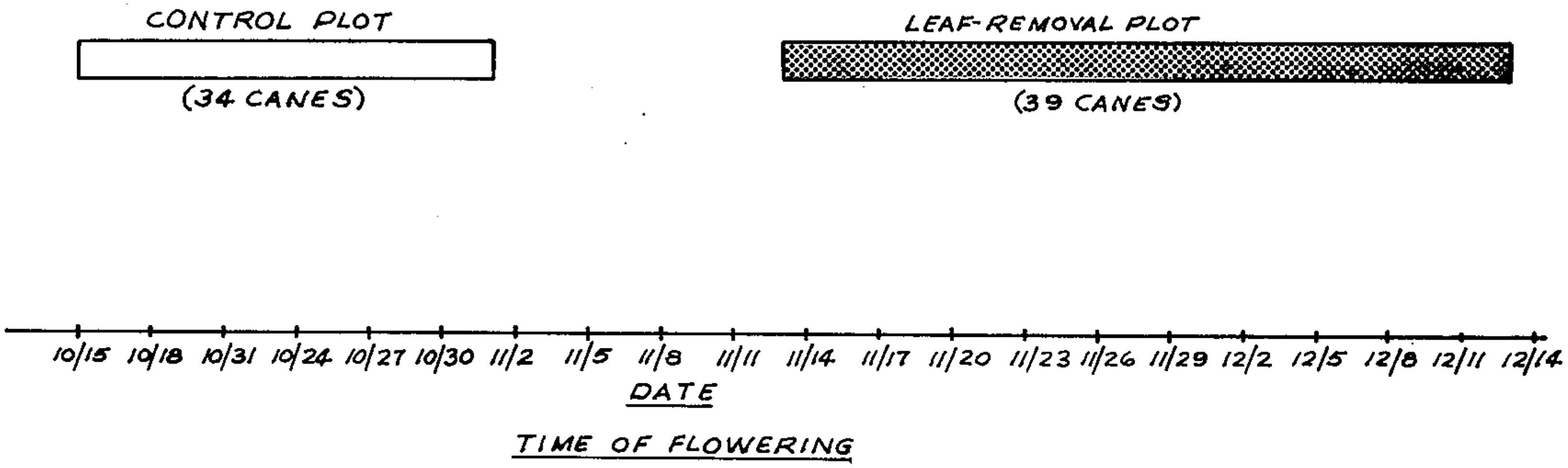

Fig. 2.-Effects of leaf-trimming on the time of flowering in *Saccharum* clone US 67-22-2.

Table 1. Performance of new PR sugarcane varieties developed from the second improvement cycle (1963-1976) [1/]

Variety	Parentage	Sucrose (%)	TCA	TSA	CK Variety	TSA Inncrease (%) Over CK	Location
PR 63-192	PR 1070 x B 3410	10.9	39.3	4.4	PR 980	16.2	Humacao
"	"	10.7	55.0	6.0	H 32-8560	17.6	"
"	"	12.2	40.2	4.9	PR 1059	10.9	Yabucoa
"	"	12.8	42.4	5.5	PR 980	25.0	Guayanilla
PR 63-227	PR 1069 x B 4098	13.0	37.2	4.9	PR 980	22.0	San Sebastián
PR 63-525	Co 421 x CP 38/34	13.4	38.5	5.1	PR 980	6.0	Santa Isabel
"	"	11.3	46.8	5.3	PR 980	21.0	Guayanilla
"	"	11.9	46.2	5.4	PR 980	13.0	Río Grande
PR 64-15	Azul x CP 38/34	12.2	42.6	5.2	PR 980	18.0	Guánica
PR 64-610	Co 421 x POJ 2878	12.8	41.3	5.3	PR 1028	8.0	Añasco
"	"	13.5	33.5	4.6	PR 980	16.0	San Sebastián
PR 64-1548	PR 1059 x (?)	10.7	25.2	2.7	B 49119	18.0	Lajas Valley (Saline)
PR 64-1618	PR 1028 x (?)	11.5	50.3	5.8	H 32-8560	35.0	Fajardo
"	"	12.1	49.7	6.0	PR 980	34.0	San Lorenzo
"	"	10.9	41.1	4.6	PR 980	21.2	Humacao
"	"	11.4	45.9	5.2	PR 1059	18.6	Yabucoa
PR 65-153	H 32-8560 x (?)	11.8	39.5	4.8	PR 980	25.0	San Sebastián
PR 65-199	H 32-8560 x (?)	12.7	54.7	6.9	PR 980	33.0	Isabela
PR 65-413	PR 1013 x (?)	12.5	31.2	3.9	PR 980	20.0	Cabo Rojo
PR 66-2281	PR 980 x (?)	10.9	45.7	5.1	PR 62-258	21.7	Ponce
PR 67-245	H 49-134 x Co 775	12.1	37.6	4.6	PR 980	20.9	Junio, Humacao
PR 67-245	"	11.4	50.9	5.9	H 32-8560	15.4	Mayo, Humacao
PR 67-1070	H 32-8560 x (?)	11.2	39.6	4.5	PR 980	18.0	Junio, Humacao
PR 67-1070	"	11.7	50.3	6.0	H 32-8560	17.8	Mayo, Humacao
PR 67-1070	"	13.6	47.2	6.5	PR 1059	47.5	Unión, Yabucoa

[1/] Mean values for three crops harvested at each location.

Table 2. Dry matter production by _S. spontaneum_ and _S. spontaneum_ hybrid clones in small field plots 1/

Clone	Classification	DM produced in 12 months - Kg	DM produced in 12 months - % of PR 980
PR 980	_Saccharum_ hybrid	23.7	100
Tainan	_S. spontaneum_	26.9	114
SES 231	_S. spontaneum_	33.7	142.1
US 72-72	_S. spontaneum_	35.1	148.1
US 7297	"	28.7	122.1
US 72-144	"	30.2	127.4
US 67-22-2	_S. spontaneum_ (BC_1)	36.0	151.8

1/ Plot size = 1/200 acre

Table 3. Crosses of the early-flowering clone US 67-22-2, with intermediate-and late-flowering canes, made possible by synchronizing the time of tassel emergence

	Parental Clones		
Date of Crossing	Female		Male
Nov. 13, 1978	F 160	x	US 67-22-2
Nov. 17, 1978	PR 68-330	x	"
Nov. 21, 1978	PR 70-3391	x	"
Nov. 28, 1978	PR 70-3364	x	"
Dec. 5, 1978	PR 67-245	x	"
Dec. 13, 1978	PR 67-1070	x	"

Table 4. Intergeneric and intrageneric tropical grasses imported to Puerto Rico as candidate biomass sources in 1978

Intergeneric Cross	Clone Identification
Saccharum x *Eccoilopus Longisetous*	US 72-1304
	US 66-301
Saccharum x *Sorgo rex*	US 61-66-6
	US 71-22-2
Saccharum x *Sclerostachya fusca*	US 66-157
	US 68-40-1
	US 64-37
	US 64-35
Saccharum x *Ripidium* sp.	US 56-1-9
Saccharum x *Miscanthus*	US 67-37-1
Saccharum x *Erianthus controtus*	US 66-163-2
Saccharum x *S. spont.* (Intrageneric)	US 72-34-1
Ripidium kanashiroi x *R. bengalense* (Intrageneric)	US 61-37-7
R. bengalense x *R. bengalense* (Intrageneric)	US 60-58

GENETIC POTENTIAL AND RESTRAINTS IN SACCHARUM AS AN ENERGY SOURCE

Presented to

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Contributed By

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Louisiana Agricultural Experiment Station

GENETIC POTENTIAL AND RESTRAINTS IN *SACCHARUM* AS AN ENERGY SOURCE [1]

J. E. Irvine and G. T. A. Benda

PHYSICISTS tell us that there are certain laws about the nature of energy that are universal. One such law says, in effect, that it is the nature of energy, on a universal scale, to be dispersed at random. Photosynthesis is one of the few processes which restrains the dissipation of the sun's energy by temporarily storing radient energy. Sugarcane is widely reputed to be the most efficient collector of solar energy and produces more biomass than any other field crop.

To consider improving the energy-gathering ability of this superior performer requires audacity as well as a knowledge of its genetic potentials and constraints. We need to know why it does so well and then we must postulate approaches to greater efficiency.

The first suggestion for improving the energy-storing ability of *Saccharum* that would occur to a plant physiologist would be to increase the rate of photosynthesis. If one could increase the rate of accumulation of that dissipated solar energy, surely one would have greater amounts of energy stored as plant material. That rates of photosynthesis can be temporarily increased in laboratory and greenhouse tests has been demonstrated; application of these techniques to field production has been unsuccessful, however. Different rates of photosynthesis per unit of leaf area have been reported for different species. An investigation showed that there were differences in photosynthetic rate among species of *Saccharum* and even among clones of the same species (Table 1). Initially an exciting prospect, selection for high photosynthetic rate failed when it was observed that the highest rates per unit of leaf area occurred in the narrow-leafed *S. spontaneum* clones, and high rates were not associated with high yields (4).

Highest yields were obtained from interspecific hybrids which had intermediate rates of photosynthesis per unit of leaf area, but which had more leaf area than the *S. spontaneum* clones. This observation led to the simple conclusion that photosynthetic rate per unit of land area is more

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[1] A contribution from AR, SEA, USDA, in cooperation with the Louisiana Agricultural Experiment Station.

important than the rate per unit of leaf area. Increasing the rate per unit of land area is accomplished by adding more leaves; increasing leaf area per unit of land area (leaf area index) quickly becomes a problem of increasing the population. Population can be readily increased by decreasing interrow or intrarow spacing. The increase in photosynthetic efficiency (calories recovered/incident calories) with decreased interplant spacing is seen in Table 2 which shows a 60% increase in efficiency with a threefold reduction in row width.

Having found the constraint on yield to be spacing, we again become enmeshed in the genetic potential of *Saccharum.* The wide differences in varietal performance on the conventional wide spacings is generally accepted, but there is no assurance that varietal performance would be similar on narrow spacings. Using a wide range of commercial germplasm, we compared the photosynthetic efficiency of 10 varieties at 10 spacings; five had upright and five varieties had spreading leaves. As expected, photosynthetic efficiency was improved by decreasing interplant spacing (Table 3). Photosynthetic efficiency also differed among varieties (there was no difference due to leaf arrangement). Although differences in efficiency were greater due to spacing than to varieties, it is clear that variety development for maximum photosynthetic efficiency must include spacing response as a criterion.

Broadleafed plants have a debit to energy storage called photorespiration, which in a wide sense refers to the consumption of energy in light and a loss of some of the CO_2 being fixed in photosynthesis. Sugarcane (as well as maize and sorghum) also respires in the light, but the carbon dioxide released in photorespiration is recycled into the photosynthetic process once the light intensity is sufficient (4). Whether this advantage, unavailable in C-3 plants, is rate-regulated and subject to genetic control is not known.

Apparently superior to many other plant forms in photosynthetic efficiency, sugarcane has the distinct advantage of continuous growth over a long season, and it has been suggested that this is the primary reason for its record of high productivity. A major factor in long-season production is its indeterminate growth habit. The growth of an individual stalk is terminated only by flowering or harvest. Stories exist of stalks over a hundred feet long in the highlands of Hawaii, where flowering is rare and harvest occurs every six or seven years.

Some constraints on growth, however, are inherent in the genus. As a perennial monocot with no cambium and little variation in terminal bud diameter, there is a limit to stem diameter. Lacking the anatomical architecture of bamboo, there is also a limit to height (not length). While the potential for aboveground branching exists at every node in *Saccharum* (but not in all of the related genera), branching as a way of increasing biomass becomes impractical because of the weak union of branch (lala) and stem imposed by the size of the bud and the absence of secondary thickening. The limited potential for branching is partially offset by the abundant potential for rooting, a potential which enhances survival in long-season production with a recumbent crop.

Underground branching is essential to tillering and the production of ratoon crops, but the lack of rhizomes is a production constraint in the commercial interspecific hybrids. Rhizomes are produced regularly in the related genera *Imperata, Sorgum* and *Miscanthus*, and occasionally in *Ripidium*. Rhizomes are produced in some clones of *S. spontaneum* and have been found in a hybrid between *S. spontaneum* and the commercial hybrid L 60-25. The advantage of rhizome production would be the self-perpetuation of the crop and insurance against poor stands due to freezes or mechanical destruction. Rhizomes would be impractical on cultivated raised rows, and their production would require (as would the production of true seed) a portion of the energy collected by the crop. A rhizomatous sugarcane would be a worthy goal if managerial techniques could be developed for its control.

Growing sugarcane from true seed is now routine at breeding stations, and it is conceivable that seedling populations from a selected cross could be grown with the same yield potential as from a selected clone from the same cross. However, sugarcane seeds are tiny, and their germination requirements have prevented field testing of this concept. Planting larger seed might make this idea commercially applicable, and crosses were made at Canal Point between sugarcane and sorghum; however, the hybrids were frequently sterile and the project was abandoned. Flowering is recognized as a production restraint in sugarcane, and seed production in a perennial crop would seem partially redundant.

Other tropical grasses have been reported to out-yield sugarcane in biomass production during short cropping cycles (1). These forms possess a rapid rate of leaf expansion, a feature shared with maize and sorghum. Believing this to be of potential benefit to sugarcane, we interplanted sugarcane, sorghum and intergeneric hybrids between the two for comparison. The sugarcane grew slowly early in the season (as is normal), while the sorghum grew quickly with rapid leaf expansion. All of the hybrids grew slowly and exhibited the leaf expansion rate of sugarcane and the early flowering and morphological characters of their sorghum ancestry.

Rapid sugarcane leaf expansion and stalk elongation occur with crowding; photosynthate partitioning thus is directed toward growth rather than tillering. Crowding also increases fiber content and has no effect on sucrose level. So we return to the concept of increasing energy storage capacity by crowding as many plants as possible into a hectare, to the concept of a forest of *Saccharum* that has a high energy content, produces a high yield of biomass, and has a low cost of production.

The genetic potential for *Saccharum* as an energy crop is largely unexplored. The great variability in *Saccharum* and its related genera and the surprising amount of intergeneric fertility create an unusually large gene pool. The imagination of the cane breeder does not face the limitations of the soybean or sugarbeet breeder. In spite of the broad spectrum of material available, the greatest potential for economic biomass production probably will come from within the genus *Saccharum*. A recent inspection of the related forms at Coimbatore indicated that some of the tropical forms of *S. spontaneum* may be the best biomass parents.

Selection of varieties for energy cropping may be incompatible with selection for a sugar crop. A recent study (3) showed that hybridizing a clone of *S. spontaneum* from Thailand with a commercial sugarcane gave an F_1 generation that was outstanding in tonnage production. Repeated backcrossing to sugarcane and selection for sucrose caused a sharp drop in tonnage and a gradual drop in total solids in cane. This happened because the breeder was selecting for high sucrose and purity and against fiber. Fiber constitutes 10 to 15% of the stalk in commercial varieties but can be much higher. One of the progenies had a fiber content of 28%, over twice that of the sugarcane parent. In some species, fiber may approach 50%. A variety selection program for energy production could focus on total solids, suitability for close spacing, lack of flowering for continuous vegetative growth, erectness (the disordered canopy produced by lodging reduces energy absorption) and intermittent formation of rhizomes.

Cane grown for energy should be amenable to production with a minimum of cost and effort. Variety production has so evolved that many modern varieties are unable to survive without high levels of nutrients, while high fertility depresses yields in some of the old noble varieties. That high yield is possible with low investment can be illustrated by the production of a wild stand of *S. spontaneum* that yielded 188 t/ha of biomass after 200 days of growth. This was from a patch that was at least 20 years old, had never been fertilized or cultivated, and had been periodically attacked with each new herbicide in an effort to eradicate it. Its dry matter production of 30 $g/m^2/day$ compared to 20 $g/m^2/day$ for our best commercial variety (fertilized with 333 kg N/ha) and to 13 $g/m^2/day$ for commercial cane at a similar age in Hawaii (2).

For maximum production we would include a variety selected for maximum solids, planted broadcast to insure maximum population, and grown in a system of flat culture. Cultivation would be omitted and weeds would be controlled by chemicals and shading. Insects and diseases would be controlled by variety resistance. Harvesting would be done either by vee-cutters or by modified combines. Harvesters, loaders for vee-cutters, and infield transport would be track mounted or provided with high flotation tires to minimize damage to the fields. Chemically induced rhizome formation would be used to repair damage to the ratoon crop. Long ratoon cycles would be used to minimize replanting. Production costs would be so low that harvesting and transport would be the major expense before processing. Production for fiber or dry matter would permit abuses of the crop through further cost reductions in harvesting and transport that would not be applicable to production for fermentables and fiber.

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Table 1. Rates of photosynthesis in <u>Saccharum</u>.

S. spontaneum		Interspecific hybrids		*S. officinarum*	
Variety	Rate of Photosynthesis	Variety	Rate of Photosynthesis	Variety	Rate of Photosynthesis
	mg/dm^2/hr		mg/dm^2/hr		mg/dm^2/hr
US 61-2-1	81.8 a[1]	CP 65-357	40.8 d	Crystalina	36.7 defg
US 60-4-6	80.3 a	L 60-25	40.2 d	Bandjarmasin Hitam	31.9 defg
Coimbatore	64.6 b	CP 66-315	38.5 de	Striped Cheribon	31.0 defg
SH 246	57.5 b	CP 65-332	37.1 def	Otaheite	30.1 efg
SES 6	55.2 c	CP 29-116	36.5 defg	28 NG 220	30.0 efg
Kinggoerang Oewis	37.6 de	Co 290	34.2 defg	Striped Tanna	29.2 efg
Krakatau	36.2 defg	CP 67-349	34.0 defg	Cavengerie	28.4 efg
Djatiroto	35.4 defg	N Co 310	33.9 defg	Badila	26.8 fg
SES 304	34.7 defg	CP 48-103	33.0 defg	Vellai	26.5 fg
Soembawa	31.0 defg	POJ 213	31.6 defg	Black Cheribon	26.2 g
Average	51.4		36.0		29.7

[1] Rates followed by the same letter are not significantly different at the 5% level of probability.

Table 2. Increasing photosynthetic efficiency of *Saccharum* by decreasing interrow spacing.

Interrow spacing	Photosynthetic efficiency[1]
61 cm	2.3
91 cm	1.8
183 cm DD	1.6
183 cm SD	1.4

[1] Ratio of the biomass yield of CP 65-357 expressed as recovered calories divided by incident calories.

Table 3. Photosynthetic efficiencies of 10 sugarcane varieties as an average of 3 close and 3 wide spacings (Net cane).

	Photosynthetic efficiency [1/]	
Variety	Avg. of 3 close spacings[2/]	Avg. of 3 wide spacings[2/]
CP 65-357	1.86	0.63
F 36-819	1.71	0.50
CP 44-101	1.61	0.53
L 62-96	1.41	0.55
L 60-25	1.36	0.56
Co 281	1.22	0.52
N Co 310	1.05	0.52
CP 36-13	1.03	0.50
Co 290	1.07	0.46
CP 61-37	0.99	0.56
Average	1.33	0.53

[1/] Calculated by dividing calories harvested as sugar and fiber from net cane by incident calories during growing season.

[2/] At close spacings plants were 26.7, 43.7 and 60.4 cm apart. At wide spacings, they were 145.3 162.0 and 179.1 cm apart.

SUGARCANE PATHOLOGY: IMPLICATIONS FOR BIOMASS PLANTATIONS

Presented To

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Contributed By

The Agricultural Experiment Station, University of Puerto Rico
Department of Crop Protection, Mayaguez Campus
Río Piedras, P. R.

SUGARCANE PATHOLOGY: IMPLICATIONS FOR BIOMASS PLANTATIONS

Table of Contents

Sugarcane Pathology: Implications for Biomass Plantations[1]

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ABSTRACT

MOSAIC, ratoon stunting, pineapple disease, leaf scald, *Pythium* root rot, smut, downy mildew and rust are diseases of major economic importance on sugarcane. These same diseases may also affect intensively cultivated plantations for biomass production in Puerto Rico. Eye spot, brown stripe, ring spot and Pokkah Boeng however, are diseases of minor importance. By integrating various disciplines (date of planting, resistant varieties, fertilization, drainage and irrigation, etc.) in a correct order, a maximum production of biomass can be achieved at a minimum cost. Production of gas such as ethylene by plants affected by viruses (cowpea mosaic virus, curly top virus, stubborn citrus virus), bacteria *(Pseudomonas solanacearum)* and fungi *(Blastomyces* and *Ceratocystis)* should also be explored as a possible source for increasing production of synthetic natural gas through bioconversion.

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SUGARCANE PATHOLOGY: IMPLICATIONS FOR BIOMASS PLANTATIONS

INTRODUCTION

MORE than 200 million dollars per year have been spent in purchasing high-priced imported oil for electric power generation in Puerto Rico (2). Energy self-sufficiency has become a must if we are going to maintain or increase our present economic growth in order to keep in pace with the everincreasing population and energy consumption on the Island (4). Of the various forms or sources of energy such as ocean thermal energy conversion, wind and solar energy, which may have a great potential for the future, bioconversion is a more realistic source of fuels and petrochemical substitutes for Puerto Rico because of its cheap, year around source of biomass (1). Hybrid sugarcanes as well as related tropical grasses are promising candidates for bioconversion in Puerto Rico as well as in the Caribbean. While efforts are being made to increase biomass production through intensive cultivation, incidence of diseases and pests may also increase either due to changes in microenvironmental conditions or due to shifting of genetic populations of microorganisms and plants.

According to Fraser (7), about 4.5 standard cubic feet of methane (synthetic gas) can be produced per dry pound of deciduous plant material (0.28 m^3/kg) through anaerobic digestion. In addition, ethylene, another synthetic gas, can also be produced through gasification of diseased plants. Increased ethylene evolution in virus, fungi and bacteria infected tissues was reported by several investigators (5, 6, 20). This report is concerned with increases in sugarcane biomass production through integrated pest management systems. The possibility of increasing ethylene production through converting plant tissues infected by pathogenic fungi, viruses and bacteria is also discussed.

Diseases of major economic importance

1. Mosaic

Mosaic was the most fearful disease in the 1940's when noble canes were grown for sugar production. Although mosaic is not prevalent in sugarcane plantations nowadays, it may still affect biomass production should severe strains of the virus occur under local conditions (11). The testing of promising varieties for mosaic resistance should continue to enjoy a priority role in research programs for biomass production.

2. Ratoon Stunting Disease

Ratoon stunting disease (RSD) has become the second most important disease of sugarcane in Puerto Rico since 1965. Losses due to RSD varied from 12 to 36 percent depending upon varieties (13). Although hot water treatment of affected seedpieces, at 50°C for 2-1/2 hours, is acceptable for commercial sugar production, it may not be economically feasible for biomass production. Since drought conditions accentuate the losses considerable, adequate irrigation and fertilization together with the use of resistant or tolerant varieties will probably achieve a maximum biomass production at the lowest cost.

3. Pineapple Disease *(Ceratocystis paradoxa)*

Pineapple disease has a tremendous effect on the seedpiece germination of susceptible sugarcane varieties. Sugarcane plants growing in poorly drained areas are highly susceptible to the disease (10). Seed treatment with benomyl at the rate of 0.12 kg/185 liters of water has controlled the disease effectively. However, it may not be economically feasible to do so for biomass production. The improvement of drainage conditions, together with the use of resistant varieties, should minimize losses due to this disease.

4. Pythium root rot *(Pythium* spp.*)*

Root rot, caused by a complex of soil microorganisms, including *Pythium* and nematodes, reduces cane production considerably. Susceptible varieties such as PR 1085 growing in a poorly-drained soil during the cooler months are highly susceptible to the disease. A combination of the following practices might possibly improve sugarcane biomass production: (a) Use of resistant varieties; (b) improvement of drainage conditions, and (c) delaying of planting date in the primavera cane. High summer temperature arrests the growth of most *Pythium* species.

5. Leaf scald *(Xanthomonas albilineans)*

Leaf scald has occurred sporadically in the humid area along the eastern coast of Puerto Rico. It is a potentially dangerous disease on sugarcane. Improving drainage conditions, together with the use of resistant varieties, should minimize the losses due to this disease.

6. Rust *(Puccinia erianthi)* (14)

Rust causes considerable damage to susceptible sugarcane seedlings as well as adult cane in Puerto Rico (14). It may be a potential threat to biomass plantations for the following reasons:

(a) Urediospores of *P. erianthi* multiply rapidly in regions with high air humidity and a warm climate. Intensive biomass cultivation provides the ideal environmental conditions for infection of sugarcane by rust.

(b) Biomass plantations tend to be harvested more frequently than commercial plantations. Young canes from 1-6 months of age are extremely susceptible to rust.

Delaying the date of planting together with the use of resistant varieties, should reduce considerably the incidence of rust.

7. Smut *(Ustilago scitaminea)* (12)

The presence of smut in our neighboring islands such as Jamaica, Guyana, Martinique, and Trinidad, as well as in the Continental United States (Florida), posses a constant threat to the PR sugar industry and to biomass production in Puerto Rico. The current intensive biomass breeding program also tends to shift the germplasm emphasis from noble canes to wild *Spontaneums* which are highly susceptible to smut. Testing of sugarcane varieties for smut resistance should be given the highest priority in the biomass program.

8. Downy Mildew *(Sclerospora sacchari)*

Downy mildew is a potentially dangerous disease to sugarcane as well as to corn, sorghum, and Johnson grass. The oospores of this fungus can remain viable in the soil for more than five years. It attacks roots of sugarcane when the environmental conditions are favorable. *Sclerospora graminicola*, which reportedly also attacks sugarcane (21), was found recently on sorghum and Johnson grass in the Lajas area. The following precautions to prevent further spread of the disease are suggested: (a) Destruction of infected plant residues to eliminate the principal sources of inoculum; (b) eradication of the infected plants through "roguing" to prevent seasonal carryover by oospores in the soil; (c) crop rotation to avoid planting sorghum, corn, or sugarcane in the same affected fields for at least five years; (d) avoiding high humidity which favors the disease development, and (e), prohibiting the use of seeds from affected fields.

DISEASES OF MINOR ECONOMIC IMPORTANCE

1. Eye Spot Disease *(Helmisthosporium sacchari)*

Eye spot causes considerable damages to susceptible varieties of sugarcane growing in irrigated fields during the cooler months in Puerto Rico. It affects mostly older leaves which probably do not contribute much to biomass production. Nevertheless, precautions must be taken not to plant highly susceptible varieties for biomass production.

2. Brown Stripe *(Helminthosporium stenospilum)*

Brown stripe causes severe damages to susceptible sugarcane varieties. Plants growing in potassium or phosphorus deficient soil are highly susceptible to the disease. Application of adequate fertilizers should minimize infection of sugarcane by this fungus.

3. Pokkah Boeng *(Fusarium moniliforme)*

This disease occurs mainly during the rainy season in warm climates. However, affected plants usually recover from the infection as soon as the rainy season is over.

PRODUCTION OF ETHYLENE GAS FROM DISEASED PLANTS

The dry biomass from sugarcane may eventually be converted through the process of pyrolysis or gasification into a mixture of combustible gasses such as CH_4, CO_2, CO, H_2 and ethylene. Ethylene, a common metabolic product of fungi and bacteria (3, 6, 8, 16) is produced also by diseased plants (18, 19, 22).

Chalutz and DeVay (5) reported in 1969 that strains of *Ceratocystis fimbriata* differed in ethylene production during growth on various culture media. Carrot and sweet potato roots colonized by *C. fimbriata* evolved more ethylene than non-inoculated roots. Ethylene production was dependent upon the rate and amount of fungus growth on agar media and in host tissues.

Ethylene was also reported as a metabolic product of *Blastomyces dermatidis* Arch. (16), *Pseudomonas solanacearum* (6), cowpea mosaic virus (15), curly top virus (20), and stubborn virus (17). Lockhart and Semancik in 1970 (15) reported that ethylene production was higher in cowpea mosaic virus infected tissues than in healthy ones. Approximately 2000 ppb of ethylene per gram of dry weight was produced from diseased tissues in 24 hours while less than 1000 ppb was produced from healthy tissues in the same period of time. Increased ethylene evolution in the curly top virus affected tissues was also reported in 1968 by Smith, et al (20). Although the amount of ethylene in diseased plants is small and difficult to assess, it should be explored as a possible means for increasing production of synthetic gasses through bioconversion.

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SUGARCANE CULTURAL MODIFICATIONS FOR MAXIMUM BIOMASS

Presented By

A SYMPOSIUM ON ALTERNATE USES OF SUGARCANE FOR
DEVELOPMENT IN PUERTO RICO

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Contributed By

The University of Puerto Rico, Center for Energy and Environment
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Río Piedras, Puerto Rico

SUGARCANE CULTURAL MODIFICATIONS FOR MAXIMUM BIOMASS

Table of Contents

SUGARCANE CULTURAL MODIFICATIONS FOR MAXIMUM BIOMASS

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ABSTRACT

In optimizing yields of sugarcane biomass, immediate consideration is given to agronomic factors such as varietal selection, water and nitrogen inputs, row spacing, harvest intervals, and trash collection. Equally important is the overall integration of agronomic, botanical and factory modifications. In a botanical sense a much broader use must be made of sugarcane's *Saccharum* relatives, particularly in marginal lands too arid or too steeply contoured for conventional cane production. Maximum sugarcane biomass is also predicted upon a careful integration of the plant with allied grasses and food crops on an Island-wide basis. Factory considerations must be based on a maximum grinding season of about eight months duration. An industrial-scale, demonstration power plant is proposed which would burn green bagasse (44% moisture) for eight months, plus a combination of mill-dried bagasse and solar-dried tropical grasses drawn from storage during the remaining four months. Supplemental fuel sources would include crop residues and woody biomass.

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SUGARCANE CULTURAL MODIFICATIONS FOR MAXIMUM BIOMASS

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ABSTRACT

In optimizing yields of sugarcane biomass, immediate consideration is given to agronomic factors such as varietal selection, water and nitrogen inputs, row spacing, harvest intervals, and trash collection. Equally important is the overall integration of agronomic, botanical and factory modifications. In a botanical sense a much broader use must be made of sugarcane's *Saccharum* relatives, particularly in marginal lands too arid or too steeply contoured for conventional cane production. Maximum sugarcane biomass is also predicted upon a careful integration of the plant with allied grasses and food crops on an Island-wide basis. Factory considerations must be based on a maximum grinding season of about eight months duration. An industrial-scale, demonstration power plant is proposed which would burn green bagasse (44% moisture) for eight months, plus a combination of mill-dried bagasse and solar-dried tropical grasses drawn from storage during the remaining four months. Supplemental fuel sources would include crop residues and woody biomass.

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SUGARCANE CULTURAL MODIFICATIONS FOR MAXIMUM BIOMASS

Table of Contents

Topic **Page**

ABSTRACT

Sugarcane Cultural Modifications For Maximum Biomass

SUGAR PLANTING vs BIOMASS PLANTING

SUGARCANE planted as an energy resource will require management practices that differ significantly from those of conventional sugar planting. Such changes will fall into four broad categories: (a) Modification of agronomic practices; (b) changes based on *Saccharum* botanical attributes; (c) modifications based on a sugarcane integration into an Island-wide food and energy program, and (d), modifications stemming from factory requirements, that is, the requirements of energy-processing installations.

To a disinterested observer a sugarcane energy plantation would differ little in outward appearance from the plantations of the past; actually, 80- or 100-ton cane doesn't look much different than 30-ton cane on casual inspection. Our observer would note some differences in the cane's compositional analyses. Sucrose content would be lower and fiber content higher, but total sugars would remain about the same. The really striking features would appear in areas where we have had little or no past experience. Forms of sugarcane (*Saccharum* species) would be seen that never before were planted on a commercial scale. Soil and topographical sites previously regarded as unsuited to sugar planting would be occupied by highly fibrous forms of sugarcane. The observer would also see sugarcane being harvested both earlier and later in the grinding season than he could recall at any time in the past. And he would observe other tropical grasses being harvested—some of them quite similar to sugarcane in appearance—during months of the year when no sugarcane of any form was ever harvested in the past.

These and other changes would come to pass in a sugarcane industry oriented to energy rather than sucrose. They are predicted upon a clear recognition of sugarcane as a renewable and domestic fuel source of decisive importance to a high-energy consuming society.

AGRONOMIC MODIFICATIONS

When evaluating means to increase yields of sugarcane biomass, priority consideration must be given to the same agronomic factors that govern sugar yields: (a) Selection of correct varieties for the task at hand; (b) row spacing; (c) inputs of nitrogen and water; and (d), frequency and method of harvest.

An added factor of potentially great importance is pest control. For sugarcane biomass in Puerto Rico the most ominous pest at this moment is the white grub (gusano blanco). In its larvae stage this insect causes serious damage to sugarcane roots, and it infests most of the sugarcane lands on the semi-arid south coast. For experimental studies we have controlled the insect with the pesticide Aldrin, a very effective chemical but one prohibited by law for commercial use. There is reason to believe that Lindane or other less residual materials will provide adequate control. Perhaps the best "control" will be the use of varieties sufficiently vigorous and sufficiently stimulated to withstand white grub injury to their roots. In this connection it should be noted that the better-irrigated sugarcane plantings are far less susceptible to white grub damage. Conversely, the insect thrives in excessively dry soils on sugarcane root systems already hard-pressed to meet the plants' need for water.

1. Variety Selection

Sugar planters have long favored sugarcane varieties having high sucrose content as their principal attribute, together with such closely allied characteristics as disease resistance, suitability for mechanical harvest, erectness,. and adaptability to regional soils and climates. The "high tonnage" characteristic was also highly favored, but only when accompanied with at least moderately high sucrose. An exceptionally high tonnage variety having only poor sucrose yields was generally regarded as little more than a conversation piece. Moreover, when high tonnage-high sucrose varieties were propagated commercially, emphasis was always given to sucrose rather than biomass; such varieties were never "forced" toward maximum stem growth for more than about half of their cropping cycle. Nonetheless, in spite of an industry preference for sugar, Puerto Rico's cane varieties have held up as biomass producers better than as producers of sucrose. The sugar industry today still recovers as much biomass per acre as it did in 1950 when very superior sucrose yields were obtained (1, 2).

Recent studies directed toward maximized cane biomass have utilized three local varieties: PR 980, PR 64-1791, and NCo 310. The two PR varieties have good (but not exceptional) tonnage records in the Lajas Valley where the work is being conducted, while NCo 310 has given a fair tonnage performance in virtually all of the Island's sugarcane zones (3).

During 1978 two distinctly high biomass varieties were identified having apparent yield potentials much superior to the varieties examined to date. These are US 67-22-2, an import from Louisiana having an exceptionally large dosage of *S. spontaneum* germplasm, and a Barbados hybrid, B 70701. US 67-22-2 was employed both as a female parent and male parent in crosses performed during the autumn of 1978 (4). Similarly, B 70701 was used as a female parent in crosses performed directly in the field during October, 1978 (Table 1). Although these crosses were conducted as part of the AES-UPR breeding program for conventional sugarcane, the resulting progeny will be examined very closely for the high biomass-yielding attribute.

In a future sugarcane energy plantation such varieties and their superior progeny would be managed for total biomass and high-test molasses (2). Biomass would probably be favored over molasses as a consequence of forced growth regimes. We expect from such cane a rather poor yield of sucrose (which in any case would be retained in the molasses), and yields of total fermentable solids roughly comparable to those of conventional sugarcane. On a per plant basis the recoverable fermentable solids could be moderately lower owing to higher contents of fiber (5), but the per acre yields should far exceed those obtained by the present sugarcane industry.

2. Water and Nitrogen Inputs

Virtually all of the *Saccharum* species examined by the author in greenhouse experiments have a pronounced responsiveness to applied nitrogen and water (6). Among the interspecific hybrids of commerce, increased nitrogen levels are associated with an increased number and vigor of buds initiated at the crown, increased number and vigor of tillers, and increased tissue expansion accompanied with higher foliar chlorophyll levels and stem succulence (6). However, under field conditions, nitrogen and water can be maximized for growth only at the expense of sucrose (8, 9, 10). Even the "sweetest" of commercial sugarcanes will attempt to produce new tissues rather than sugar if they are given access to water and nitrogen in a suitable temperature regime (6, 7). Studies in Puerto Rico have shown that to fertilize heavily with nitrogen beyond the second month of the new ratoon crop can produce plants still trying to grow at 10 to 12 months, that is, at a time when they should be "ripening" or accumulating sucrose in vegetatively inactive stems (8). Similarly, it was never possible to maximize irrigation when sucrose alone was the desired product. To do so, particularly during the later stages of the crop cycle, would promote the inversion of stored sucrose for use in revitalized growth and respiratory processes.

For maximized biomass production in Puerto Rico it is reasonably certain that N fertilization rates will need to be increased at least several-fold over levels currently used by the PR sugar industry. By 1976, as an Island-average, elemental N applications amounted only to about 120 pounds per acre year, administered largely in the early stages of ratoon regrowth. Initial data from DOE-sponsored studies at Lajas indicate that 300 pounds per acre year, administered in three increments (1/3 at planting and 1/3 each at months four and eight), were insufficient to maximize dry matter yields. These levels may have to be raised as high as 600 pounds per acre year. However, the entire macronutrient management of high-biomass sugarcane must be reevaluated in terms of fertilizer source, total quantities required per year by specific varieties in specific regional zones, and number and frequency of incremental treatments.

Irrigation requirements for maximized biomass also need additional research. Present data from DOE studies in the Lajas Valley suggest that some 3-1/2 to four acre feet of water will be needed to sustain growth in that region. These estimates are based on border irrigation treatments amounting to about three acre inches per application administered 14 times over a time-course of 10 months. It is doubtful whether the present sugarcane plantings on the Island's south coast average half this amount per annum. Water stress and outright symptoms of water deficiency are commonly observed from Cabo Rojo to Guayama. Roughly 1-1/2 to two acre feet would also be needed on a seasonal basis in Puerto Rico's humid zones.

Further to this, it should be borne in mind that higher N and water applications are not necessarily synonomous with year-round applications. Just as the sugar planter is hesitant to administer growth-stimulatory agents late in the crop cycle, when sucrose should be accumulating in the cane stems, it may be necessary to restrain such treatments at some point to encourage maximum dry matter accumulation in cane planted for total biomass.

In addition to evaluating the plant water requirements for optimized biomass growth, more research is needed on design and installation of suitable water delivery systems, together with cost analyses for long-term development of Puerto Rico's water resources. Water resource development will probably constitute the ultimate limiting factor in the utilization of Puerto Rico's biomass resources for energy. It appears likely that development costs for irrigation water on the semi-arid south coast will be as high as $150 to $200 per acre foot (1979 dollars).

3. Plant Density Modifications

There is considerable evidence to show that commercial sugarcane planted at 4- to 6-foot row centers does not produce enough stems to fully utilize the light, water, and nutrient inputs to a given field surface. This is particularly true in the early stages of a plant crop when the young sugarcane plants are perhaps more concerned with establishing the crown and root systems than in closing their overhead canopies. Plant densities can be increased by placing more seed pieces in the furrow or by narrowing the distances between furrows. Reports from Louisiana indicate that significant tonnage increases will result from narrowed row centers (11, 12). Other studies suggest such tolerances to an increased density of stems is an inherited characteristic (13). If this is correct, then the customary evaluation of new progeny from sugarcane breeding programs at constant row spacings acts as an unfair constraint upon those plants having the high-density attribute.

Recent studies in Louisiana revealed favorable responses to close spacing (12). Identical experiments in Florida gave similar responses early in the crop but yield gains were much diminished after about the sixth month. Very similar trends were recorded in Puerto Rico (3, 14). In the latter instance very large yield gains were obtained from close spacing (20 inch vs 60-inch row centers) up to six months after seeding, but these increases were largely lost between months six and 12 (Table 2). Only one of three varieties tested showed dry matter yield increases at 12 months, and this amounted to less than three tons per acre.

Crown development rather than canopy closure appears to be the decisive factor in optimizing sugarcane density in Puerto Rico (3, 14). In this respect it may be more desirable to increase seeding rates at standard row centers than to narrow the distance between rows. Also, new varieties may emerge that do respond well to close spacing. Otherwise the only advantage for close spacing in Puerto Rico that one can visualize at this time would be in the unlikely event that sugarcane is propagated only as a 6-month plant crop, that is, in a crop rotation system where sugarcane must give up its site fairly frequently to another crop.

BOTANICAL CONSIDERATIONS

As a domestic energy resource, sugarcane's most effective contribution would be made in the context of a year-round, fully-integrated input of biomass feedstocks to a range of energy-conversion systems. Hence, any serious study of sugarcane's energy attributes must include *Saccharum* botanical resources together with the more familiar attributes of the field and factory. This is especially true in Puerto Rico for several reasons: (a) Conventional sugarcane cannot realistically be harvested more than about eight months of the year; (b) Puerto Rico's land and water resources are too highly diversified to be accommodated by any single clone or variety; and (c), the genus *Saccharum* has as many botanically-distinctive forms as Puerto Rico has distinctive agricultural zones. It is probable that some of these forms would find a home in Puerto Rico where conventional hybrids have never before been planted.

1. *Saccharum* Species in Marginal-Land Agriculture

Puerto Rico has approximately 270,000 acres suited to mechanized agriculture (15). These lands essentially conform to SES classes I and II. They have adequate water and drainage to sustain intensive cropping. However, a much larger acreage is too steeply contoured, too arid, too poorly drained, too saline, or too acid to support mechanized or intensive production operations. It is important that future energy cane planters do not confine themselves exclusively to Puerto Rico's superior lands—in a kind of perpetual competition with food crops. Rather, Puerto Rico must capitalize on *Saccharum* aptitudes for survival within marginal environments and with minimal production inputs.

Puerto Rico has access to a large number of *Saccharum* forms sometimes depicted as "species" (many distinct clonal types reside within a species) or "wild" sugarcanes. For convenience these can be grouped into three broad categories: (a) Select representatives of *Saccharum* species, maintained in USDA or world collections as germplasm sources; (b) "escaped" *Saccharum* clones maintaining themselves in the wild (in some cases apparently hybridizing in the wild) where natural rainfall is adequate; and (c), unidentified *S. spontaneum* forms, within groups (a) and (b), having a pronounced underground expansion capability and variable tolerance to drouth. The third group is surmised mainly from the superior growth potentials observed in hybrid canes having large dosages of *S. spontaneum* germplasm (US 67-22-2, US 72-70), and also from annual internode expansion patterns of local *S. spontaneum* or *S. spontaneum* hybrids growing wild in the San Juan area. In the latter instance such clones do not appear to have migrated yet to the semi-arid south coast, but they do maintain exceptional growth throughout the north coastal dry season. Underground expansion proceeds at a rate of six to eight feet per year. These clones thrive without human aid of any sort.

Saccharum clones of this type are desired in several capacities for the sugarcane biomass program. One category is needed on the semi-arid south coast as a fill-in for lands disqualified from conventional sugarcane planting by lack of water or water-delivery systems, or are too steeply sloped to accommodate standard harvest machinery. These regions receive from 25 to 48 inches of rainfall annually—mainly on a seasonal basis—and fall within SES classes I-IV. Basically a minimum-tillage operation, the *Saccharum* clones would receive only limited water and fertilizer inputs, ie, at planting to promote germination and initial root establishment, and as stubble applications immediately following harvest at about 6-month intervals. In some instances the harvests would be mechanized operations in which the cut cane would be left in the field for solar drying and subsequent bulk baling. Most of the biomass would be harvested manually and removed from the fields to access roads by labor crews. The relatively low yields expected from such crops would be offset in part by low production costs and by the rural employment thus offered in an economically-depressed region.

A second category of *Saccharum* clones would be propagated as private cash crops on small land holdings in Puerto Rico's humid uplands. All production and harvest operations would be manual. As noted by Bonnet (1), these crops would combat soil erosion and rural unemployment while contributing biomass feedstocks to an Island-wide biomass fuels reservoir. It is estimated that full-time employment would be created for one man for every 10 acres planted into wild *Saccharum* clones.

A third category of marginal-land cropping with *Saccharum* would include "problem" areas such as the Caño Tiburones region near Arecibo on the humid north coast. Roughly 4,000 acres of potentially productive land is rendered nearly useless by lack of suitable drainage. Several *S. spontaneum* clones already available in Island colllections are good potential candidates for this area. An additional candidate, *Arundo donax*, a highly fibrous and water-loving wild grass, should be tested there as a non-*Saccharum* supplement.

2. Harvest Frequency vs Maturation

The growth and development characteristics of commercial sugarcane hybrids, wild *Saccharum* species, and both related and unrelated tropical grasses dictate that these plants should be planted and managed in distinct cropping categories if their optimal biomass yields are to be realized. This point was very effectively underscored by initial attempts to grow three sugarcane varieties as frequently-recut forages (3, 14). Testing a hypothesis that the more one cuts a grass the more grass one will have to cut, these canes were harvested at frequencies of 2–, 4–, 6–, and 12 months for one year. The results very clearly showed that the more one harvests sugarcane the less sugarcane he will harvest (Table 3). A single harvest at 12 months after planting yielded four times the biomass obtained from six, 2-month harvests combined. Even the harvesting at 6-month intervals, ie, twice per year, greatly constrained the sugarcane's yield capability.

Napier grass recut at the same frequencies gave somewhat different responses. Maximum dry matter yields were obtained from 4- to 6-month harvest intervals (Table 3), while allowing 12 months to pass before harvest actually reduced yields. These differences reflect distinct phases of growth (tissue expansion) and maturation operating in napier grass and sugarcane. Napier grass produces very rapid growth for about eight weeks after seeding. The plant is about 90 to 92 percent water at this time and is quite suitable for harvest as cattle feed (16, 17). During the subsequent two months the plant matures to a highly fibrous state, roughly 32 to 36 percent dry matter, which renders it useless as a cattle forage. Nonetheless, for optimal biomass yield, one must wait as least four months for growth and maturation processes to be complete. For sugarcane, one should wait at least 12 months before harvesting, and it is possible that 16 to 18 months would be better still.

Recognition of discrete tissue-expansion and maturation phases in the tropical grasses is critically important in planning the correct agronomic management of these plants as energy resources. But the essentially determinant factors are botanical (physiological) in nature. Hence, sugarcane once planted should be left unmolested for at least a year, and napier grass for at least six months, in conformation with the plants' botanical capabilities for initiating tissues, expanding these tissues, and filling the tissue space with as much dry matter as the candidate species is botanically able to accumulate.

MULTIPLE CROP INTEGRATION

1. Tropical Grasses in Rotation with Food Crops

The use of wild *Saccharum* clones in marginal-land energy cropping, together with the intermediate- and long-rotation crops discussed above (napier grass and sugarcane), is in conformation with the specific energy-crop categories needed by Puerto Rico to accommodate her diverse land, water, and botanical resources (2). Another category of decisive importance includes the "short-rotation" candidates. These are plants having not only large growth potentials but also the ability to complete their tissue expansion and maturation phases within eight to 12 weeks after seeding. We are fortunate in having several commercially-available varieties that can do this (3, 18). Sordan 70A is especially adept at rapid growth and maturation. Yet Sordan 70A itself may soon be replaced with superior varieties, ie, by Sordan 77 (more tolerant to drouth) and Trudan 5 (downy milldew resistant). Each of these varieties is an intergeneric hybrid developed by the Northrup King Company.

An added value of short-rotation species is their special ability to fill out the gaps in the rotation of food crops having a priority claim to an agricultural site. The management of a series of discrete food crops propagated on a year-round basis in a given agricultural zone is no easy task. Even if all the necessary technical data were available, that is, the correct varieties, varietal planting sequences, soil and water conditions, pesticides for preemergence to post-harvest operations, EPA regulations and standards, etc., much can happen to disrupt the flow of a cropping sequence or to shut it down altogether for an indefinite period. Weather can be unseasonably cold, hot, wet, or dry; equipment breakdowns, labor problems, market fluctuations, and problems of finance can all step in to disrupt the best-laid plans. In such cases cultivated fields will lay idle for many weeks or months. These lands are not only non-productive, but they are also subject to weed regrowth, leaching of residual nutrient elements, and erosion by wind and water action on exposed soil surfaces.

However, to the advantage of both food and energy planters, such gaps can be filled very nicely with fast-growing crops such as Sordan 70A. They are easily seeded with a grain drill and their rapid canopy closure (within 2 to 3 weeks) precludes any appreciable weed development. They are good scavengers for residual nutrients and erosion is totally eliminated. Moreover, owing to an extremely rapid maturation phase (Fig. 1) they can produce four to six tons of dry matter within eight to 10 weeks after seeding. It should be noted that this yield from a 10-week crop in Puerto Rico is very comparable to a one-year yield from temperate forest species (19). There is no reason why food and energy crops in the short-rotation category cannot collaborate in the most favorable use of a given agricultural site.

2. Agriculture and Factory Integration

The most urgent need for sugarcane biomass in Puerto Rico is in the capacity of a boiler fuel for electrical power generation (2). Quite understandably, we are looking to the Island sugar mills as the most readily available installations for biomass fuel combustion (20, 21). By its basic nature, a sugar factory is a centralized site for gathering biomass together, for dewatering it, for drying it to a combustible state, for burning it to produce low pressure steam, and for generating electricity with steam turbines.

However, even though Puerto Rico has a year-round growing season, sugarcane biomass cannot realistically be delivered to our sugar mills on a year-round basis. The sugar industry at present grinds sugarcane over a 5- or 6-month period from mid-January to late June. This interval could be lengthened to about eight months by grinding from December 1 through July. The period from mid-August through November is ordinarily rainy in Puerto Rico. It is doubtful whether field operations with heavy equipment can be performed at this time without unnecessary damage to the soils, plant stubble, and equipment. Manual harvesting during the rainy season is a possible alternative.

A more favorable option is the use of sugarcane and allied tropical grasses as a combination of fresh- and storage-fuel sources. The factory itself, operating on a 12-months basis, could receive direct fuel inputs in the form of bagasse for about eight months, and dried fuels, in the form of mill-dried bagasse and solar-dried grasses, during the remaining four months. As noted by Samuels (22), the bulk of the sugar recoveries would be made during the period February-May. The mills would operate essentially as dewatering sites for sugarcane fuels both before and after the favorable months for sugar.

SUGARCANE-TROPICAL GRASSES INTEGRATION FOR AN INDUSTRIAL-SCALE COGENERATION PLANT

Sufficient data are available on Puerto Rico's energy needs and cane fuel-producing capability to establish a demonstration-scale plant for electrical energy production from sugarcane. Essentially a cogeneration system based on a conventional sugar factory installation, this facility would provide a year-round electrical energy supply to the WRA power grid. The proposed plant would burn 1000 tons of biomass fuel per day, having a year-round fuel requirement of 365,000 tons (Fig. 2). At this combustion level, accurate data would emerge relative to biomass production, delivery, mill-drying, and incineration performance. These data in turn would serve as a basis for the design of future industrial-scale plants.

For the proposed facility, 2/3 of the annual fuel input would consist of dewatered sugarcane in the form of bagasse and trash, and 1/3 would derive from "allied" tropical grasses. The latter would include the non-sugar bearing *Saccharum* species together with intermediate- and short-rotation species such as napier grass and Sordan 70A. As depicted in Figure 2, "green" bagasse (mill-dried to about 44 percent moisture) would be the predominant boiler fuel throughout an 8-month period when sugarcane is being ground. No sugarcane would be milled during the remaining four months. At this time the factory furnaces would continue to operate using a range of biomass fuel sources, all of them drawn from storage in a dry state of preservation.

A limited portion of the 4-months fuel reserve (perhaps a one-month supply) would consist of excess bagasse mill-dried to about 16 percent moisture (ambient moisture). It is proposed that hot flue gasses be used for drying this bagasse. Flue gasses would also be used to dry the green bagasse from 51 to 44 percent moisture. In the latter instance, open-air drying of the bagasse is also a viable option for study. The bulk of the 4-months fuel reserve would derive from 8-10 weeks old Sordan and 16-weeks old napier grass. All of this material would be cut with a rotary scythe, solar-dried, and bulk-baled in the field as part of the fuel production operation.

A supplementary biomass fuel reserve is also depicted in Figure 2. This reserve could include any crop residues that are reasonably collectable, or wild biomass residues of virtually any form. However, the most important contributors in this category are a series of woody biomass species having proven superior growth potentials but which are essentially untested as local boiler fuels. These include several fast-growing species of *Eucalyptus, Casuarina,* and *Albizia* (23).

A preferential site for the cogeneration facility would be located on the southwest coast. The

Guánica mill, adjacent to the Lajas Valley, would appear to be ideal. The Cortada site east of Ponce would also be very suitable. This site would favor solar-drying, open-air drying of bagasse, and storage tests in the mill's immediate vicinity.

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Table 1. *Saccharum* crosses performed during the autumn of 1979 by the AES-UPR sugarcane breeding program; AES-UPR Gurabo Substation

Date Of Cross	Parental Clones			Type Of Cross	No. Of Tassels	Remarks
	Male		Female			
Oct. 20, 1978	US 67-22-2	x	B 70701	BP	3	Performed in field
Nov. 13, 1978	F 160	x	US 67-22-2	"	5	
	US 67-22-2	x	US 67-22-2	"	3	
Nov. 17, 1978	PR 68-330	x	US 67-22-2	"	5	
Nov. 21, 1978	PR 70-3391	x	US 67-22-2	"	4	
Nov. 28, 1978	PR 70-3364	x	US 67-22-2	"	3	

Table 2. Yield responses to narrow row spacing for sugarcane harvested at variable intervals

	DM change (%) with close spacing, at harvest interval —				
Variety	2 Months	4 Months	6 Months	12 Months	Mean
PR 980	46.5	34.0	16.0	-20.3	19.1
PR 64-1791	36.7	37.0	9.1	- 4.3	19.4
NCo 310	46.0	23.2	22.0	13.7	26.2
Mean	43.1	31.4	15.7	- 3.6	

Table 3. Sugarcane and napier grass yields as a function of harvest frequency. From Alexander, et al (14)

Harvest Interval (Mo)	Total Harvests/Yr 1/	Tons DM/Acre Year, For —	
		Sugarcane	Napier Grass
2	6	6.5	12.7
4	3	11.1	22.6
6	2	16.6	25.6
12	1	25.5	19.3

1/ Plant crops; Lajas Valley.

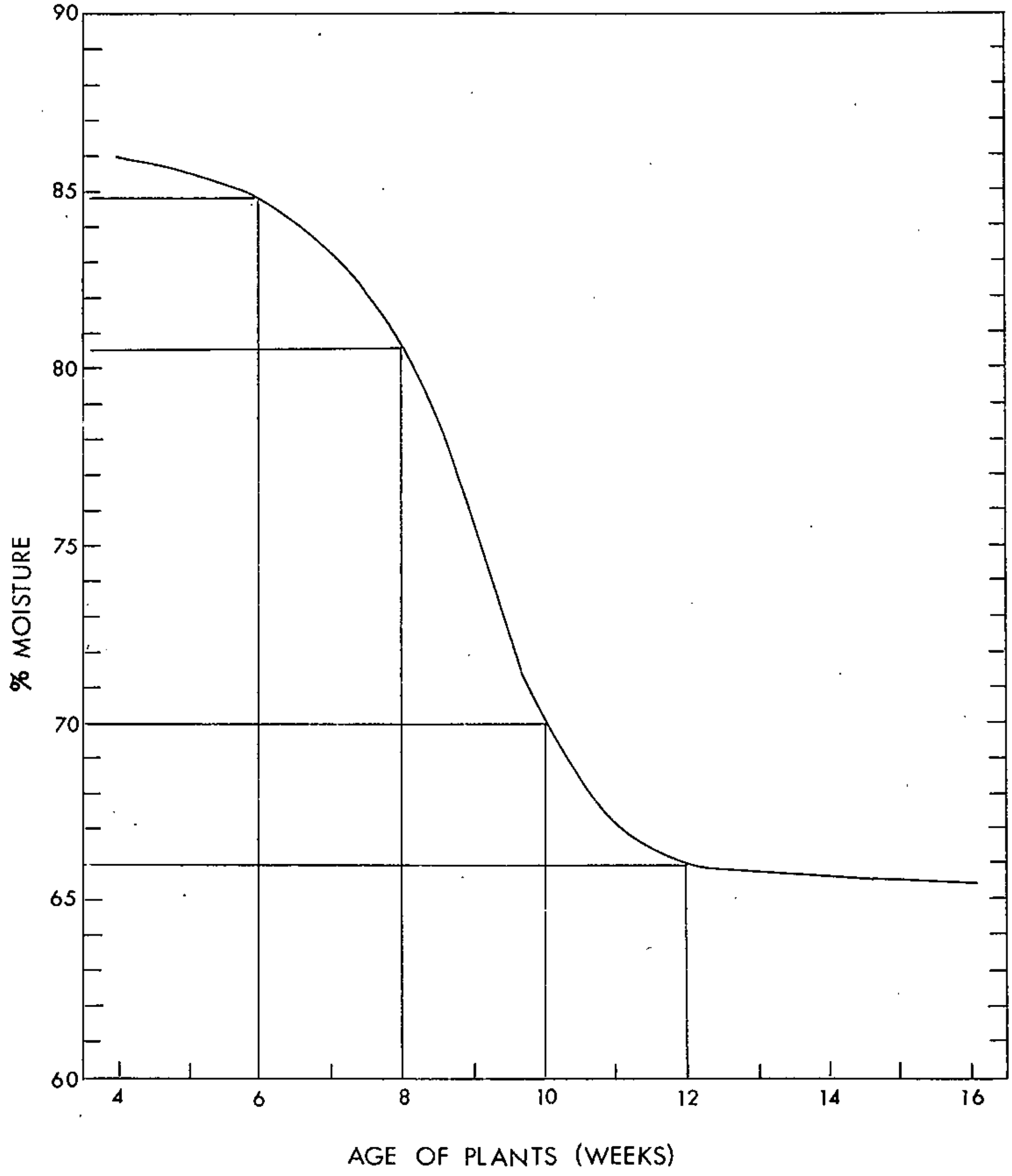

FIGURE 1. A plot of the declining moisture content (maturation curve) for Sordan 70-A. The decisive period for fiber accumulation is the 2-week interval from week 8 to 10.

SUGARCANE IN FOOD AND ENERGY CROP ROTATIONS IN PUERTO RICO

Presented To

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SUGARCANE IN FOOD AND ENERGY CROP ROTATIONS IN PUERTO RICO

Table of Contents

SUGARCANE IN FOOD AND ENERGY CROP ROTATIONS IN PUERTO RICO

George Samuels[1]

ABSTRACT

From its agrarian past, Puerto Rico has emerged as an industrialized and insular society which imports both food and energy sources. A proposed modern agricultural program will allow almost self-sufficiency in food crop production by 1988, limiting sugarcane for domestic sugar production. Island energy costs by 1988 will be over $2 billion. Sugarcane, a climatically-favored energy crop for Puerto Rico, can be grown for combustible organics and fermentable solids rather than sucrose to reduce, and in time, to eliminate dependence on foreign energy imports. Limited resources of mechanizable land make it impossible to support optimum production of both food and fuel crops. An alternate plan of one third of the limited mechanizable area to intensive culture of food crops and two thirds to fuel crops is suggested for a possible critical situation where steamship contact is cut off or under heavy constraint. When increased imported energy costs rise to a level to disrupt the Island's economy, the mechanizable land can be devoted to energy planting to satisfy almost all domestic energy requirements. Imports of rice, beans, and starchy vegetables could replace the displaced food crops without providing a severe drain on external expenditures. The stage is now set where agricultural planners must use great care in their choice as to food or fuel cropping for Puerto Rico.

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SUGARCANE IN FOOD AND ENERGY CROP ROTATIONS IN PUERTO RICO

SUGARCANE has gained primary recognition in the world as a source of food; that is, as a source of sugar and molasses. Yet, this finest living collector of solar energy can produce massive quantities of combustible and fermentable solids as stored energy sources. Faced with a surplus of sugar and decreasing sugar prices on one hand, and shortages of fossil fuels and rising fuel prices on the other, the perspective is drastically changing. Sugarcane now offers to the world a renewable energy source. In the future its new role as an energy crop may outweigh its importance as a food crop.

Many tropical nations have limited land, water, and technological resources despite year-round growth potentials. Their resources are under increasing pressure to provide food and clothing for large populations. Government planners are obliged to seek maximum development of domestic agriculture while minimizing foreign expenditures for food and fuel. However, the need for energy in these areas is also mounting. Since 1973, cost increases for fossil fuels has imposed a severe strain on their economic balance of imports and exports. Domestic biomass production offers a solution, but places a severe demand on land and water resources that must be diverted from food production.

A case in point is the problem of food versus energy production in Puerto Rico. An agrarian society for most of its 450-year history, the Island was largely self-sustaining in its food production. Beginning in the 1940's, industrialization was stressed as the principal means of employment. Over a period of two decases the Island attained a rapidly-rising standard of living coupled with increased dependence on foreign supplies of food and energy. Sugarcane, the Island's largest agricultural crop in the 1940's and 1950's, with a maximum sugar yield of 1.36 million tons in 1952, has declined to one fifth of this production today. Yet, this crop in a new role offers Puerto Rico a chance to relieve its dependency on imported sources of energy.

The objective of this paper is to present possible choices in achieving a balance between food and energy production with sugarcane within the limited land resources of Puerto Rico.

DISCUSSION

1. Land and Human Resources

A proposed modern agriculture program for Puerto Rico developed by a competent group of agricultural scientists and planners (14) divides the soils of the Island into 12 groups based on their capability for agricultural production (Table 1). Of a total of 886,245 ha (2,189,026 acres), there are 364,977 ha (901,494 acres) available[2] for agriculture and 370,818 ha (915,921 acres) available for forests, wildlife, recreation, aquaculture and ecological reserves. Classified as improved mechanizable lands with adequate moisture or irrigation are 108,982 ha (269,186 acres).

Puerto Rico's human resources comprised a population of 3.31 million in 1977, projected to an estimated 3.58 million in 1988 (14). An average of 41,000 persons, from a total of 739,000 persons employed on the Island, worked in agriculture in 1977 (12).

The total value of agriculture at the farm level was $486 million in 1977 (12). The imports for food amounted to $1.12 billion for the same period and imports for fuel (petroleum, natural gas, gasoline) $1.39 billion for 1975-76 (10).

2. Sugarcane as a Food Crop

To place sugarcane as a food crop in proper context, it is necessary to take a look at the entire food crop needs of Puerto Rico. The modern agricultural plan for the Island (14) has designated 901,494 acres for food crop production (including dairying and beef cattle). Almost two thirds, 632,308 acres, are located on partially-mechanizable lands with rolling topography for production of coffee, citrus, plantains, bananas, mangos, avocados, dairying and beef cattle. The level lands suitable for mechanization, amounting to 269,186 acres, have received food-crop area assignments as shown in Table 2.

Under the proposed modern agriculture plan for Puerto Rico, sugarcane as a food crop land

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[2] Of the total area, 20% has been discounted for urban and industrial uses, for roads, and for other non-agricultural purposes.

area will be reduced to 70,000 acres, or 26% of the mechanizable land on the east, west, and south coasts, to produce 200,000 tons of raw sugar for domestic consumption. No attempt will be made to export sugar due to the accumulated losses of the present sugar industry. These losses are explained by the fact that the cost of producing one pound of raw sugar on the Island is 26 cents while the New York price for a pound of sugar is 13.5 cents.

From the 391,763 acres occupied in 1951-52 to produce over a million tons of sugar, sugarcane will take its place as a local food crop occupying 7.8% of the total area devoted to food crops. The new place for sugarcane in food crop production is a balanced one considering the food crop requirements of Puerto Rico.

The agricultural planners designation of 70,000 acres for production of 200,000 tons of sugar is very conservative. The modern production techniques they will employ in field and factory should produce more than three tons of sugar per acre by 1988 (14, p 527). Production should attain four tons per acre to be economical and commensurate with the modern production techniques they will employ. Thus, some 50,000 acres will actually be needed to produce the 200,000 tons of sugar for local consumption, releasing 20,000 acres for other usage—preferably for sugarcane as a fuel crop.

Although some may seriously question the classification of rum as a food, this alcoholic beverage is an important economic product of sugarcane consumed both domestically and exported. Rum sales, including taxes, are a major source of Island revenue amounting to $212 million in 1977-78. The molasses needed anually for rum production amounts to 114 million liters (30 million gallons), of which more than half is imported from other Caribbean islands.

3. Sugarcane as an Energy Crop

The planners of the modern agricultural program for Puerto Rico omitted one very important crop in drawing up their comprehensive plan. This was sugarcane as an energy crop. Sugarcane must be reevaluated as an energy crop where total biomass rather than sucrose is the prime consideration. As a food crop, sugarcane offers small economic potential for Puerto Rico; as an energy crop, its economic potential is very large.

One ton of oven-dry bagasse (6% moisture) has an energy content of 4.16 million kg calories (15 million BTU's) which has an electrical equivalent of 17.4 billion joules (1,500 KWH). This in turn is equivalent to 2.6 barrels of petroleum. At present in Puerto Rico the average cane yield is about 35 green tons per acre, including tops and trash[3], or nine dry tons in a 12-month crop. Yields of 60 green tons per acre year are common. Incidentally, at the present time, the cane tops and trash are burnt before cutting the cane as a means of easing harvest operations and to reduce the amount of extraneous matter being shipped to the mill. This amounts to two tons per acre of dry trash which is equivalent to 5.2 barrels of oil per acre being sent up in flames.

Sugarcane has been grown for over 400 years in Puerto Rico with the objective of producing high yields of sugar. Varietal selection, agronomic practices, and milling procedures all have been aimed at maximization of sucrose. Sugarcane tonnage can be vastly increased when total biomass rather than sucrose is the principal product. A three-fold increase over the average yield for the Island's sugar industry was obtained by Alexander (1) when initial attempts were made to maximize tonnage. The increases resulted from such changes in management as selection of a high-tonnage variety, increased fertilization, use of narrow row centers, and inclusion of cane trash (tops and dry leaves) in the final yield calculations. With further research in optimizing varieties, fertilizer, and spacing variables, Alexander believes it is reasonable to expect production levels in the order of 35 to 40 tons per acre year. This is not an exaggerated premise considering the climatic potential of Puerto Rico for growing sugarcane. The research work to date is being done with existing varieties and production technology. With breakthroughs in the *Saccharum* problem of genetic constraints, it may not be unreasonable to expect varieties capable of yields approaching 50 tons of dry biomass per acre year (1).

From the 270,000 acres of mechanizable land, sugarcane as an energy crop could yield sufficient biomass to produce 29.3 x 10^{15} joules (8.1 billion KWH) of electricity. This is equivalent

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[3] The quantity of tops and leaves was obtained by multiplying the millable cane production by 30% (5, p. 84).

to 77% of the electricity used in Puerto Rico in 1975-76. In 1988, the electrical power needs of Puerto Rico will grow to an estimated 45 x 10^{15} joules (12.5 billion KWH), of which 65% could be satisfied by this energy crop. In terms of oil imports and dollar payments, the energy produced on this area would be equivalent to 14 million barrels of bunker oil, which, at the present OPEC price of $16 per barrel, has a value of $224 million. Considering sharp increases in future oil prices of up to $20 to $25 per barrel by 1988 (or sooner), the savings in dollar leakage from the Island economy would amount to $280 to $350 million.

Sugarcane's total biomass consists of combustible organic material (fiber) and fermentable solids. We cannot overlook the energy potential of the fermentable solids in the form of alcohol (ethanol). Brazil has undertaken a vast program to produce alcohol from both sugarcane juice and molasses. The alcohol produced is added to gasoline at rates up to 20% of the total mixture. At present Brazil is producing 719 million gallons, with projections of 793 million gallons by 1980 (3). The resulting gasoline-alcohol mixture (gasohol) burns cleaner with less pollution than gasoline alone and will produce a saving of $300 million in replaced petroleum.

Although Puerto Rico has the potential to produce alcohol for use as a motor fuel, the present and near-future uses of sugarcane fermentable solids will center on rum production, in view of the high tax revenues from rum returned to the Island each year. At present the rum industry must import over half of the molasses needed for its rum production. The 270,000 acres of mechanizable land, besides producing combustible solids, could produce approximately 235 million gallons of alcohol per year. This is sufficient to cover both the needs of the rum industry and gasohol for motor fuel. The use of 20% alcohol in a gasohol mixture would have meant $2.1 million saved for gasoline expenditures in 1975-76.

The use of sugarcane as a fuel crop rather than a food crop allows for a more efficient and economical use of labor and equipment. For sugar production, cane harvesting must be limited to three to four months for maximum sucrose values; for alcohol production the harvest period can be lengthened, because maximum total sugars is the objective. In a sugar-alcohol cane rotation, cane would be harvested from about November to August with the February to April period used for maximum sucrose and the remaining months for alcohol production.

A sugar-alcohol or alcohol-fiber rotation will allow for the use of a simple and relatively inexpensive milling process as compared to the present process and equipment being used to produce sugar only. Thompson (13) predicts that with rising capital costs of milling and manufacturing machinery, millers would probably elect to extract only 70% of the sucrose from the cane for the purpose of making sugar in a simple and relatively inexpensive milling process. A set of cane preparatory devices and a five-roll mill would be all that is necessary. Power requirements would be very low. This simple process would yield 55-60% of the sugar recovered at present. The molasses, with a purity of about 70%, will go directly to the adjacent distillery for alcohol production. If production is for fiber and alcohol, the mill set-up would require only crushing the cane with the juice going directly to the distillery for alcohol production. The bagasse from the single milling unit will contain as much as 30% of sucrose in the cane. This combination will be eligible for a fermentation process to convert sugars to alcohol, a hydrolysis process to convert cellulose to a fermentable intermediate product, and leaving a residue of lignin to be burnt as a source of heat in the conventional boiler furnace.

Not to be forgotten in the sugarcane energy complex is the value of the residues from the sugar and alcohol industry. Stillage, or distillery slops, was once regarded as a waste material to be dumped into rivers or the ocean. Prohibited by environmental restrictions from dumping, the Brazilian sugar industry has found this material to be a valuable source of fertilizers. Every 1000 tons of cane being used directly for alcohol production yields 203,000 gallons of stillage which contain about 470 lbs. N, 200 lbs. P_2O_5, and 2060 lbs. of K_2O (11). From the 236 million gallons of ethanol that could be produced from the fuel cane planted on 270,000 acres in Puerto Rico, the distillery slops would provide 3,553 tons N, 1660 tons P_2O_5, and 15,570 tons K_2O. This amount of fertilizer elements available from distillery slops exceeds the potash fertilizer needs, and amounts to 25% of the N and P_2O_5 used in the Island for 1975-76 (4). The value of the fertilizer imported for this period was $5 million (10).

Another residual from the sugar mill is filter-press cake, or "mud." This organic material filtered from the crusher juice is a fertilizer source for N and P. Every 1,000 tons of cane ground produces 10.5 tons of filter-press cake containing 400 lbs. N, 600 lbs. $P_2 0_5$ lbs. N, and 80 lbs. $K_2 0$. The filter-press cake obtained from cane planted on 270,000 acres would provide 3,024 tons N, 4,536 tons $P_2 0_5$, and 550 tons $K_2 0$.

The use of sugarcane biomass to produce electrical energy is no futuristic dream for Puerto Rico. For decades, the electrical power needed to run the sugar mill has been obtained from bagasse-fired boiler furnaces. Excess electrical power from the mills has been sold to nearby towns or cities to help meet their electrical needs. In 1975-76, the Puerto Rico Water Resources Authority purchased from sugarmills and the Isabela irrigation system some 337,641 KWH, 2.4 times the amount of electricity produced by the Island's hydro-electric system, and 2.7% of the total electrical energy produced on the Island for that period.

Research has indicated the possibility of many inovations which will increase efficiency, lower costs, and widen the scope of the use of sugarcane biomass in energy production. Some of these are:

1. Increasing the efficiency of steam and power generation by preheating combustion air in bagasse-fired boilers, using waste heat from the furnace-stack gasses (6).

2. Closer spacing of the cane plantings to increase tonnage of biomass per unit area (6-8).

3. Breeding of varieties capable of increased yields of total fermentable solids and fiber, and total biomass, plus varieties responsive to intensive cultivation on prime lands and to extensive cultivation on marginal lands (1).

4. Densification of the bagasse by compression to give savings in transportation, storage, and capital investment (9).

5. Bioconversion of starches and cellulose to ethanol through fermentation and distillation (13).

6. Separation of the sugarcane rind from the pith by a low-cost process (Canadian Separation Equipment Process), making possible new product mixes with higher potential revenue (6).

7. Use of pyrolitic methods of energy conversion of organic combustibles to increase efficiency by 75-100% over direct combustion (6).

8. Using the glucose residing in the cellulose and hemicellulose complexes of bagasse as fermentation feedstock (1).

SUGARCANE: POSSIBLE WOOD AND ENERGY CROP ROTATIONS

Agricultural planners in Puerto Rico must weigh carefully the merits of energy planting versus food planting for the Island's available land resources. There are about 270,000 acres of level, mechanizable land available for either cropping system. If devoted to food crops, the estimated farm value in 1988 will be $250 million with near self-sufficiency in food crop production, including sugar. However, energy costs for 1988 will be over $2 billion to be paid out for foreign oil.

The other extreme would be to devote the mechanizable land to the energy cropping of sugarcane, with a farm value of about $150 million. Approximately two thirds of the Island's energy requirements would be satisfied domestically. Imports for food would be about $190 million and oil $670 million. In terms of a more favorable trade balance for Puerto Rico, energy cropping is better than food cropping on these strategic mechanizable lands. This choice sounds almost heretic in light of Puerto Rico's attempt to build up its food crop production potential. Yet, Puerto Rico does not have sufficient mechanizable lands to sustain both food and energy crops at optimum area for its needs.

A choice of energy cropping of sugarcane does not mean that Puerto Rico must import all of its food crops. The 672,000 acres not used for sugarcane fuel planting can supply the meat, milk, fruits, starchy vegetables, bananas and plantains for Puerto Rico. The rice, beans, vegetables, and sugar critical to the Island's diet can be produced quite effectively by mainland farmers, but farmers on the mainland cannot produce energy for export to Puerto Rico.

A critical situation could arise for Puerto Rico where steamship contact is cut off or under heavy constraint. Under such a critical situation, sugarcane as a fuel crop will be able to take care of a major part of Island energy needs. Approximately 85,000 acres (50% of the planned sugar, rice, vegetables, starchy vegetables and dry beans) could be devoted to food cropping. The remaining

185,000 acres would be able to supply 44% of the 1988 energy demand. With energy conservation practices by the government and population, about two thirds of the energy needs could be met.

Another critical situation would arise when the increases in fossil energy costs cannot be paid without decisively disrupting the structure of the Island's economy. With the present Iranian oil crisis, this situation is approaching rapidly. Under such a critical situation, the mechanizable land can be devoted to energy planting to satisfy almost all domestic energy requirements. Imports of rice, beans, and starchy vegetables could replace the displaced food crops without providing a severe drain on external expenditures.

A change-over to sugarcane fuel crop production from food crops would not create any unemployment. A labor force of 17,500 persons are projected for the food crop production in the critical mechanizable area (14). A labor force of about 23,000 persons will be needed for the full energy crop production on the same land.

The need of raising sugarcane for domestic consumption can be solved by several means and still allow sugarcane to be grown as a fuel crop. In the production of biomass, there will be sucrose available that could be diverted from fermentable solids to sugar. Another future sugar source will be the conversion of bagasse fiber to sugar using an enzymatic process. An immediate sugar source, if needed, would be through importation of sugar from the mainland where production costs are lower than those in Puerto Rico. This last suggestion may appear to be degrading for Puerto Rico, a once proud exporter of sugar; but in view of world conditions, it offers an immediate economic advantage.

In the production of certain food crops, especially vegetables, there are periods of time which would allow a rotation with a short-term fuel crop such as Sordan 70A, a hybrid forage grass. Alexander (2) has shown production of about four tons of dry matter per acre in eight weeks. Even rice has an energy value potential in the straw amounting to 4,000 tons of dry matter per 1,000 acres (equal to 200 acres of sugarcane biomass). The use of such short-term fuel crops will depend, in great part, on transportation costs.

Sugarcane in food and fuel crop rotations in Puerto Rico cannot assume a classical form of alternate cropping of sugarcane for food and energy. Shortage of land and rising fuel costs will always place a greater demand for sugarcane as an energy crop if proper attention is given to the value of this crop. Varieties and cultural practices will differ in growing sugarcane as a food or fuel crop, as will factory procedures. The change-over from present day sugarcane practices for sucrose to the new biomass potential is not too difficult or impracticable. The fallacy would be to try to grow sugarcane in the same way for both sugar and energy.

CONCLUSIONS

Puerto Rico can produce almost all of its food needs and over two thirds of its energy needs by 1988, but not both at the same time. A critical area, 270,000 acres, of mechanizable land is available for sugarcane fuel production and/or intensive food crops production. For the immediate future, a compromise may be the best practical approach. Some of the projected program for producing rice, dry beans, and vegetables on the mechanizable area could be put into practice to obtain a base of knowledge and experience needed should a critical situation arise limiting ocean transportation. AT the same time, planting of sugarcane as a fuel crop must begin. These fuel crop plantings must increase yearly. Limited imports of certain food crops will not be as disruptive of the Island's economy as the increasing drain of dollars for imported fuel. Great care must be exercised in planning the cropping of the critical areas of mechanizable land available in Puerto Rico, for they hold the future means of alleviating the impending energy crisis by use of sugarcane as an energy crop.

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Table 1. Soil resources of Puerto Rico grouped in accordance with their agricultural potential, ha (acres) (14, p. 572)

Soil grouping	Crops	Available area *
Humid coastal region		
A. Deep alluvial	Sugarcane, rice, starchy vegetable	41,833 (103,326)
B. Deep red	Pineapples, pigeonpeas starchy vegetables, dairying	38,255 (94,490)
Humid midlands		
C. Rolling topography	Plantains, citrus, dairying	43,593 (107,674)
Humid Mountain regions		
D. Deep 50% slopes	Coffee, plantains, bananas, citrus, dairying, beef cattle	196,483 (485,312)
E. Medium deep 50% slope	Commercial forests	113,547 (280,462)
F. Shallow or 50% slope	Natural woodlands, wild life, recreation	92,140 (227,585)
G. Shallow calcareous	ditto	32,959 (81,408)
Semi-arid region		
H. Deep, level, heavy irrigable	Sugarcane, hay, dry beans, new crops	19,090 (47,152)
I. Deep, level, friable, irrigable	Vegetables, dry beans	9,805 (24,218)
J. Gently rolling (some adopted to drip irrigation)	Mangos, avocados, and other fruits	15,920 (39,322)
K. Steep, shallow	Natural woodlands, wild life, recreation	93,124 (230,016)
Coastal lowlands		
L. Saline, organic, marshy or sandy	Aquaculture, ecological reserves	39,049 (96,459)
Total		735,796 (1,817,415)
Available for:	Agriculture	364,977 (901,494)
	Forest, wildlife, recreation, aquaculture, ecological reserves	370,818 (915,921)
	Full mechanization	108,982 (269,186)

* Of total area 20% has been discounted for urban, industrial, roads and other non-agricultural uses.

Table 2. Proposed areas for 1988 and related data for the crops to be grown on the level mechanizable lands in Puerto Rico 1/

Crop	Area	Farm value million	Persons employed	Farm value per ha (acre)
	ha (acres)	$		$
Sugarcane	28,340 (70,000)	60	6,000	857
Rice	20,243 (50,000)	55	1,500	1,100
Vegetables	6,073 (15,000)	36.3	4,000	2,420
Pineapples	4,858 (12,000)	12.8	1,600	1,067
Pigeonpeas	3,441 (8,500)	4.6	600	541
Starchy vegetables	3,036	18.7	1,500	2,490
Dry beans 2/	5,466 (13,500)	10.7	500	793
Hay	2,024 (5,000)	4.8	100	960
Dairying	35,628 (88,000)	48.4	1,750	556
Total	109,109	251.3	17,500	

1/ Adopted from (14).

2/ 2 crops yearly.

MACHINERY DEVELOPMENTS AND OUTLOOK FOR HIGH-DENSITY BIOMASS

Presented To

A SYMPOSIUM ON ALTERNATE USES OF SUGARCANE FOR
DEVELOPMENT IN PUERTO RICO

Caribe Hilton Hotel, San Juan, Puerto Rico
March 26 and 27, 1979

Contributed By

The Department of Agricultural Engineering, Mayaguez Campus
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MACHINERY DEVELOPMENTS AND OUTLOOK FOR HIGH DENSITY BIOMASS

W. F. Allison[1/]

INTRODUCTION

THE planting and harvesting of field crops as a source of renewable energy feedstocks present new problems to the agricultural engineer that will require the development of new machines and methods to meet the needs of tomorrow. Solutions to some of these problems only require the selection of existing equipment and techniques, but others have yet to be found.

The plant breeders, agronomists, and planners have yet to determine many of the parameters of the crops to be grown for their biomass productivity, and even their findings of today have yet to be adapted to field operations from seed bed preparation through harvesting, transporting, and perhaps storage. However, some principles are known and can be discussed and evaluated according to the current stage of the art. Harvesting appears to be the most formidable undertaking and is the basis for the following discussion.

CLASSIFICATION OF HIGH DENSITY FORAGE CROPS ACCORDING TO HARVESTING REQUIREMENTS

Based on the type and size of equipment required for mechanical harvesting, the forage type crops being considered as potential sources of biomass by size at harvesting can be classified into three groups: (1) those crops that are harvested before reaching 20 tons per acre green weight; (2) crops harvested at green weights of 20 to 50 tons per acre; and (3) those crops harvested at green weights of 50 to 120 tons per acre such as 12 to 14 month sugarcane. Each of these classifications of crops have different characteristics and present distinct differences in mechanical harvesting.

Crops can further be classified according to the desired state of the harvested material and the processes to be used for converting the biomass to usable energy sources. Whether the material is to be used for direct burning, pyrolysis, or fermentation has a direct bearing on the equipment and

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methods of harvesting, drying, transporting, storing, etc. Also, the type of crop and stage of maturity affect the machinery requirements. For direct burning the material should approach the air dry moisture level, while the pyrolysis process needs material at about 25 percent moisture, and the fermentation process requires total saturation. Material for future conversion needs to be stored at the equilibrium moisture level of its surroundings, thus material for direct burning or pyrolysis normally requires the removal of some moisture while that used for direct fermentation requires the addition of moisture, and material stored needs drying.

Also, portions of the crop may need to be separated for alternate processing into more valuable or higher forms of by-products. The separation of portions of the crop demands unique equipment.

AVAILABLE MACHINERY FOR HARVESTING BIOMASS

Equipment and technology is currently available to harvest the two to 20 tons per acre high density forage crops either as green chop or field dried. The typical cycle bar mower is not suitable for this job, but the flail type chopper such as the rotary sythe can cut and condition this crop. Followed by the heavy duty side delivery rake or heavy duty tedder the crop can be field dried when the weather permits and then baled with the round or rectangular baler for transporting and storing.

The heavier crops present more of a problem, but some of the current sugarcane harvesting equipment can be easily adapted to the harvest of the larger crops such as one-year cane or elephant grass. These high-tonnage, high-density crops have several common parameters that can be utilized in harvester design and systems.

The tube, as developed in Puerto Rico, demonstrates two of these principles. The material can be fairly easily pushed down to allow the machinery to pass through the field and the wheel or track of the machine snaps or breaks the stems at the ground level. The push rake as developed in Hawaii actually cuts the plant at the ground level and the rake pushes the material into piles for grab loading. However, both of these systems harvest a considerable amount of soil along with the desired material.

The Hawaiian V-cutter with the live blade as built by Cane Machinery and Engineering Company largely for the Puerto Rican sugarcane industry, and the inverted V-cutter as developed by the Belle Glade Sugarcane Growers Cooperative, can be easily adapted to cut and windrow most crops. The windrow can then be picked up, chopped, and loaded with some separation taking place during the process with such machines as the U.S. sugar chopper-loader or the Belle Glade Coop chopper-loader.

The Claas sugarcane harvester, developed in Cuba and manufactured in Germany, does a good job of harvesting sugarcane crops up to 90 tons per acre. It also separates most of the leaves and tops from the cane stalk. In green cane of 75 to 85 tons per acre, approximately 14 tons of tops and leaves are separated from the cane with four to five tons of stalks being left with the tops and leaves as stubble. Hand cutting normally leaves three to five tons of stalks per acre. This so called trash can be collected directly behind the cleaner or left on the field to sun dry and be baled for further processing. The cane stalks can be sent to the mill for de-watering, and the residue (bagasse) can be further dried with the flue gases from the de-watering process while the juice can be processed for sugar, molasses, or direct fermentation.

SUMMARY AND RECOMMENDATIONS

With some modification, machines are available to harvest the high density biomass crops. However, they must be field tested and modified to meet the demands of the crop as required for processing and re-growth of the stubble for future harvests. The live bladed V-cutter followed by a continuous loader can handle most field and crop conditions.

When separation of cane stalks from the leaves and tops is desirable, the Claas-Libatadora cane harvester shows the most promise of the existing machines. Elimination of the final trash extraction fan would provide a total high-density, high-tonnage biomass harvester-separator system.

Research is needed on planting and harvest systems that permit the use of these large machines with minimal effect on re-growth of the crop. Experience in cane harvesting has shown that this is a major problem in maintaining high productivity following harvest.

SUITABILITY AND MANAGEMENT OF PUERTO RICO SOILS FOR INTENSIVE BIOMASS PRODUCTION

Presented To

A SYMPOSIUM ON ALTERNATE USES OF SUGARCANE FOR DEVELOPMENT IN PUERTO RICO

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SUITABILITY AND MANAGEMENT OF PUERTO RICO SOILS FOR INTENSIVE BIOMASS PRODUCTION

Table of Contents

Topic **Page**

ABSTRACT

SUITABILITY AND MANAGEMENT OF PUERTO RICO SOILS FOR INTENSIVE BIOMASS PRODUCTION

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ABSTRACT

Plotted dual curves for sugar and fiber in Puerto Rico cane reveal small relative differences in the 1944 crop but progressively larger differences over the subsequent 35 years. The sugar and fiber components are compared for both high and low production years. Total biomass produced per acre is discussed, together with the possible effects of cane trash burning at time of harvest.

A PR soil series acreage inventory, based on a detailed taxonomic survey completed in 1976, is presented. The areas of Puerto Rico's soil series that are suitable for mechanization, and for cane sugar, fiber, and total biomass production, have been calculated and are herein reported. Marginal lands comprised of organic or organic-mineral soils, and lands too steeply sloped for mechanization, are discussed as potential new areas for sugarcane biomass production. In the instance of mountainous areas biomass production is seen as a means of erosion control and of reducing rural unemployment. The effects of flooding and water-table fluctuations on sugarcane yields are also discussed.

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SUITABILITY AND MANAGEMENT OF PUERTO RICO SOILS FOR INTENSIVE BIOMASS PRODUCTION

PUERTO RICO'S sugarcane plantations developed originally around the variety *Creole*, a noble cane brought to the Dominican Republic by Columbus on his second voyage in 1493 (3). For more than four centuries, *Creole* and other varieties collected solar energy and stored it in the forms of sugar, fiber, and trash. Sugar and molasses were the products that sustained Puerto Rico's industry as a profitable enterprise until around 1965. From that time onward a combination of declining sugar yields and rising labor costs imposed increasingly severe financial losses on the industry culminating in a loss of $57.7 million in 1978. This figure raised the cumulative loss total to $384 million. Puerto Rico cannot continue to produce sugar at a cost of 26 cents per pound while selling it at a subsidized price of 14.5 cents per pound..

The bagasse produced during cane milling operations has always been a calorific energy asset to the sugar industry; however, its monetary value has not been considered in the business budget. If one considers that a single ton of oven-dry bagasse has a fuel value equal to 2.5 barrels of oil this becomes a factor of major importance in view of Puerto Rico's rising oil costs which are expected to exceed $16 per barrel by the close of 1979.

SUGAR AND FIBER COMPONENTS OF PR SUGARCANE

The sugar and fiber contents of Puerto Rico's sugarcane since 1944 are plotted graphically in Figure 1. The dual curves open up in a distinctly trumpet-like form. This is a result of simultaneous sugar losses and fiber increases which have progressed steadily over a time-course of 35 years. On a percent dry weight basis, a difference of only 1.4 percent between fiber and sucrose was recorded in 1944. By 1973, the year when the largest difference between sucrose and fiber was recorded, this value had grown to more than 12 percent. The fiber content of the sugarcane increased in those 35 crops at an average rate of 1.34 percent per year, while sucrose content declined by an average rate of 1.66 percent per year. The data indicate that, up to 1968, the sucrose yield was around 10 percent and the fiber content under 16 percent, which was not so bad. In the subsequent decade the sugarcane production scenario was more favorable for producing fiber than sucrose.

1. High and Low Sugarcane Yields: 1944–1978

The highest sucrose yield, amounting to 12.92 percent, was obtained from the 1944 crop[1]; the second highest yield, 12.12 percent, was obtained in 1950 (Table 1). The fiber content for 1950 was 14.12 percent. Also in that year, 10.6 million metric tons of cane were harvested from 356,000 acres. The lowest sucrose yield, 7.10 percent, was obtained in the 1978 crop. Some 2.8 million metric tons were harvested in 1978 from 93,346 acres (Table 1).

The sugarcane components for the 1950 crop consisted of 4.21 metric tons of fiber per acre, 3.61 tons of sucrose, and 0.60 tons of trash, for a total dry biomass yield of 8.41 metric tons (Table 2). Conversely, sugarcane components for the 1978 crop consisted of 5.53 metric tons of fiber per acre, 2.26 tons of sucrose and 0.45 tons of trash, for a total dry biomass yield of 8.29 metric tons. By way of comparison, Bonnet (1), working with the interspecific cane hybrid M 336 propagated in sand culture, produced an equivalent of 40.86 metric tons of dry matter per acre. Some 8.1 metric tons, roughly 20 percent of the total yield, was obtained from roots. This cane received an equivalent of 210 pounds of elemental nitrogen per acre (Table 3).

2. Consequences of Trash Burning for the PR Cane Industry

The practice of burning trash[2] as a preharvest operation began on a small scale around 1960 and eventually extended throughout all the plantations. The sugarcane industry was forced to reduce manual labor expenses and, as a result, herbicides were introduced in large numbers. Prior to 1960 sugarcane was cut and loaded by hand and arrived at the factory in a clean and fresh condition. Sucrose yields were relatively high. However, with the advent of mechanized harvest operations, cane deliveries consisted of burned and dirty materials which had to be washed prior to milling. This required expensive laundry-type machinery, sucrose inversion losses were high, and sucrose yields were low.

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[1] Fiber-yield data for 1944 are not available.

[2] Cane "trash" refers to aged leaf blades and sheaths that have died, desiccated, and detached, or partially detached, from the cane stalk.

The burning of cane trash also contributed to air pollution throughout Puerto Rico. The Commonwealth Environmental Board has prohibited this practice beyond the year 1982. This will have the effect of increasing the total dry biomass yields of the cane crop. In addition, it will help to conserve soil moisture and soil organic matter.

3. Chemical Composition of Sugarcane Leaf and Stem Tissues

Bonnet (2), in 1930, reported the chemical composition of dry leaves for the sugarcane varieties POJ 2714 and SC-12-4. Similarly, Deerr (3) reported the composition of sugarcane pith, stalk, and rind tissues. The principle constituents of sugarcane fiber are cellulose, hemicellulose and lignin. In leaf tissues these were found to comprise between 66.57 and 69.17 percent of the total composition (Table 4). In the pith, stalk, and rind, they reportedly made up some 95.1, 93.7, and 95.1 percent, respectively, of the total composition (Table 5). Cellulose is a crystalline material, composed of glucose polymers, which performs a critical structural role in the cell walls of most plant materials. As a long-term prospect the cellulose of sugarcane will be increasingly valued as a feedstock for the fuel and chemical industries.

BIOMASS-SOIL INVENTORY

Prior to 1942, sugarcane biomass yields in Puerto Rico were reported as green metric tons per acre of cane, or as dry metric tons of sugar per acre. In that year, Roberts and Party (4) published their Detailed Soil Survey for Puerto Rico. Subsequent yields were reported for each respective classified Soil Type-Series. The acreage for each series was also reported. The Soil-Type Series were located in four colored map sheets at a scale of 1:50,000.

In 1976, the New Detailed Taxonomic Soil Survey of Puerto Rico was completed and partially published. Six major Areas are identified (Fig. 2), including: Lajas (5), Mayaguez (6), and Humacao (7) which have been published, and San Juan, Arecibo, and Ponce which remain to be published. The soils are further classified in Series. Their respective acreages are reported and they are located in individual soil maps at a convenient scale of 1:20,000. The New Taxonomic System for soil classification now in use in Puerto Rico was developed and published by the USDA Soil Conservation Service (8).

Some 164 Soil Series are classified in Puerto Rico by the New Taxonomic System. These are further distributed and evaluated in five higher Categories, including Family, Subgroup, Great Group, Suborder, and Order (Table 6). For land-use analyses it is simpler and more meaningful to combine the Soil Series maps into 54 divisions of the Family Category. This combination includes properties important for root growth and broad subtextural and mineralogical classes. It would also be useful to prepare simpler maps for the 37 divisions of the Great Group Category. This would record the presence or absence of properties associated with wetness, climate, parental material, and vegetation. Moreover, this would show the degree of development of soil horizons, with emphasis on the upper horizon, base status, moisture regime, and presence of hardpans that interfere with soil plowing operations and the attendant production of sugarcane biomass.

INVENTORY OF PR SOILS FOR PRODUCTION OF SUGARCANE

An inventory of Puerto Rico soils has been calculated on a percentage basis for each of the nine Taxa in the superior Category (Order), of the 1976 Taxonomic System, for each of the six Areas surveyed and for all of Puerto Rico (Table 7). The total area occupied by soils, rockland, marshes, roads, etc., in Puerto Rico is 2,188,711 acres. The acres occupied by each of the Survey Areas is also given (Tables 8 & 9). A similar inventory is presented for soils that can be mechanized or have slopes less than twenty percent (Table 11).

1. Soils Classification for Puerto Rico

Entisols are young soils without developed horizons that are affected by floods and high water tables. They can also have drainage problems and may be shallow over rock. *Inceptisols* are soils with incipient developed horizons in sloping land. *Alfisols* are moist soils with argillic (clayey) horizons, having a medium to high base status (calcium, magnesium), and low percolation. *Mollisols* have dark horizons and a high base status. *Vertisols* are the cracking, clayey soils. *Spodosols* have a thick, white sandy horizon over a second horizon, with accumulations of Al and organic matter. These are very rare in Puerto Rico. *Histosols* are the organic soils.

Oxisols are the unique, reddish-brown soils of the humid tropics. They occur on very old and stable land surfaces. They are acid, have a low exchange capacity for bases, and are in an advanced state of weathering. They consist of a mixture of hydrated oxides of aluminum or iron, or both, with variable amounts of kaolinitic clay and insoluble quartz sand. They also have good drainage. *Utisols* are the acid soils found in regions of high rainfall where leaching exceeds base liberation. They also have a low base status and a clayey subhorizon more acid than the surface owing to the presence of aluminum hydroxide. These soils have a low permeability.

2. Soils Suitable for Mechanized Cane Production

Some 531,857 acres, about 24 percent of Puerto Rico's total soil area, are suitable for mechanized planting of sugarcane, whether for sugar or for total biomass (Table 11). Of these, there are about 28,666 acres in 25 Series that must be omitted because they are too sandy, cannot be irrigaged, are shallow or gravelly, are saline, or are affected adversely by low temperatures. The rest of the soil Series suitable for mechanization, amounting to 523,191 acres, can be planted in cane for sugar or fiber. Each of the soil Series included here is given a rating, in the six Soil Taxonomy Survey Reports, for production of sugarcane in metric tons per acre under actual conditions, and the increases expected under optimized management practices. The acid soils should be adequately limed or fertilized with nitrogen, well drained, and irrigated if necessary, to obtain high yields of sugar or total biomass.

Pineapple is planted in the Entisols (Bayamón and Espinosa Soil Series) suited for mechanization in the Arecibo Area. Approximately 14,000 pineapple plants propagated per acre can produce about 42 dry tons of biomass per year. Both Series have good drainage. There are 22,405 acres of the Bayamón Series and 7,934 acres of the Espinosa Series in the Arecibo Series, a total of more than 30,000 acres. Sugarcane planted in these soils will produce high sugar yields if partial irrigation is provided during the dry season.

Rice is another crop with farming possibilities in the wet, poorly-drained soils of the Arecibo Area that are otherwise suitable for mechanization. Two crops of rice per acre year can produce about five tons each of grain and fiber.

EFFECTS OF FLOODING AND WATER-TABLE FLUCTUATIONS

Two Soil Series, Coloso and Bajura (classed in the Entisol Order), occupy 29,181 and 15,824 acres, respectively, in the humid area of Puerto Rico (Table 9). They are affected by flooding and fluctuating water tables (Table 10). The Puerto Rico Soil Survey for 1942 reported that the Coloso and Bajura soils yielded 60 and 54 metric tons of cane per acre, respectively, for the 18-month sugarcane crop. The 1976 Taxonomic Soil Survey indicates that yields for the Coloso and Bajura Series were reduced to 45 and 40 tons of cane per acre, respectively, during the prior 34-year period. Both flooding and water-table problems appear to have contributed to this decline. Flooding occurred more than once per year for the Bajura soil, and once in one to five years for the Coloso soil. Water tables varied from four to 30 inches from the surface for the Bajura soil, and from 15 to 30 inches for the Coloso soil. Yield reductions of 15 tons per acre for the Coloso soil and 14 tons for the Bajura soil represent losses of dry biomass in the order of four to five tons per acre.

Sugar yields also declined markedly in the Arecibo Area where Coloso and Bajura soils occupy 9,076 acres (Table 9). Central Cambalache experienced a sucrose reduction from 10.93 percent in 1953 to 5.44 percent in 1978, a loss of 5.49 percent in 25 years.

Flooding has also affected a high sugar producing soil, the Toa Series, whose water table is low. In 1942 there were 40,640 acres of Toa soils in Puerto Rico, and in 1976 there were 26,035 acres. This is a reduction of 14,605 acres, of which 3,373 acres were found to have high water tables, while the remainder, 11,232 acres, were used for construction purposes (Table 9). The 3,373 acres together with the 5,731 acres of Coloso soil, both affected by flooding, contributed to an increase of 9,104 acres of Bajura soil since 1942.

Serious attention must be given to the improvement of gravity drainage in the three soils Series affected by flooding and high water tables. This can be accomplished by installation of deep drainage ditches at adequate distances, by establishing subsoil ditches with a "bullet"-type plow, or by installation of plastic tubing in the subsoil. Each of these drainage systems will operate most effectively when emptying into a series of canal mains whose levels are maintained sufficiency low by use of pumps. These operations are necessary to obtain higher yields of sugarcane biomass in the Coloso, Bajura, and Toa Series, and to stop the conversion of the better Toa and Coloso soils into the less desirable Bajura Series.

MARGINAL LANDS FOR SUGARCANE FIBER PRODUCTION

There are approximately 4,012 acres of unplanted, marginal organic soils classified as Histosols, and of organic-mineral soils classified as Entisols, suitable for the mechanized production of sugarcane fiber. These soils are located in the Caño Tiburones Area of Arecibo. There is an excess of fresh water mixed with brackish or saline sea water in the area which requires continuous pumping back to the sea. With the establishment of suitable canals and drainage ditches, and proper maintenance of the drainage system, these marginal lands will produce high yields of sugarcane fiber, eventhough conventional sugar planting has not been regarded as a profitable enterprise in this region.

There are also some 237,000 acres of unplanted marginal lands in the mountain area. These have slopes ranging from 20 to 40 percent, but they can be planted into *Saccharum* varieties having high potential yields of total biomass. This would also appear to be an advantageous means of controlling soil erosion. Essentially a manual operation, the sugarcane biomass would be planted in strip-cropping designs which conform to the local land topography. These plantings could also be made in planned rotations with food crops such as corn, upland rice, sweet potatoes, pigeon peas, yuca (cassava), dasheen, and others (Table 7).

CONCLUSION

Puerto Rico produced a total of 2,997,138 metric tons of dry sugarcane biomass (sugar, fiber, and trash) in the high sugar production crop of 1950, and 769,460 tons in the low sugar crop of

1978. Yields per acre for the two crops were 8.41 and 8.29 metric tons, respectively. There are about 523,000 acres of land suitable for mechanized production of sugarcane at comparable rates of yield. These yields can be increased with modified management technologies and correct soil conservation practices.

There are about 4,000 acres of marginal lands consisting of organic and organic-mineral soils that are presently unplanted and which could be planted for sugarcane fiber production. In addition, there are 236,790 acres in the unplanted mountain area that can be planted for sugarcane biomass. The latter have slopes in excess of 20 percent and therefore cannot be mechanized, but they can be managed as manual operations. They can also be managed as strip-crops to control soil erosion in planned food- and energy-crop rotations. Such rotations can reduce appreciably the problem of rural unemployment while simultaneously providing fuels for generating electrical energy to be used in these areas.

ACKNOWLEDGEMENTS

Thanks are given to Mr. Guillermo Esteves, Jr., President of the Sugar Board of Puerto Rico for supplying data on sugarcane yields in certain crop years, and to Dr. Alex Alexander for helpful suggestions in the preparation of this paper.

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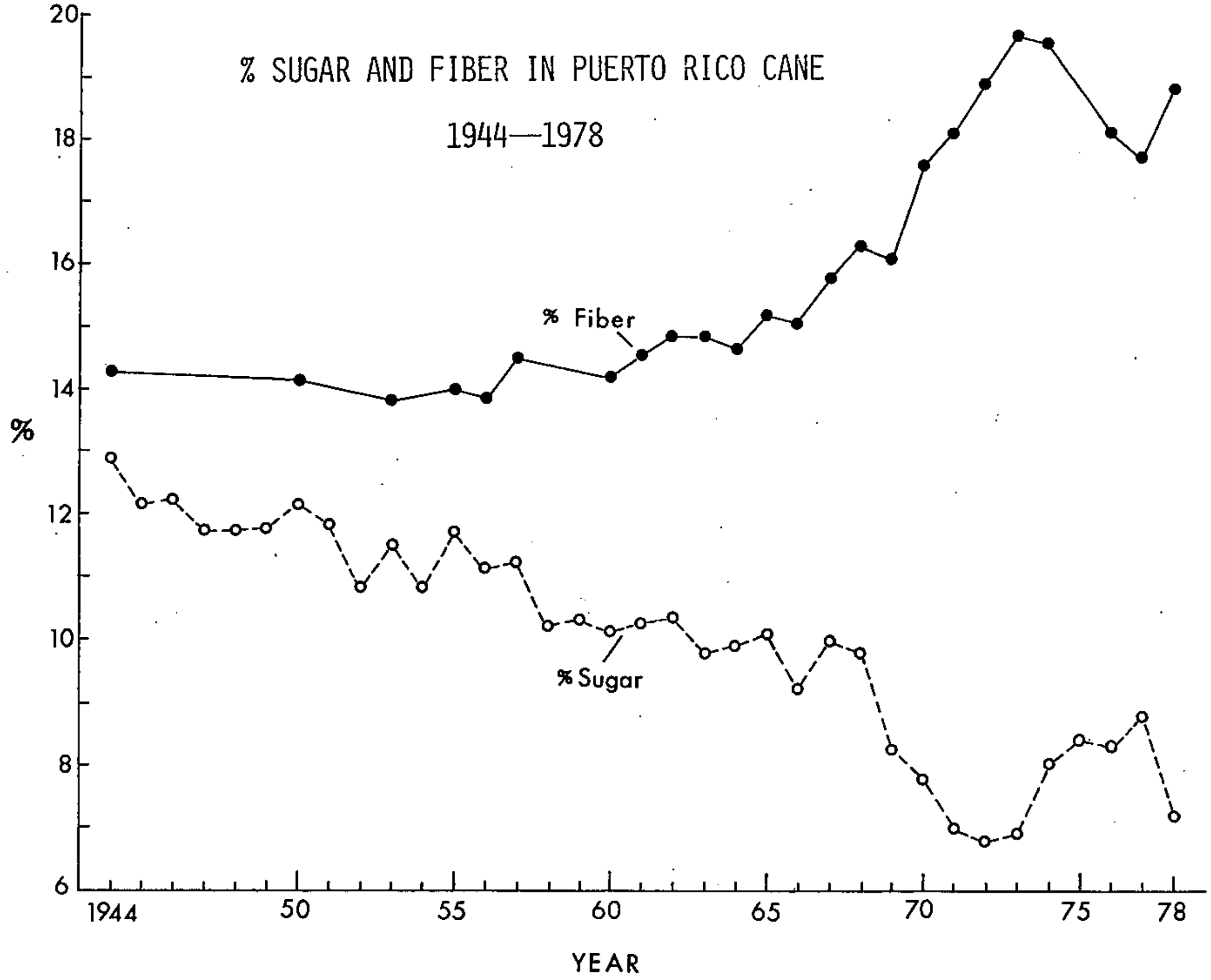
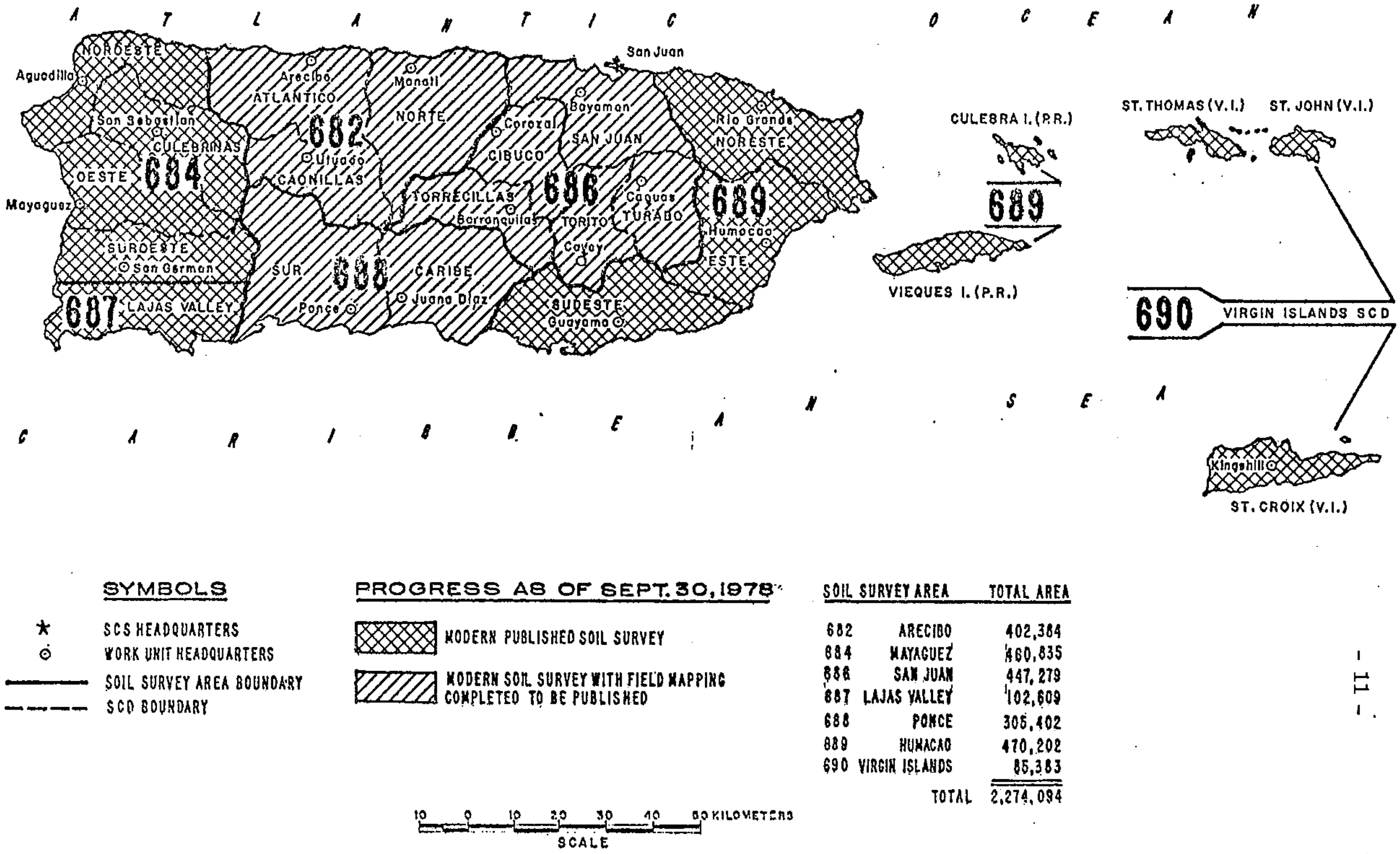


Fig. 1. Percent sugar yield and percent fiber in Puerto Rico sugar crops from 1944 to 1978.

Fig. 2. SOIL CONSERVATION DISTRICTS IN THE CARIBBEAN AREA
SHOWING SOIL SURVEY AREAS



SOIL SURVEY AREA		TOTAL AREA
682	ARECIBO	402,384
684	MAYAGUEZ	460,835
686	SAN JUAN	447,279
687	LAJAS VALLEY	102,609
688	PONCE	306,402
689	HUMACAO	470,202
690	VIRGIN ISLANDS	85,383
	TOTAL	2,274,094

Table 1. A comparison of Puerto Rico sugarcane yields for the high-sugar crop of 1950 and the low-sugar crop of 1978

	Yields for harvest season —	
Yield Parameter	1949-1950	1977-1978
Total acres	356,447	93,346
Total tons of cane 1/	10,615,000	2,835,435
Tons cane/acre	29.8	30.0
Total tons of sugar	1,286,000	211,175
Sugar Yield (%)	12.12	7.10
Fiber Content (%)	14.12	18.82

1/ Metric tons.

Table 2. Composition of Puerto Rico sugarcane for the high-sugar crop of 1950 and the low-sugar crop of 1978

	Total metric tons for —	
Component	1949-1950	1977-1978
Sugar	1,286,000	211,175
Fiber	1,498,838	516,050
Trash 1/	212,300	42,235
Total	2,997,138	769,460

	Metric tons/acre, for	
	1949-1950	1977-1978
Sugar	3.61	2.26
Fiber	4.21	5.53
Trash 1/	0.60	0.45
Total	8.41	8.29

1/ Assumes 20 percent by weight of cane.

Table 3. Sugarcane biomass yields, including roots, for variety M 336 propagated by sand culture with variable nitrogen supply

Treatment 1/ (lbs N/acre)	Mean yields (tons/acre) for —				
	Cane	Sucrose	Trash	Roots	% Sucrose
30	20.0	2.1	5.8	4.0	10.3
75	27.8	3.1	8.1	5.9	11.2
120	50.1	5.9	11.9	8.4	11.9
165	62.8	8.3	13.8	7.5	13.1
210	73.8	10.0	16.1	8.1	13.7
255	81.3	11.0	19.0	7.7	13.5
300	83.1	10.7	19.0	7.3	12.9
LSD, 0.01:	13.2	1.4	4.0	3.3	1.9
0.05:	9.6	1.0	2.9	2.4	1.4

1/ Each treatment received an equivalent of 135 lbs P_2O_5 and 195 lbs K_2O per acre. From Bonnet (1).

Table 4. Composition of mature, oven-dry leaves (trash) of sugarcane varieties POJ-2714 and SC 12-4 1/

	% Composition for —	
Chemical constituent	POJ-2714	SC 12-4
Ether-soluble fraction	2.34	1.85
Cold-water soluble OM	4.42	1.92
Hot-water soluble OM	2.17	1.56
Alcohol-soluble fraction	0.56	1.25
Hemicellulose	25.33	26.32
Cellulose	29.71	32.85
Lignin (N and ash free)	11.53	16.00
Water-insoluble protein	2.00	2.25
Total ash	12.79	6.30
Totals	90.85	90.30

1/ From Bonnet (2).

Table 5. Composition of sugarcane stem tissues [1]

	% Composition for tissue —		
Chemical constituent	Pith	Stalk	Rind
Ash	1.68	3.58	1.64
Fat and Wax	0.41	0.72	0.98
Cellulose	49.00	50.00	51.00
Pentosans	32.04	28.67	26.93
Lignin	14.03	15.03	17.17
Protein	1.94	2.00	2.10

[1] From Deerr (3), p. 15.

Table 6. Category characteristics of the New Taxonomy System for classifying Puerto Rico soils

Category	Number of Taxa	Characteristics
Order	9	Soil-forming processes as involved in the movement, addition or losses, transformation or translocation of mineral and organic materials in the soil horizons.
Suborder	22	Genetic homogenity. Subdivision of Orders according to presence or absence of properties associated with wetness, soil moisture regime, major parent material, and vegetational effects as indicated by the organic, fiber stage in Histosols.
Great Group	37	Subdivision of Suborders according to similar kind, arrangement, and degree of expression of horizons, with emphasis on upper sequum: Base status, soil temperature and moisture regime, presence or absence of diagnostic layers (plinthite, fragipan, duripan)
Subgroup	106	Central concept Taxa for Great Group and properties indicating intergradation to other Great Groups, Suborders, and Orders; extragradation to "not soil".
Family	54	Properties important for plant root growth, broad subtextural classes averaged over control section or solum; mineralogical classes for dominant mineralogy of solum; soil temperature classes based on mean annual soil temperature at 50 cm depth.
Series	164	Kind and arrangement of horizons; color, texture, structure, consistence, and reaction of horizons; chemical and mineralogical properties of the horizons.

Table 7. Percentage distribution of Puerto Rico soils, by Order, in the six Soil Survey Areas of Puerto Rico 1/

	Percent distribution for Area —					
Order	Lajas	Mayaguez	Humacao	Arecibo	San Juan	Ponce
Entisol	11.2	4.8	7.6	5.0	1.2	1.3
Inceptisol	27.8	27.3	47.0	15.6	50.8	56.2
Alfisol	5.0	3.1	5.6	7.6	3.2	0
Mollisol	8.0	6.7	3.7	16.6	2.8	22.9
Vertisol	24.7	0.3	2.0	0	0	5.3
Spodosol	0	0	0	0.6	0	0
Histosol	0	0	0	1.2	0	0
Oxisol	0	4.6	0	6.0	0.4	0
Ultisol	4.2	32.2	16.4	28.8	28.7	11.5
Totals	80.9	78.9	82.2	81.4	87.1	97.1
Other	19.1	21.1	17.8	18.6	12.9	2.9

1/ Areas occupied by:
Lajas----------------102,609 acres
Mayaguez-------------460,835 "
Humacao--------------470,202 "
Arecibo--------------402,384 "
San Juan-------------447,279 "
Ponce----------------305,402 "

Table 8. Percentage distribution of Puerto Rico soils, by Order and regional Survey Area, that are suitable for mechanized production of cane 1/

Order	Percent distribution for Area —					
	Lajas	Mayaguez	Humacao	Arecibo	San Juan	Ponce
Entisol	1.5	2.7	4.2	4.2	1.2	1.3
Inceptiso	13.3	4.4	9.4	1.2	3.6	6.1
Alfisol	1.5	0.5	3.6	1.8	1.7	0
Mollisol	5.0	2.9	3.7	4.5	2.0	10.8
Vertisol	24.7	0.3	2.0	0	0	5.3
Spodosol	0	0	0	0.6	0	0
Histosol	0	0	0	1.2	0	0
Oxisol	0	4.3	0	5.8	0.4	0
Ultisol	1.0	10.4	3.6	11.6	5.7	0.7
Totals	47.0	25.5	26.5	30.9	14.6	24.2

1/ Areas occupied by:

Area	Acres	
Lajas	102,609	acres
Mayaguez	460,835	"
Humacao	470,202	"
Arecibo	402,384	"
San Juan	447,279	"
Ponce	305,402	"

Table 9. Acreages of the Soil Series Coloso, Bajura, and Toa, classified in 1942 for five Puerto Rico Areas, and classified again in 1976

	1976 Acres, in Soil Series —			
Area	Coloso	Bajura	Toa	PR Total
Mayaguez	10,599	3,088	8,295	21,982
Humacao	10,031	5,423	5,417	20,871
Arecibo	5,911	3,165	6,180	15,256
Ponce	0	0	1,160	1,160
San Juan	2,640	4,148	4,983	11,771
1976 Totals	29,181	15,824	26,035	71,040
1942 Totals	34,912	6,720	40,640	82,272
Difference	-5,731	9,104	-14,605	-11,232

Table 10. Flooding frequency and duration, and water table fluctuations, in two Soil Series having severe drainage problems

Series	Flooding		W. T. Fluctuations		Permeability (in./hr.)
	Frequency (Yrs)	Duration (days)	(Depth (in)	Duration (days)	
Coloso	Once between land 5	2-7	15-30	2-6	0.63-2.00
Bajura	More than one	2-7	4-30	2-6	0.06-0.20

Table 11. Percentage distribution, by Order, of mechanized and non-mechanized soils of Puerto Rico 1/

Order	Mechanized	Non-Mechanized	Total
Entisol	2.8	1.7	4.5
Inceptisol	5.4	33.2	38.6
Alfisol	2.1	2.1	4.2
Mollisol	4.4	5.5	9.9
Vertisol	2.4	0	2.4
Spodosol	0.1	0	0.1
Histosol	0.2	0	0.2
Oxisol	1.9	0.2	2.1
Ultisol	5.1	18.1	23.2
Totals	24.4	60.8	85.2

1/ Calculated on the basis of 2,188,711 acres for all Puerto Rico

ECONOMIC CONSIDERATIONS IN FOOD AND ENERGY PLANTING

Presented To

A SYMPOSIUM ON ALTERNATE USES OF SUGARCANE FOR DEVELOPMENT IN PUERTO RICO

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ECONOMIC CONSIDERATIONS IN FOOD AND ENERGY PLANTING

Table of Contents

ECONOMIC CONSIDERATIONS IN FOOD AND ENERGY PLANTING

Hugh C. Thorne[1]

ABSTRACT

Microeconomic analysis determines feasibility prices and markets in a given economic environment. The environment itself is created by different economic, social, and political forces, some of which are not controlled by Puerto Rican society. Studying the effects of these variables and the response of the macroeconomic system at different points in time is a precondition to analyzing costs and benefits.

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ECONOMIC CONSIDERATIONS IN FOOD AND ENERGY PLANTING

INTRODUCTION

A GENERALLY accepted definition of economics is "the study of how people and societies end up choosing, with or without the use of money, to employ scarce productive resources that could have alternative uses, to produce various commodities and distribute them for consumption, now or in the future, among various persons and groups in society. Economics analyzes the costs and benefits of improving patterns of resource allocation" (22). Of the generally accepted forms of productive resources (land, labor, capital goods, and technical knowledge), the most severely limited is land, being the only constant, of which Puerto Rico has some 870,000 acres (29) of surface useful for high-density cultivation to support over three million people. This does not include some 850,000 acres of shallow soils and pastureland (16). Whatever the decision for the use of this land, either a total commitment to biomass for fuels (1), or a total commitment to biomass for reduction of food imports (29), or some intermediate configuration, there remains less than 0.60 acres per capita to accomplish a given mission.

How then shall we go about making this choice? An examination of the major relevant variables may help to signal the direction in which the decision may move.

EXTERNAL VARIABLES

Of the more important variables that are external to the Puerto Rican decision process, the rate of price inflation is probably the most unpredictable and far-reaching in its effects. Inflation—along with the demand for farm land in a hungry world—has helped double the price of U.S. farmland since 1972. These price increases eventually find their way through the economy to raise the consumer price index. Food prices rose 10% in 1978. Inflation is also of major concern to the OPEC countries, who have stated their intention of pegging the rate of increase of oil prices to the rate of increase of world prices, that is, to the inflation rate. American trade deficits and consequent devaluation of the dollar, 28% since December 1976 (27), induced OPEC members to raise prices in order to regain purchasing power for their ollar reserves. These continuing price increases may have two opposing effects on the Puerto Rican economy. The immediate effect is to raise the price of fuels, making biomass production increasingly attractive. On the other hand, the U.S. agricultural sector is heavily dependent on energy-related inputs such as pesticides, herbicides, and fertilizers, not to mention machinery and fuels. It is estimated that the production of a food kilocalory placed at the farm gate requires an equal energy input. But inputs for transportation, processing, packaging, storage, and distribution raise the energy expenditure to 6.5 kilocalories for each kilocalory of food that is eaten (23). The fact that 87% of the raise in food prices since 1973 has occurred after the food left the farm may support the previous statement (25). In 1977, for the first time, workers in the food processing plants, canneries and supermarkets got more (32%) of the retail food dollar than farmers did (31%).

It seems then that a unit increase in energy prices produces a multiple increase in food prices. Although U.S. food products are favored by lower unit costs, the sale of the mainland's agricultural products in Puerto Rico may eventually be curtailed by the "energy crisis" itself, especially when the additional cost of refrigerated shipping is considered. Table 1 shows the consumer price index for the three classes of commodity that concern us at present; food imported from the U.S., food produced locally, and fuels and electricity. Figure 1 indicates that U.S. imports have lost their price advantage on the retail market since the "oil crisis" of 1974. The consumer price of fuels and electricity does not reflect the actual cost to the economy because of various subsidizing measures.

Another important external variable is U.S. agricultural policy. Sweeping changes in Federal farm laws enacted since 1973 have forced farmers to adopt yet another skill; marketing. Farmers now sell their crops throughout the year according to price movements, rather than at harvest time as was traditional. This development helps to assure them a higher price for their produce, and raises the food price index. The Federal government has virtually removed itself from the food markets, forcing nearly all foodstuffs on to the private market. If market prices fall below government-set target prices, farmers receive cash payments from Washington. These target prices supposedly cover most, but not all, production costs. This development does not help younger, undercapitalized farmers who have over-borrowed and bought too soon, and are now being squeezed by inflation. These less efficient farmer-managers are being moved off the scene by the "invisible hand," making way for agribusiness, that is, large agricultural operations with better business linkages. These groups have the staying power to eventually assure that *all* production costs will be covered by target prices, producing slight rises in the costs to the consumer, and favoring the growth of food in Puerto Rico. On the other hand, U.S. farm product exports have tripled in the last six years years to almost \$27 billion, helping to offset the cost of imports and reduce the current trade deficit. Food is fast becoming a political instrument in this hungry world, and a farm policy that favors low food prices on the mainland would favor biomass in Puerto Rico.

Another aspect of U.S. farm policy is the quota system, designed to stabilize U.S. market prices of the various commodities affected. The result was a trade restriction on the traditional products where Puerto Rico had a comparative advantage. This quota system might be revived in the future to protect U.S. farmers competing in markets against Puerto Rican cash crops.

An interesting political variable is the movement towards a balanced budget in the U.S. Although supporters of proposition 13 seem to have lost some momentum at present, it might be revived next year. A balanced budget was also a campaign promise of President Carter. The prime purpose is to fight inflation by eliminating deficit spending by the Government, which itself would reduce Federally-sponsored welfare spending. Puerto Rico is heavily dependent on welfare measures and unilateral transfers; the total was \$2.5 billion in 1978 although the net was \$1.34 billion (18). Of this total, \$879 million was a result of the Food Stamp Program. These injections increase consumer purchasing power and help the sale of secondary products, some of which are non-basic foodstuffs. The final effect of a reduction or elimination of these programs is not clear as yet although prices could fall slightly (4). This would produce a slight shift towards biomass.

President Carter's energy plans favor decontrol of domestic oil prices by 1980, an inflationary move that will allow an increase of worldwide price levels. Eventhough temporarily postponed by the recent OPEC price increases, Treasury Secretary Michael Blumenthal indicates that decontrol may be inevitable because "the choice is between greater inflation now or a greater energy problem in the future" (25). Since there is no special contemplation of agriculture's energy needs in the recent Energy Act, one would expect the price increases to go through the food system and appear to be multiplied by a factor of six as indicated above. This may lean heavily toward food production in Puerto Rico.

Our final external variable might be the availability of chemical fertilizers at relatively low prices. Although price increases do multiply the cost to the consumer, availability should be our main concern. World fertilizer consumption has increased at a rate of 10.6% per year since the early 1960's. The 1967 consumption level was six times the 1945-47 level. Projections made in 1968 called for another sixfold increase in Asia, Africa and Latin America in order to maintain dietary levels for the 1980 population. Consumption of fertilizers in the U.S. farm system increased from 39.6 million tons in 1970 to 51.6 million tons in 1977 (28). Although the acreage treated showed a 19% increase between 1969 and 1977, the cost increase was 138.6% during the same period. Pimentel (14) has demonstrated the decreasing marginal returns of chemical fertilizers in American agriculture. Thus biomass supporters might soon be required to prove the feasibility of maintaining high yields with increasingly lower inputs of this finite resource. Food producers may eventually be required to support the population without the intensive use of chemical fertilizers. Other industrial sectors which use the same basic materials necessary to produce fertilizers—nitrogen, phosphorus and potash—will continue to compete in spite of future shortages of food.

INTERNAL VARIABLES

It is not generally understood that the most important variable in economic development is the model used to stimulate this very development. The model that has been used in Puerto Rico for over 25 years is based on relatively cheap local labor and the attraction of capital from already developed countries, primarily the United States. Within this model one must ascertain the role assigned to agriculture. Agriculture's traditional role in the development process has been as a supplier of labor for the industrial sector, as a supplier of primary goods to support a growing industrial population, as a major source of savings for investment in the industrial sector, and as a source of export goods to be exchanged for industrial raw materials. These roles require increased agricultural productivity, which in turn require inputs from other sectors, the production of which is a stimulus to the manufacturing sector (6). Moreover, the development process itself begins in agriculture. Postan and Habakkah, in *The Cambridge Economic History of Europe* indicate that "there is a considerable weight of evidence in support of the hypothesis that the process of economic development had gathered a formidable momentum in Britain before the industrial revolution took shape" (15).

The Chardón Plan of 1934 had previously undertaken to develop industries based on local resources. Emphasis was placed on production for domestic consumption and the use of local resources as inputs to industry (17). However, after the 1947 decision by PRIDCO to utilize tax incentives and government subsidies to attract private firms to Puerto Rico, agricultural and industrial development policy split--never to be effectively reunited. Incoming firms were allowed to maintain their previous market linkages and were not encouraged to develop new ones in Puerto Rico. In the absence of an agricultural land preservation policy, and with virtually no assistance in maintaining balanced growth alongside industry in the rapidly-changing environment of the industrialization years, agriculture began to stagnate. Today, more than ever, it is recognized that "industrialization and agricultural development are not valid alternatives. Effective development plans must embrace both goals" (9). In policy circles agriculture was treated more as a liability than as an asset during the growth years in Puerto Rico, and after 1947 the term economic development became synonymous with industrialization. One former policy maker recently stated that "agriculture has ceased to be an economical industry in Puerto Rico, which explains the quick reduction in its volume of activity during the last 20 years" (5). This seems to contradict the experience of other countries in various stages of development as summarized in Table 2.

A second-order consideration is the financing of agriculture and the relative importance attached to the two competing sectors; manufacturing and agriculture. In 1954 a study of the credit problems suffered by agriculture was commissioned by the Commonwealth Government which revealed that banks generally discriminated against agriculture (13). Although the Government

Development Bank was established in 1945, its express purpose was the creation of credit for the industrial sector. Thus the first government bank was biased toward industry (11). After the Perkins Report, the Agricultural Credit Corporation was created in 1960 to develop agricultural credit (12). Yet, two years later, a survey revealed that credit was still the major obstacle in agricultural development (8). Serious limitations still exist in the functions and instruments of the A.C.C. (2), but the Government does not perceive the general bias against agriculture as a development problem, although the Bank of America was allowed to start operations here in 1977 with the understanding that the volume of agricultural credit would increase on the Island. In short, agriculture in Puerto Rico has been stripped of virtually all its traditional roles by the development model that was adopted.

A second variable to be considered internally is the organizational efficiencies of the food and fuel marketing systems. Fuel marketing uses modern facilities and management techniques at the importer and wholesaler levels, and only propane marketing is relatively antiquated at the retail level. Food marketing is not so modern. Choudhury's research indicates that approximately 50% of food wholesalers use obsolete equipment and techniques (4). The handling of local produce is usually done by independent truckers who serve as wholesalers, retailers, and price analysts. These truckers tend to look at the Island as several local markets which regionally determine prices, rather than an integrated market with a stable price structure. Undoubtedly the present market structure favors the efficient handling of fuels rather than foods.

The availability of human resources in the quantities and of the quality that is necessary is an unknown factor. Migration patterns in Puerto Rico have virtually removed the more vigorous members of the rural population. In 1964-65, some six thousand Puerto Ricans emigrated (although the net total was only ten thousand). Sixty-nine percent were from the rural areas. Almost seventy percent of these emigrees were males between the ages of 14 and 24, and 63% came from poorly-educated families with incomes below $2,000 per year (7). The attractions of city life and the wage differential which favors industry make it difficult to attract the labor needed in the agricultural sector. This favors machine-oriented agriculture such as a biomass system would be. An additional concern is the attraction of high quality managerial personnel. At present agriculture does not attract many M.B.A.s, or industrial engineers, the equipment is not state-of-the-art, the salaries are unattractive, and the job is low-profile, i.e., not in the public eye or high on the prestige scale. If biomass does not presently attract large numbers of the high-calibre personnel just described, the food system virtually rejected them until recently. The scale of operations of most farms does not permit employment of these persons. The general financing schemes usually reject farmers who are not "Bonafide," i.e., those having previous experience and willing to live on the farm, or at least to derive the greater part of their income from the enterprise. Management consulting for the agricultural sector is virtually unheard of.

The financial capability of the Island's economy is another consideration. Whichever decision is adopted, there will be a large requirement for capital to invest in field machinery, a requirement that will be worth several millions of dollars. A recent estimate places additional distilling capacity for production of ethanol, in an amount necessary to displace 20% of the volume of gasoline consumed on the Island in 1977, at nine times existing capacity (3). This investment alone, to displace 5.0% of total energy consumption (20), would severely tax the financial structure of the economy.

Table 3 illustrates the maximum allowable debt margin under present law, the percentage used, and the dollar value of the free margin. The largest free margin was $43 million in 1976. At this rate it might take 24 years to complete a billion dollar investment. This restriction could be very severe, considering that public debt was generally used to create physical infrastructure, and thus provide jobs during slow periods in the business cycle. This task is being carried on with Federal money such as the present EDA/Local Public Works Program, worth over $300 million. In 1961 it was pointed out that the European Common Market and the European Free Trade Association would compete against Puerto Rico for American money (28). We would later add Taiwan, South Korea, Singapore and others to the list of small countries offering the same advantages we do, but with cheaper labor. It is unlikely that agriculture would be given priority for scarce public money under the present model conceptualization. The possibility of turning a biomass system over to the private sector for financing and operating might be unpalatable in a political sense. The raising of property taxes to increase loan margin is even more unsavory to politicians. This limitation in available capital could help push the decision towards food, as there are several local and Federal programs available for small individual farmers.

The present method of taxation on agricultural land is recognized as a contraint to development of the sector (29). The government does not penalize speculators who would deny the use of productive land in order to achieve a capital gain.

An interesting variable is the behaviour of the Puerto Rican economy during the next decade. Although the economy responded after previous recessions with a vigorous growth, the response to the 1975 recession exhibits structural difficulties which could have very serious consequences in the short run. The economy is still relatively stagnant in real terms. Personal Consumption Expenditure is larger than Gross National Product (Table 4), but real merchandise exports are at 1974 levels, so the economy is sustained by transfer payments which have averaged 28% of the GNP since 1976 (Table 5). Although there are savings generated in the private sector, economic policies have historically favored the financing of consumption rather than of capitalization. This helps to keep workers unemployed or on the government's payrolls. Since 1973 there have been more workers in public administration than in manufacturing. This makes for a precariously balanced economy that has little reserve capacity to deal with the business cycle. A preference for investment in construction (18) rather than manufacturing may explain the continuously high unemployment rates in Puerto Rico, officially fluctuating between 11% and 24%.

OBJECTIVE FUNCTIONS FOR AGRICULTURE

The existence of a clearly stated objective for each sector of the economy is a precondition to integrated, balanced development. The set of objectives for agriculture has not varied much in the last 20 years. The first Development Plan produced by the Planning Board declared four basic objectives for the sector (19):

1. Stabilization of production in traditional industries, that is, sugarcane, coffee and tobacco, at levels compatible with a modern Puerto Rico.
2. Stimulation of local production of food, especially livestock and fruit.
3. Diversification of agriculture, with emphasis on existing enterprises or new ones with development possibilities.
4. Improvement of the quality of life in rural areas.

To date, the objective that has varied most is the one dealing with diversification of production. Yet to deal with the present conditions that surround agriculture there are several additional objectives which should be analyzed:

1. The stabilization of food prices should be complementary to our present development model. A requirement for the availability of cheap labor is relatively cheap food. Whether we care to recognize it or not, imports of primary goods from the Dominican Republic at lower prices than are locall available have helped produce this effect on food prices.
2. Stabilization of prices for certain energy forms might be just as productive, as industrialization has made us heavily dependent on imported fuels. A relatively stable price for some fuels or feedstocks might assure the continued viability of certain energy-intensive industries in Puerto Rico.
3. The maximization of employment on a regional level would help reduce migration to our overburdened cities. If coupled with a decentralization of industry, this should help remove the "north-south" phenomenon from our growth pattern.
4. It is also possible to attempt maximization of domestic or national income by trading high-valued cash crops on foreign markets.
5. The minimization of food imports or energy imports in dollar terms might be worth evaluating. A reduction in our balance deficit coupled with increased circulation of money in the economy could strengthen our ability to finance capital expenditures which would help the sector grow, as well as to increase our debt margin, a development which would increase our capacity to deal with crises.
6. The production and stockpiling of strategic reserves of food and fuels would deal with emergencies arising from isolation due to acts of man or nature. Present estimates of food inventory levels vary between 28 days (17) and 75 days (4). Even if the seed and land were immediately available, it is doubtful that one could organize for production and distribution on such short notice. A physiological constraint would be the average of 60 days that vegetables take to mature (10). Present organization does not assure a democratic distribution of these existing inventories.
7. The production of raw materials for vertical integration of the agricultural and industrial sectors might be another function, which was clearly defined and well understood by the 1934 Chardón Plan.

8. A possible objective sub-function would be the minimization of the use of chemical fertilizers and pesticides, in view of the unclear future of our ecosystem should these types of inputs continue to grow. The fact is that under present agricultural technology our attempts to reduce our dependence on generally recognizable energy forms such as fuel and electricity might be done at the expense of another type of dependence; chemical fertilizers, herbicides, and pesticides.

9. Another second-order consideration could be the minimization of capital inputs which would deal more directly with our capital generating constraint and debt margin. The maximization of the use of unskilled labor is also an objective sub-function to be considered, as it is well understood that training of this labor for some specific task in the agricultural sector may be simpler and more efficient than attempting to employ them in industrial endeavors.

The flexibility to absorb labor displaced by movements during the business cycle might be worth considering.

In order to evaluate this series of objectives it will be necessary to produce coefficients relating each objective to the different variables involved in the economic structure. Micro-economic analyses will consider wage rates, capital requirements, interest rates, land productivity, prices of food and/or fuels produced, and the costs, both present and future, of the various system inputs.

LONG TERM CONSIDERATIONS

Our objective functions consider the present levels of variables directly related to agriculture. Nevertheless, it is best to take a look down the road to help create scenarios of the situation ten or twenty years from now.

The development of cost effective electronic communications as a substitute for physical movement, and the patterns of immediate adoption by the Puerto Rican social system, may help reduce the need for fuels for personal transportation. This will reduce the relative value of immediate investment in a biomass system. Coupling this with a definite and explicit transportation policy which may tend to reduce the relative use of private vehicles will make support of a biomass system more difficult.

The trend of industrial policy in developing countries may be turning to the less energy-intensive enterprises. If the objective of industry continues to be maximization of employment, then our real concern is to increase value added. Some of the industries that increase value added while paying medium-level wages include optics, camera assembly, and electronics.

Another long-term consideration may be the changes in the generally accepted economic models of development. For two centuries economics has predicted continued growth as a measure of well-being. Yet continued growth is not possible with finite resources. Eventually, saturation will be reached and a steady-state will come into being. Under present economic terms steady-state is synonymous with *stagnation*. Yet the most powerful force in our environment, nature's ecosystem, thrives on and veritably demands steady-state conditions. Should economic models in the future favor more static conditions we would have to recognize the implicit demand for a more equitable distribution of income, an emotionally charged consideration which fosters with political uncertainty. One would have to examine which of the two proposed land-use systems, or which intermediate configuration, would provide fundamental stability to a social system in a steady-state economy.

A final consideration is reversibility, the opportunity cost in future options denied by today's decision. The Puerto Rico Land Authority, parent company to the Puerto Rico Sugar Corporation, presently manages 90,000 of the 870,000 acres of choice land. This 10.3 percent of the land might follow two distinct pathways over the next 10 to 15 years. One might be the massive production of food, which would mean the administrative fragmentation of the land into more manageable plots. This would be necessary since the government dares not to compete with private food growers in our present economic system. Should this fragmentation occur it will be virtually impossible to reassemble the land into the large tracts of a size necessary to support a biomass and refining system. That is to say that the adoption of food in the immediate future as a solution to our major problems would virtually preclude the eventual institution of a biomass system. On the other hand, the adoption of biomass in the near-term future presents a different type of problem. Although it would virtually guarantee retention of control of the land by the Land Authority, and therefore not close out the options of future fragmentation of the land for food production, there is a seemingly more concrete consideration to be taken into account. The institution of a biomass system will require an enormous investment in capital and in human resources. Once established, it would be a requirement to protect this system against future encroachment from food-producing units. This would virtually force future governments to ignore relative increases in food prices and reduction in per capita production volumes, which in itself may be the most pressing problem in a world with little grain reserves. The point is that the so called "energy crisis" is a crisis in two dimensions; the production of vegetable matter for human consumption and the production of vegetable matter for the operation of machinery. With the limited resources available to us we must be prepared to be "flexible" in the use of land allowing for changing proportions of this resource for the different projects. Rigid boundaries in the use of human resources and capital which do not allow for quick readjustment to a changing world situation may be our most potent institutional barrier.

CONCLUSIONS

Though we will not attempt to suggest a decision for the land-use problem, we do hasten to point out the most salient bits of information that at present are not available. First, the economic development model to be applied in Puerto Rico needs to be reconsidered, redefined and adopted in an integral fashion throughout all sectors of the economy. This in itself will mean a clear definition of objective functions for the agricultural sector, prioritized according to the perceptions of our development policies.

The second step would be the investment of our time and money in the generation of the applicable coefficients relating our objectives to our resources and to market variables. A final step would be the specification of institutional relationships: Can the objective best be reached through government or through the individual? What kind of training is needed for our human resources? Can an agency designed to maximize food production learn to optimize fuel production?

In the absence of this information we will attempt to create "maximum likelihood (most probable) scenarios" for mid-term and long-term conditions in Puerto Rico. The mid-term conditions reflect what could be the response of the present structure to the coming recession. Essentially we are considering a period of time dedicated to restructuring the model and its policies to capture more of the locally-generated savings and to deal with increasing price differentials between our products and those of other regions, both inside and outside of the U.S. Long-term conditions reflect a more stable structure depending less on outside investment for capital, and with a greater proportion of available funds dedicated to agriculture. These funds might be redirected from the construction sector. There is also the possibility of increasing exports to nearby regions in the Caribbean and Central America by taking advantage of existing infrastructure and technical knowledge in Puerto Rico.

In the words of Waren Bennis, past President of the University of Cincinnatti, from his short paper "A Bright Future for Complexity" (Technology Review-February, 1979): "The problems of our world are too complex for any one person to get his head around, for any organization or institution to absorb let alone deal with. The fact is there are too many predicaments, too many grievances, too many institutions under attack; and too few institutions trying to understand them. There are too many ironies, polarities, dichotomies, dualities, ambivalences, paradoxes, contradictions, confusions, contraries, complexities, and headaches. Especially headaches."

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Table 1. Consumer Price Indices for Selected Goods, 1967=100 1/

Year	Imported Foods	Local Foods	Fuels and Electricity	Food Consumed in U.S.A.
1971	113	117.0	102.6	118.4
1972	117.8	123.8	110.5	123.5
1973	124.3	127.0	110.9	
1974	167.8	151.0	134.1	161.7
1975	197.6	183.8	121.1	175.4
1976	206.4	187.0	122.5	180.8
1977	201.1	193.5	125.7	192.2
1978	221.4	200.6	128.2	209.3

1/ Sources: United States Statistical Yearbook, and Puerto Rico Department of Agriculture

Table 2. Index Numbers of Agricultural Production (Food), 1961/65 - 100 1/

United Kigdom	114	118
West Germany	116	118
Denmark	93	97
Netherlands	137	159
Japan	121	130
South Korea	133	163
U.S.A.	114	141
Israel	143	199
Developed Market Economies	115	135
Developing Market Economic	124	145
Puerto Rico	83	83

1/ Sources: United Nations Statistical Yearbook, and Puerto Rico Department of Agriculture

Table 3. Use of Loan Margin [1]

Year	Percent Used	Available Margin ($ mill)
1970	64.07	25.4
1971	65.22	27.9
1972	66.91	30.5
1973	64.89	37.3
1974	68.32	37.7
1975	75.15	31.7
1976	68.84	43.4
1977	82.05	28.5
1978	83.28	32.7

[1] Source: Puerto Rico Planning Board, Economic Report to the Governor.

Table 4. U.S. Gross National Product, Puerto Rico Gross National Product, and Puerto Rico Personal Consumption Expenditures [1/]

	1972	1973	1974	1975	1976	1977	1978
U.S. GNP current ($bill)	1171	1307	1413	1529	1707	1890	
Yearly percent change	9.2	11.6	8.1	8.2	11.6	10.7	
P.R. GNP current ($bill)	5.73	6.27	6.79	7.14	7.51	8.09	8.94
Yearly percent change	9.1	9.42	8.29	5.15	5.18	7.7	10.5
Personal Consumption Expenditure current ($bill)	4.74	5.22	5.69	6.39	7.36	8.17	9.01

[1/] Sources: U.S. Department of Commerce, 1978 Statistical Yearbook, and P.R. Planning Board, 1978 Economic Report to the Governor.

Table 5. Exports, Personal Consumption, Personal Savings, and Transfer Payments 1/

Year	1970	1971	1972	1973	1974	1975	1976	1977	1978
Merchandise Exports $1954(mill)	1180.6	1198.1	1266.2	1506.0	1554.9	1250.7	1239.4	1561.7	1561.1
Personal Consumption Expenditure $1954(mill)	2648.8	2918.7	3120.1	3317.2	3247.2	3198.2	3428.0	3671.7	3879.7
Personal Savings $1954(mill)	-127.8	-192.4	-175.2	-115.9	-71.7	28.0	-82.7	-254.0	-224.9
Transfer Payments to Persons $1954(mill)	404.7	460.7	515.8	567.9	524.9	789.1	1006.1	1035.8	1083.4
Transfer Payment as Percent of GNP $current	12.2	12.9	13.7	14.3	15.0	22.1	28.8	28.5	28.2

1/ Source: Puerto Rico Planning Board, 1978 Economic Report to the Governor.

THE TILBY CANE SEPARATION SYSTEM

Presented To

A SYMPOSIUM ON ALTERNATE USES OF SUGARCANE FOR DEVELOPMENT IN PUERTO RICO

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Contributed By

Ander-Cane Inc., 1310 Cabio Court, Naples, Florida 33942

THE TILBY CANE SEPARATION SYSTEM

Table of Contents

THE TILBY CANE SEPARATION SYSTEM

Richard A. Andersen[1]
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ABSTRACT

The Tilby Cane Separation System represents major new innovations in the recovery of fermentable solids from sugarcane, and in the separation of pith, rind, and wax components of the sugarcane stalk, traditionally, these have been milled together and recovered together in the bagasse by-product. A complete description of the System is presented together with the historical background of its development. Research accomplished on the System to date in Florida is presented and ongoing activities in product development are discussed. An outline of future plans and programs for the Tilby System is also presented.

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THE TILBY CANE SEPARATION SYSTEM

INTRODUCTION

MUCH has been written and presented about the value of sugarcane as a source for fuel, alcohol, re-constituted wood products, paper, cattle feed, and many other uses other than for edible sugar. Yes, edible sugar is an important component of the sugarcane plant but as we all know the economics of today in the production of this product as a profitable enterprise are fast diminishing. Many studies and improvements have been made over the years in the varieties, planting, growing, harvesting, milling, and refining of cane to try and improve the profit margins. Up to this time only limited progress has been made.

A new innovation, and this has been declared as the "most consequential innovation in many decades," has been developed and that is the Tilby Cane Separation System.

Those who have studied the many problems of the industry have said that if we could separate the fractions and develop these fractions to the fullest potential and reduce the inherent costs in the present methods, we might be able to turn the economics around to where the cane industry is profitable. E.S. (Ted) Tilby and R.B. Miller recognized the need to divide the cane stalk into its fractions and set out to try and accomplish this task.

In this connection I wish to present to you the following topics:

(a) The Tilby System and how it works
(b) A brief history of how the system evolved
(c) What has been done in Florida
(d) Product development activity to date
(e) Future plans and programs

THE TILBY SYSTEM AND HOW IT WORKS

Basically, the separator receives the cane billet at high speed and drives it lengthwise over a knife blade which separates the billet into two halves. Each half is then passed over rotary blades that scrape the pth from the rind. The rind continues through another set of blades that scrapes the epidermis from the outer portion of the rind. The rind then passes thru a set of slitters that cuts it into sticks or slivers about 1/8 inch wide.

This is a very brief description of the separation process but there is more to the system in order to make it successful. Let's start at the beginning, in the field.

It is important that the cane be in billets so a harvesting machine is used that will produce a billet from 10 to 14 inches long. If the cane is hand cut, the pick-up harvester used can have its cutters set to produce the correct length of billet.

At the separator site the cane is dumped so it can be moved to a leveling conveyor to provide a uniform flow of billets through the cleaning system. It is also important that the cane be as clean as possible relative to trash, tops, rocks, and stubble. This is for reasons of contamination and use of energy that is lost in processing materials that are non-essential. The removal of leaves and tops in our operation is done by a spiral-roll type machine. This is followed by an inspection station where rocks, stubble, and foreign objects are removed. The cane then moves to a bin that meters the flow of billets to the surge conveyor. The metering conveyor is designed so that only the desired amount of billets is allowed to pass. Volume is controlled by the speed of the conveyor.

The billets then move to a surge conveyor that levels the cane and delivers it to the feed conveyor. This travels at a high rate of speed and aligns the cane while on its path to the separator. The billet must be oriented lengthwise in order to pass over the knife blade in the proper direction. After the cane passes through the separator the pith, fiber, and epidermis are conveyed away to where these fractions are further processed.

HISTORY OF THE SYSTEM

In 1964 Ted Tilby, a Canadian architect, and his friend R.B. Miller, a Canadian building contractor, while on a trip to the Caribbean visited a sugar mill and were impressed with the cane fibers they found in bagasse. They reasoned that this was a great potential for fibers but felt strongly that the present method of processing cane was wrong and that a separation process was necessary to get the three main components, pith, rind, and epidermis separated. They visualized the pith, which contains the juice, going to the mill for extraction and the resultant pith being used for other purposes. They felt the rind fiber portion could then be processed and used for wallboard, or pulp for paper, while the epidermis would be processed to recover the wax. Again, they reasoned that if an efficient and economic process could be developed then the method of utilizing the three components would easily fall into place and they could potentially revolutionize the existing methods of processing sugarcane.

Tilby and Miller then formed a Canadian research and development company to get their project started. They soon found the company was going to require more financial support than what they had so they brought in other Canadian businessmen. They also persuaded the Canadian Government, through one of their aid programs, to financially help support the project. They also made arrangements with a London firm to participate. They owned a sugar mill at St. Kitts in the Caribbean and here they would install their equipment and do their testing.

A prototype was built and installed and over the next five years, up to 1969, several million dollars were spent to try to perfect the separator system. They were not able to run on a sustained basis and concluded that much more development was necessary. Two more years went by and after more evaluation it was decided to obtain more assistance from the Canadian Government and to build a new machine to be installed at the Uplands Sugar Mill in Barbados. By now it was also very apparent that the cane must be clean and properly prepared prior to entering the system

In 1974 the new system was ready and for the next two years some progress was made. After the grinding season of 1975 the Canadian Government approached the Arvid Machine Company of Windsor, Canada, who later formed Intercane, Inc., to take over the separator and perfect it mechanically. Arvid studied all of the work that had been done at St. Kitts and Barbados and succeeded in making improvements for the 1976 season. This effort was successful and by the end of the 1977 season the separator was perfected and the problems of handling the components was to be the next major effort.

DEVELOPMENTS IN FLORIDA

In 1977, Ander-Cane, Inc. was formed in Florida and this was the first real entry into the entire project by a U.S. company. Some U.S. firms had heard of the Tilby process and some U.S. consulting firms had been asked to evaluate the system and make tests but nothing tangible had been done toward setting up a production operation.

In December of 1977, Ander-Cane received the first C-10 separator and related metering and feeding equipment for installation in Florida. A joint venture was developed with the Seminole Sugar Company who were cane growers and also owned a large cattle feeding operation. The program was to provide cane for the separation process, feed the pith containing juice to the cattle, and the fiber would be processed into re-constituted wood products. In 1978 a joint venture was entered into with U.S. Sugar Corporation for essentially the same purpose, except more emphasis was to be applied to removing the juice from the pith and developing a better cleaning system for the cane. These ventures resulted in the establishment of the pilot operation that Ander-Cane felt was necessary to display the Tilby system and further prove its economic value.

There were six objectives of the pilot operation. These are briefly described in the following text:

Objective 1:

To further prove the C-10 separator on a sustained production basis. The C-10 rated at 15 tons/hr was a new machine with many improvements over earlier models and it was necessary to have proven field tests. As pointed out in the history of the Caribbean tests, the many problems revolved around the inability to run on a sustained basis.

Results: The work done at Seminole Sugar in 1977-78 was very gratifying and much shake-down work was accomplished. The separator performed very well for long periods but we did have to shut down periodically because trash from dirty cane would clog the slitters. Because of the construction of the machine it was easy to clean and get back in operation.

All phases and components of the C-10 stood up under many tests for endurance and reliability. At the end of the season a complete inspection was made and no wear was detected except the dull edge on the knife blades.

Objective 2:

To further prove the metering and feeding system since they had been revised considerably from the earlier mill operations.

Results: The metering conveyor does an excellent job. We are able to adjust the rate of flow of billets to the surge and feed conveyors in quantities from 10 tons to over 20 tons per hour. The feed conveyor runs at high speed and the design of the belt system proved very effective in delivering the billets in the proper orientation. At the end of the season the belts and other components again showed almost no wear.

Objective 3:

Improve the methods and system for detrashing cane in the field and at the separator site.

Results: The experience of the 1977-78 season with Seminole Sugar further emphasized the need to have cane free of trash. The U.S. Sugar Company had done extensive research and had many years of experience in the field of cane cleaning. New field harvesting equipment was used this season and we were able to obtain cane from that operation. It proved to be the cleanest we had ever seen. Cleaning was still necessary at the separator site to remove leaves, tops, stubble, and foreign matter.

This cleaning is done by passing the billets over two sets of spiral rolls where the leaves and tops are removed. Rocks and stubble are removed by hand inspection along one of the conveyors. This method is used since the pilot operation is relatively small and we encounter very little of this kind of trash. The cane processed this season was very clean and this solved many of the problems of the previous year. Florida cane does not contain as much soil as in other states so no washing is necessary.

Objective 4:

Use of a screw press or other techniques to remove juice from the pith.

Results: In 1977-78 the pith, containing juice, was fed to cattle at the feed lot. No planned study took place because of the short time we were in production. A six month period with a balanced ration program is necessary to obtain measurable results. During this season we wanted to exercise several options: (a), Send the pith directly to the mill to recover the juice or (b), perform a juice separation at the separator and pump the juice to the mill. We decided on the latter approach and also wanted to extract the juice as soon as possible after the separation to determine the quality and quantity in the pith. We ran some preliminary tests at Louisiana State University using their French Screw Press and the results were good enough so that we moved the press to the pilot operation. This is a relatively small machine but we were able to prove that this technique is very feasible and the results were excellent. We thought, because the pith does not contain the course rind fiber, that the machine would just compress the cellular pith and no extraction would take place. This proved to be not true.

The pith that was delivered after the pressing was very dry and the juice was free of contamination as compared to the old grinding method. It is felt that with these results the juice can be pumped directly to the clarifier and the pith used for some economically-viable product with little additional processing. Another juice extractor is being developed by Intercane, Inc., using a different principle and we are optimistic it will do an excellent job as a result of early tests.

Objective 5:

Develop techniques and equipment for processing the fiber for product development.

Results: Tests indicate that there is about 19% fiber in the cane stalk and of this some 8% sugar is present. For the manufacture of re-constituted wood products it is important to have only 5% or less sugar in the fiber. This should be removed as soon as possible in order to prevent any fermentation. One method we are testing is the difussion process and this is being done in a Tilby designed machine originally made for juice extraction from the pith. The results to date have been very good and this will provide a clean, dry, low-sugar fiber. A tank-type washing system can be used but this requires much water that must be removed before drying. We know that clean fiber, when bales, can be stored for an extended period of time.

Objective 6:

Evaluate operating and maintenance costs.

Results: 150 hp is required to run this 15 ton per hr system and this is distributed between 15 motors rated from 2 hp to 25 hp. The system is controlled through two large electrical panels located for easy access and operation. Power requirements can be calculated on the basis of the utility rates of the area. Maintenance costs have been so low they are almost negligible. This is because of the excellent design and high quality of the equipment. The total results to date of the pilot operation in Florida has been up to expectations. Many problems have been solved and new ones will appear but we feel these can be solved with continued effort.

PRODUCT ACTIVITY TO DATE

As previously pointed out in many studies and reports, the value of the individual fractions is enhanced when applied to the products that can be produced. Re-constituted wood products, high quality papers, cattle feed, alcohol, chemical absorbants, and a host of other items have been produced and the results to date have been excellent. I will not attempt here to cover all of these efforts because each in itself would be a complete presentation. I will review some of the results we have had during the past year in association with others who are vitally interested in this program.

Re-constituted wood products was one prime effort. In conjunction with Intercane, Inc., and Helmut G. Moeltner & Associates Ltd., some very interesting products and results were realized. Several tons of fibers generated by the pilot operation during the 1977-78 season were shipped to Windsor, Canada, for processing and then sent to Waferboard Corp. Ltd. at Timmins, Canada, for manufacture into board products.

The initial objective was to develop specifications for manufacture of composition boards using rind fibers. This would result in products conforming with C.S.A. Standard 0188-1975, and TECO CS 236-66 standards for Mat-Formed, wood-based particle board. Work was also done in producing dimensional composition lumber (studs) to be used as a substitute for wood-based dimentional lumbers. The standards applied to the physical properties as related to structural requirements would be in Density (lbs/cu ft), Modulus of Rupture (MOR-psi), Modulus of Elasticity (MOE-psi), Internal Bond (B-psi), and Linear Expansion (LE-%). These standards vary as they apply to the type of board produced, such as Waferboard and Particleboard. The physical properties of a structural composition board must meet or exceed the specifications of established standards in order to find market acceptance.

Early laboratory tests with many composits using the rind fiber were so encouraging that it was decided to arrange for a production run by an existing commercially-established particleboard and waterboard plant. The cane fibers sent to Intercane were used in this production run and supervised by the H.G. Moeltner & Associate engineers. The results were promising but the products did not meet the required structural standards nor were they as good as the laboratory samples. A complete study revealed the cane that was harvested at that time and the fibers used was from old cane that had been standing from the previous year. Also the cane fibers had not been washed as soon as possible after the separation process. Resultant sugars allowed for fermentation and this destroyed some of the needed properties to meet the standards. Another run was made using fresh cane, the fibers were washed thoroughly, dried, and then sent to the board plant for processing. The results of this effort produced excellent material and the boards equalled or exceeded the required standards. Testing is still continuing on this material for life-test data.

The resultant effort of the project has indicated that sugarcane fibers produce an excellent product, provided the proper systems for production, separation, processing, and fabrication are all in place and each being properly executed to obtain a high-quality board product that will command premium prices for profitability.

The manufacture of paper from bagasse has been done for many years but the process to get the needed fibers separated from the pith is costly, particularly now when fuel costs are increasing. Fibers have been supplied to mills for research and testing but the results are not complete at this time so I cannot cover the subject in detail. Based on the problems of bagasse processing it is felt that the end results of the testing will be satisfactory.

Cane fiber and pith are being used for research in the advancement of the DOE Biomass energy program. We have sent material to Universities such as Purdue, M.I.T., Rutgers, California-Berkley, L.S.U., as well as overseas. This subject is being presented by others and in great depth. The Tilby Separation Process is a very real and active ingredient in the energy program and development is a continuing effort.

Pith has been used in the past as an absorbent in products such as pharmaceuticals, explosives, and industrial processes, but again the removal of the pith from the bagasse was expensive and some of these uses have been discontinued. With the Tilby process producing a clean pith we are re-opening some of these areas of use and are optimistic about the future, particularly in pharmaceuticals.

An additional use of fibers has come to our attention and this is in the area of fillers for paint, asphalt, plastics, and cement. Tests are being conducted now and here again we are very optimistic about the market area for this use of cane fibers.

FUTURE PLANS AND PROGRAMS

We believe the production technology for separating sugarcane components has been proven to be reliable and economically feasible on a small scale. Future planning will focus on evaluating the difficulties which might be encountered if the level of operation were greatly increased. Feasibility studies are underway for the construction and operation of manufacturing facilities for energy-producing materials. Plans and engineering are complete for the construction of a fiberboard plant using cane fibers instead of wood fibers. As mentioned before, new products are being developed using cane fibers and pith and we expect to support this activity to the fullest.

In summary, the Tilby Separator System provides a major new technology for processing sugar crops. It makes possible more products and higher quality products from sugar crops than can be obtained from present technology. It also provides for a reduction in energy requirements, capital investment, and processing costs per ton of material handled. However, before reasonably precise values can be estimated regarding these varied benefits, more production experience is required. We feel strongly the Tilby System is proving that the words of a Canadian newsman are true: "This is one of the most important and consequential innovations in many years."

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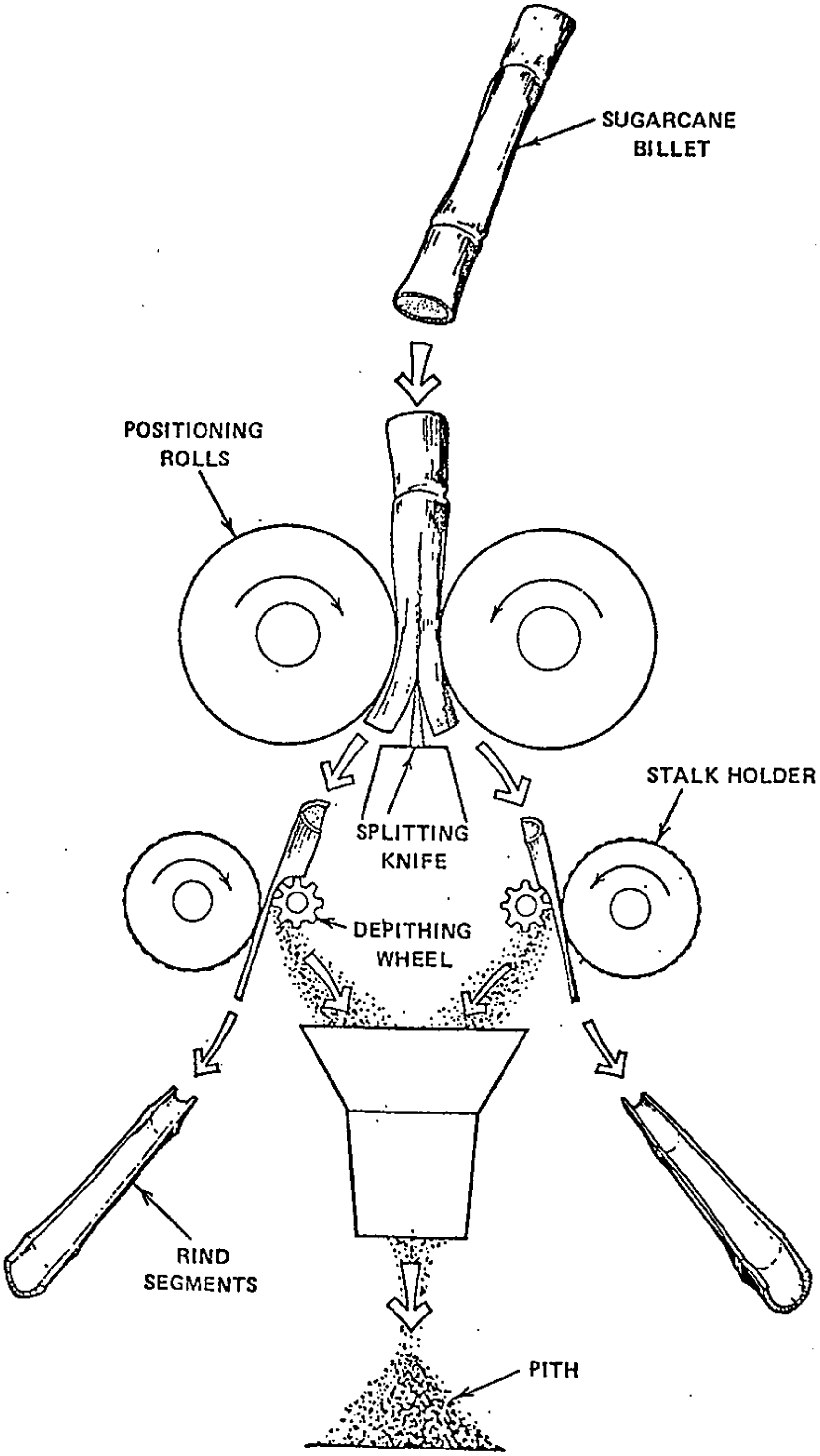
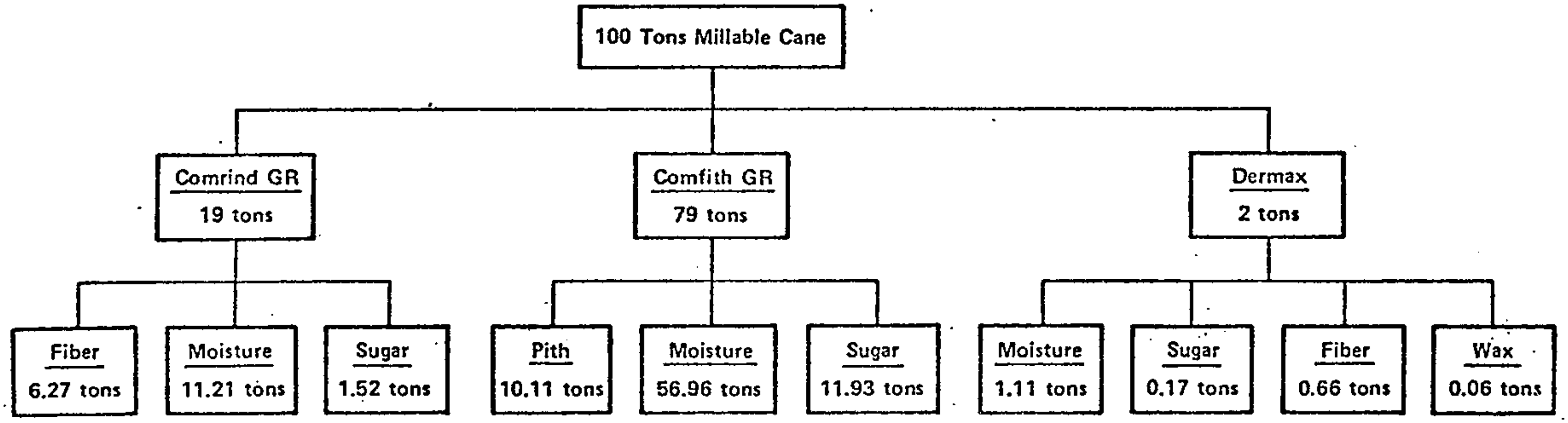
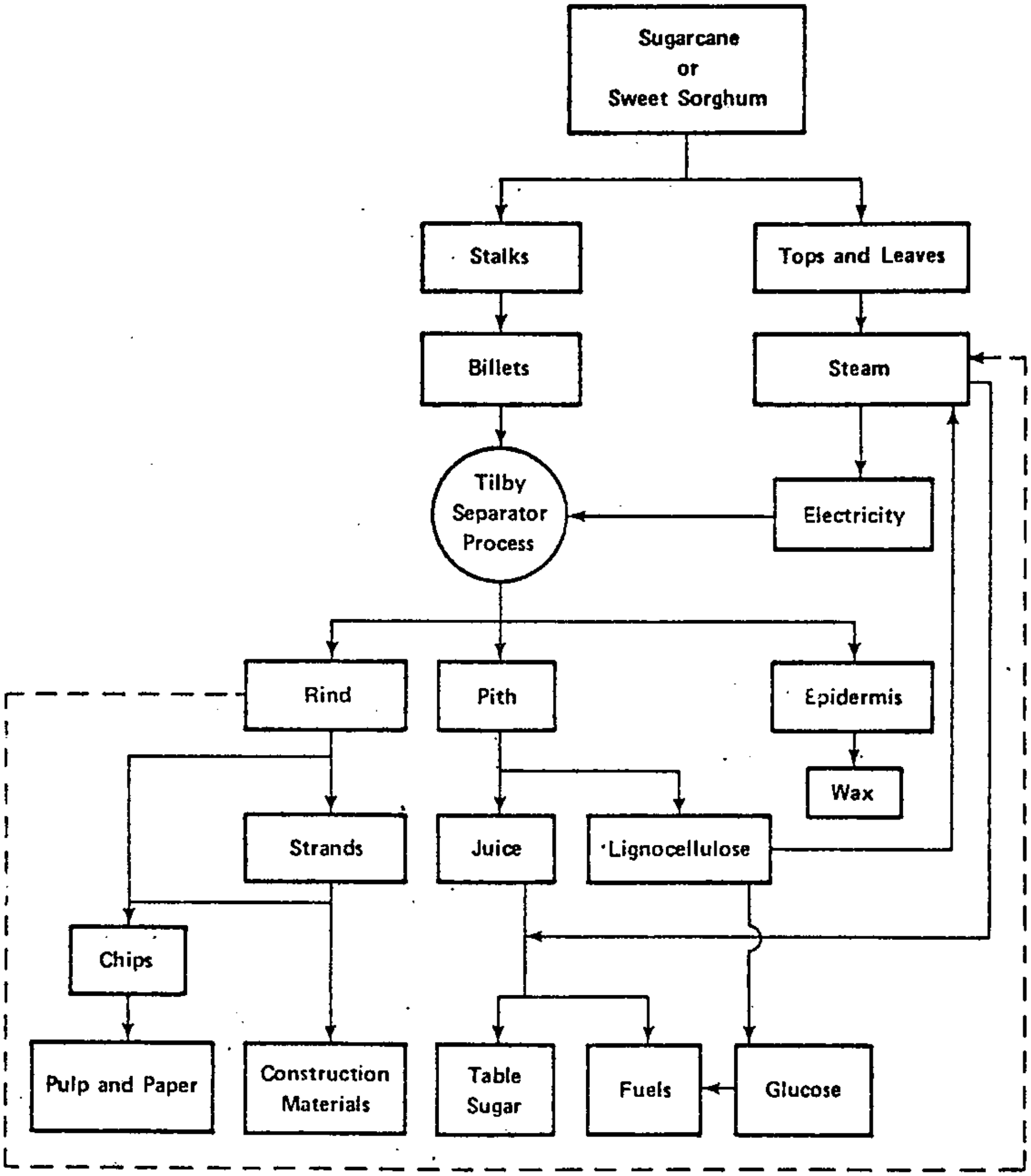


TILBY SEPARATOR PROCESS

SOURCE: ANDER-CANE, INC.



FRACTION YIELD OF THE CANE SEPARATION PROCESS



THE TILBY SYSTEM

CONVERSION OF A TYPICAL PUERTO RICAN RAW SUGAR MILL FOR THE INTEGRAL UTILIZATION OF SUGARCANE AS A SOURCE OF ENERGY

Presented To

A SYMPOSIUM ON ALTERNATE USES OF SUGARCANE FOR
DEVELOPMENT IN PUERTO RICO

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GPO Box 2374, San Juan, P. R. 00936

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Table of Contents

CONVERSION OF A TYPICAL PUERTO RICAN RAW SUGAR MILL FOR THE INTEGRAL UTILIZATION OF SUGARCANE AS A SOURCE OF ENERGY

Héctor M. Rodríguez Torres and Gil L. Horta[1]

ABSTRACT

A concept is presented for the maximum recovery of energy from sugarcane as it is presently delivered to Puerto Rican sugar factories. Proven technology is utilized throughout the concept. It is proposed that all fermentable solids should be converted to ethanol, which in turn would fuel a gas turbine driving an electric generator. Heat from the gas turbine would be recovered in the mill boilers, and flue gasses from the boilers would be used to dry green bagasse to a moisture content of approximately 30 percent. High-pressure steam from the boilers would drive a turbo generator producing additional electrical power. Low-pressure steam is to be used for sugar-manufacturing operations. Within this scheme, an existing sugar mill grinding 4800 short tons of cane per day would produce an estimated 32,000 KW for sale to the PR Water Resources Authority. An additional 160,000 Lbs/hr of low-pressure steam could be sold to an adjacent steam consumer, or sold in the form of chilled water.

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CONVERSION OF A TYPICAL PUERTO RICAN RAW SUGAR MILL FOR THE INTEGRAL UTILIZATION OF SUGARCANE AS A SOURCE OF ENERGY

DURING yesterday's sessions we received ample information on the botanical and agronomic aspects of energy farming, particularly as related to sugarcane and its congeners. It is heartening to know that it is technically possible to harvest agricultural biomass yields of the order of three to four times that obtained at present from the average Puerto Rico sugarcane plantation. Similarly, we have just heard of a new method of processing sugarcane which requires only a fraction of the energy input needed under present methods. We certainly hope that all these wonderful things may come to happen in the not too distant future. Our paper, however, will deal exclusively with what may be done using present proven technology in order to obtain a maximum energy yield from a typical raw sugar mill in Puerto Rico, with the average sugarcane quality received at the mills during the last few years.

We have worked out a scheme by which such a mill, crushing 4800 short tons of cane per day, converts practially all the combustible materials in bagasse and the fermentable sugars in the extracted juice into energy in the form of approximately 32,000 KW for sale to the public utility (P.R.W.R.A.) and some 160,000 lbs/hr of low-pressure steam for sale to an adjacent user as steam or in the form of chilled water.

In order to attain these results we propose converting all the fermentable sugars into ethyl alcohol which will be used to fire a gas turbine driving an electric generator. The heat in the exhaust gasses from this machine will be recovered in the sugar mill boilers where it will supply one half the air required for burning the bagasse. Flue gasses from these boilers will be used to dry the green bagasse, to a moisture content of 30% by weight. Similarly, high-pressure steam produced by the mill boilers is fed to a steam turbo generator to produce electrical energy. Medium-pressure steam is extracted from it to move the mill engines, or turbines. All low pressure exhaust steam is used for sugar boiling, distillation of alcohol, concentration of stillage, heating various process streams, and the balance is sold as steam or as chilled water.

In this study, we have considered only the technical feasibility of carrying out the concept of total utilization of the energy content of sugarcane. We have purposely abstained from going into its economic feasibility because we know there are many factors, social and economic, which are outside the scope of this presentation. Among these factors are present and future costs and availability of petroleum and its derivatives, market values of sugar and alcohol for competing uses (such as rum or gasohol), cost of sugarcane, length of harvest season, social welfare and unemployment insurance programs, etc., which are too complicated to consider in this short paper.

As mentioned before, we have based our estimates on an imaginary sugar mill with an actual crushing capacity of 200 tons per hour, or 4800 tons per day, which is about the size of the average raw sugar mill in Puerto Rico, according to figures published by the P.R. Sugar Board for the 1978 harvest. We have used a fiber content of 18% by weight of cane, the mean for last year's crop; sugar content and bagasse analyses are typical. In order to obtain the highest possible energy yield we have considered the following procedure:

FIRST: Use a bagasse dryer to bring down the moisture content from 51% to 30% by means of the boiler flue gasses. With this moisture content a bagasse boiler efficiency of 74% is attainable while reducing excess combustion air to 30% over theoretical instead of the 100% plus currently in use.

SECOND: Raise boiler output steam conditions to 425 psig and 200°F superheat. This produces an increase of 8000 KW in the steam turbo-generator over that produced if current steam pressures of 150-200 psig are used.

THIRD: Bleed steam at 150 psig to supply the steam drive movers which are universally used in Puerto Rican mills. Exhaust from these units will be used for heating and concentrating juice as done in current mill practice.

FOURTH: Lime, heat and clarify juices as is presently done. Return filter cake to green bagasse before it enters dryer. Concentrate clarified juice to a total fermentable sugar content of 21-22% only. This process requires less than two-thirds of the available heating surface of the typical mill's multiple-effect evaporators.

FIFTH: The concentrated juice is fermented to ethyl alcohol in an adjacent installation, distilled and if necessary dehydrated, using low pressure exhaust and electric power generated at the sugar factory.

SIXTH: The hot stillage (slops) is returned to the sugar mill where it is evaporated to a density (60° Brix) suitable for sales as a component of cattle feed. The balance of the multiple-effect evaporator capacity not used for juice is used for stillage. Low pressure exhaust from the steam turbo-generator supplies the necessary heat for this process.

SEVENTH: The alcohol produced is used to fuel a gas turbine which drives a generator. The hot

> exhaust gasses enter the bagasse furnaces where they produce enough steam to generate 4700 KW hrs in excess of those based solely on bagasse. The estimated total electrical power output from the sugar mill, for a grinding capacity of 200 tons per hour, is presented in Table 1.

Let us now look at the BTUs which come into the sugar mill in one ton of cane. The fiber content is taken as 18%, the average for the 1978 season. Therefore, one ton of cane contains 360 lbs. of 100% dry fiber with a higher heating value of 8577 BTUs per pound, equivalent to 3.09 x 10^6 BTUs per ton of cane.

The soluble solids content, which includes ash, sugars, and other organic materials was, for the 1978 season, 13.90% based on cane. These solids include approximately 35 lbs ash, leaving a balance of 243 lbs combustibles, mainly carbohydrates, with a higher heating value of 7110 BTUs per lb for a total heat content of 1.73 x 10^6 BTUs per ton of cane. Thus, the total heat content of one ton of cane is 4.82 x 10^6 BTUs. The distribution of the heat content of sugarcane is illustrated in Figure 1. Relevant energy values for Figures 1 and 2 are presented in Table 2.

In the actual utilization of this energy the proportions are different because bagasse contains all the fiber and some of the soluble solids, known by sugar technologists as Brix, and some ash, while the remaining sugars and other solids are not fired as such but pass through a fermentation cycle producing principally ethyl alcohol. Figure 2 shows the actual distribution of this heat energy in terms of bagasse and alcohol.

The scheme for total utilization of the energy in sugarcane which we propose can best be visualized if we divide it into four groups of machinery and equipment. Thus we have indicated four areas termed *Sugar Factory*, *Alcohol Distillery*, *Boiler House* and *Power House*, respectively (Figure 3).

The Sugar Factory will encompass the usual functions of cane preparation, crushing, juice heating, clarification, and concentration to a 25-30° Brix syrup. Auxiliaries such as mud filters are included. Obviously only a fraction of the installed evaporative capacity of a typical sugar factory is required for this purpose. The sugar factory will deliver the wet milled bagasse to the boiler house and concentrated juice to the distillery, and in turn will receive the necessary electric power and steam from other areas.

The distillery receives its raw material from the sugar factory and electric power and low pressure exhaust steam from the power house (Figure 4).

It produces either 95% or anhydrous alcohol, depending on its final use. If used for fuel it is pumped directly to the power house. The hot stillage is evaporated to 60° Brix which can be sold for cattle feed. If it cannot be disposed of in this way, it can be burnt in the boiler furnaces for its heat content.

The boiler house receives wet milled bagasse with filter cake and possibly concentrated stillage mixed with it (Figure 5). This material enters a dryer heated by hot (600°F) flue gasses and emerges with a moisture content of approximately 30%. The heavy soil and dirt particles in the filter cake and bagasse are separated as part of the drying and handling operations. The emerging flue gasses (300°F) pass through a pollution abatement process prior to being discharged to the atmosphere.

With bagasse of this moisture content it is possible to reduce excess air to only 30%, hence the overall boiler efficiency should be expected to be around 74%. Since one half of the air required for combustion is provided by the gas turbine exhaust which is at around 1100°F, it is expected that even higher efficiencies can be achieved.

All of the high pressure steam, except for the small amount required for boiler auxiliaries, is used in the power house turbo-generator.

At the power house there are two electric power generators. One is driven by a gas turbine using alcohol as fuel, and another by a high pressure steam turbine. Intermediate-pressure steam is extracted to drive the milling equipment at the sugar factory. The balance is expanded to low pressure (20 psig) and supplies all the heat required by the sugar factory and distillery. Any excess can be sold as low pressure process steam or as chilled water for air conditioning. The gas turbine, when fired with alcohol, requires at least 150% excess air which contains more than 45% of the oxygen needed to burn the bagasse.

The electric power generated is enough to meet all power needs of the four areas with a sizable surplus for sale. For a factory crushing 4800 tons of can per day, we estimate this surplus at

32,000 KWH/hr.

Let us now look more closely at the problems associated with feeding raw wet bagasse to the boiler furnaces (Figure 6). The mean moisture content in bagasse during last year's crop is given by the Sugar Board as 50.27%, so let us use 51% as the basis for the following estimate.

The higher heating value of 1 lb of bagasse containing 51% water, 3% Brix, 1% ash and 45% fiber is 4072 BTUs, while the effective value is only 3263 BTUs, a loss of 809 BTUs, of which 562 BTUs or approximately 70% is due to the moisture absorbed on the fibers. This amount of heat is lost on 48% combustibles in the bagasse. Based on dry bagasse the loss would be 1147 BTUs per pound.

Obviously, any effective plan to recover the maximum amount of the energy contained in sugarcane should give full consideration to drying bagasse with the heat in boiler flue gasses which would otherwise be lost through the stack.

We have found that under our assumed conditions it is possible to reduce bagasse moisture to around 30% by the heat released on a 300°F temperature drop in the flue gasses. In order to be able to do this and yet keep the stack at a reasonable temperature, it is necessary for the flue gasses to leave the boiler at around 600°F.

When 51% moist bagasse is dried to 30% moisture, each pound will produce 0.70 lbs of the dried material with an effective heating value of 3576 BTUs/lb. The increase in effective fuel value is only 313 BTUs or 10%, but this dried bagasse can be burnt with only 30% excess air while raw bagasse requires over 100% excess over theoretical. The overall result is that boiler efficiency will rise from 62% to 74%, therefore, a net saving of 4891 BTUs per lb of raw bagasse entering the dryer. This is 19% more heat absorbed in steam, equivalent to around 375,000 BTUs recovered per ton of cane crushed.

For a sugar mill crushing 4800 tons of cane per day, the net results are shown in Figure 7. There would be a net electric power production for sale of 32,000 KW, and 155,000 lbs per hour of low pressure steam equivalent to 145 million BTUs or 7500 tons of refrigeration. The by-product normally associated with a sugar factory, filter cake, is incinerated with the bagasse. Slops produced in the distillery are concentrated to 60° Brix and sold for cattle feed in the amount of 120 tons per day. Otherwise, it is incorporated in the dry bagasse and burnt for its fuel value.

While all phases of this plan may not be economically feasible today, a time may come when the cost of fossil fuels, if at all available, will alter the economic balance in favor of its implementation. In the short run, however, if alcohol could be sold for other competing uses at the current selling price of approximately $1.20 per gallon, it may be substituted by kerosene or other distillate fuel in the gas turbine at the rate of two gallons of distillate for every three gallons of alcohol. At present prices $1.20 buys approximately 2.2 gallons of kerosene or distillate fuels in Puerto Rico, although this may change at any moment. Another point of interest lies in the current use of approximately four gallons residual fuel oil per ton of cane crushed. At present this costs around $1.55 per ton of cane which would be enough to buy around three gallons of distillate fuel at present prices, out of the 10 gallons necessary to substitute all the alcohol produced by one ton of cane entering the sugar mill.

Naturally, this strategy depends to a very great extent on the availability of sugarcane and/or agricultural equivalents in sufficient quantity and steady flow to insure a long harvest season of not less than 250 effective grinding days a year. We certainly hope this may become feasible in the near future.

Table 1. Estimated potential electrical power output from a modified sugar mill grinding 200 short tons of cane per hour

Source	Electrical Power (KW)
Gas Turbine	20,600
Steam Turbine	15,200
Total	35,800
In-House Usage	4,000
Net for Sale	31,000
Produced From Alcohol (%)	70
Produced From Bagasse (%)	30
Stillage For Sale (60% Solids)	120 Tons/day
Low-Pressure Steam For Sale	155 Lbs/hr

Table 2. Energy values relevant to sugarcane and some of its products [1/]

Component	BTUs/Short Ton Lower Heating Value	 Lower Heating Value
Fiber	3.09 x 10^6 (=64.1%)	2.88 x 10^6 (=59.7%)
Other Organics	1.73 x 10^6 (=35.9%)	1.59 x 10^6 (=32.9%)
Losses in Water Vapor		0.35 x 10^6 (= 7.4%)
Total Energy	4.82 x 10^6	

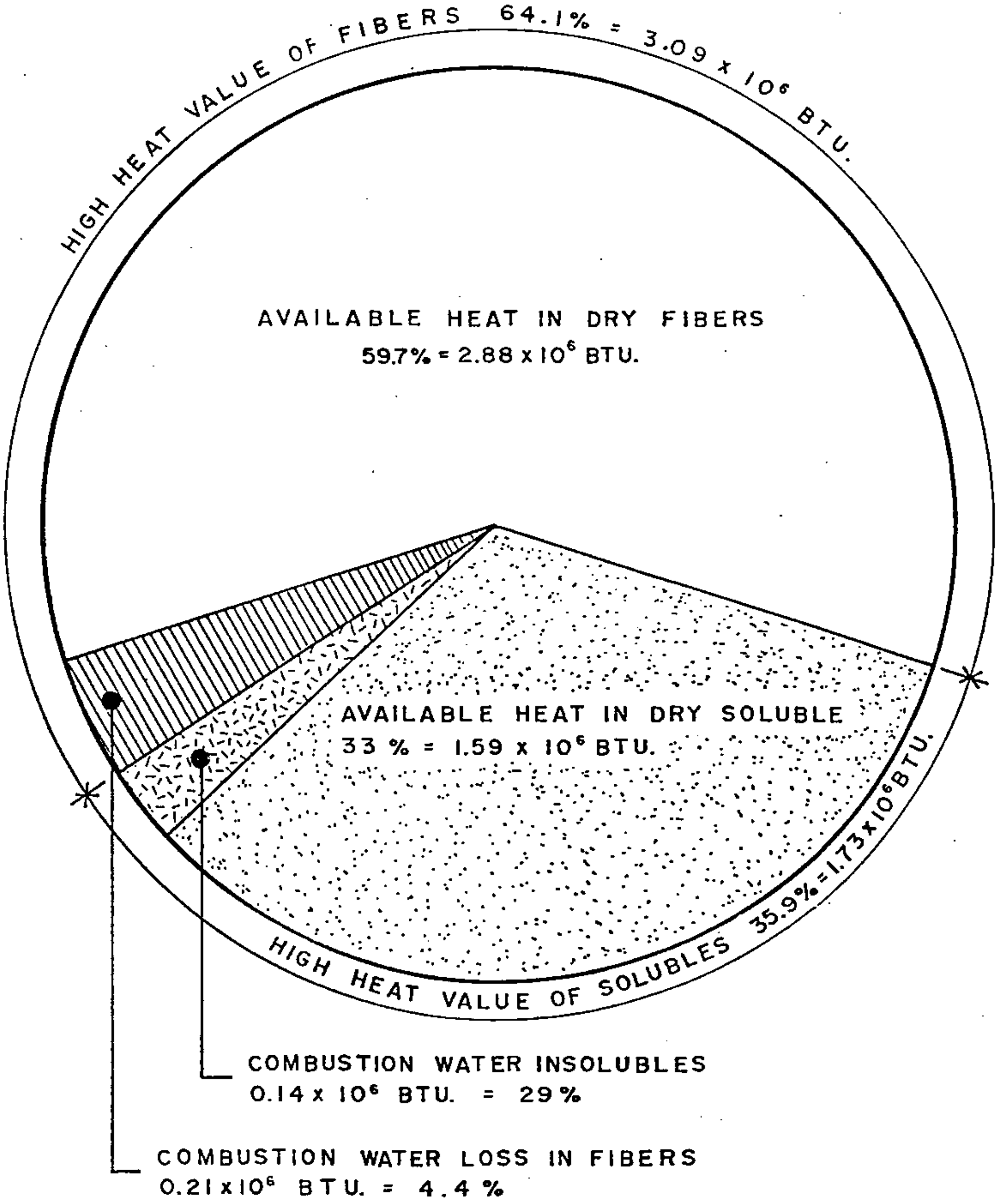
	BTUs/Short Ton		
Green Bagasse at 51% Moisture	3.18 x 10^6	(=780 Lbs x 4073)	
100% Ethyl Alcohol	1.34 x 10^6	(=15.6 gal x 8600)	
Total	4.53 x 10^6		
Losses in Fermentation and Distillation Processes	-0.30 x 10^6		
Available BTUs:			
In Bagasse	2.55 x 10^6		(=52.9%)
In Alcohol	1.88 x 10^6		(=24.5%)
Losses:	1.09 x 10^6		(=22.6%)
Breakdown of Losses:	8.7%	(.42 absorbed water)	
	6.2%	(.30 process-alcohol)	
	7.7%	(.37 water of combustion)	
Total	22.6%	1.09 x 10^6 BTUs	

[1/] Basis: 39% bagasse in cane.

TOTAL ENERGY CONTENT IN SUGAR CANE

FIG.1

BASIS: ONE SHORT TON = 4.82 MILLION BTU. - H.H.V.

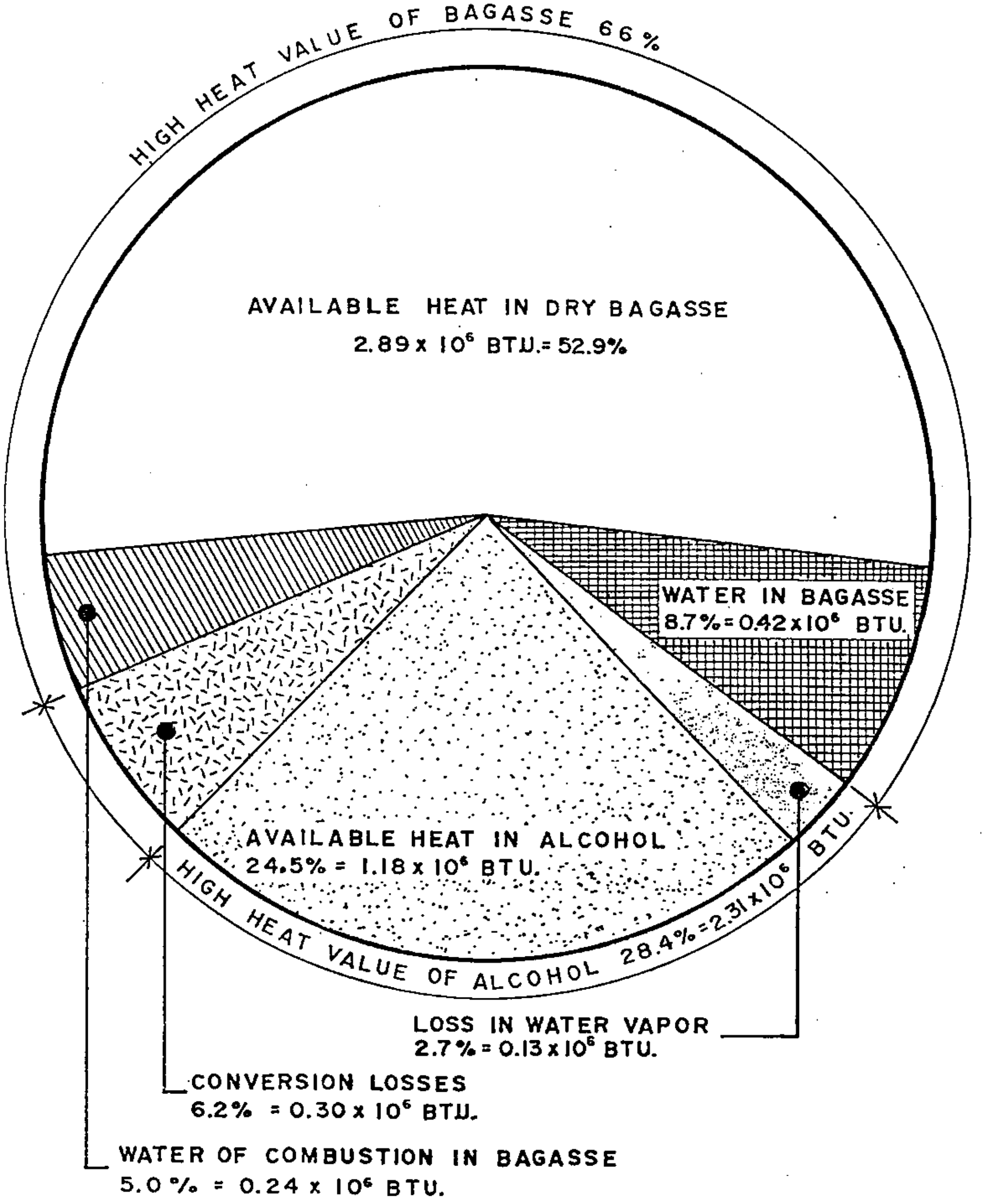


TOTAL ENERGY CONTENT IN SUGAR CANE

FIG. 2

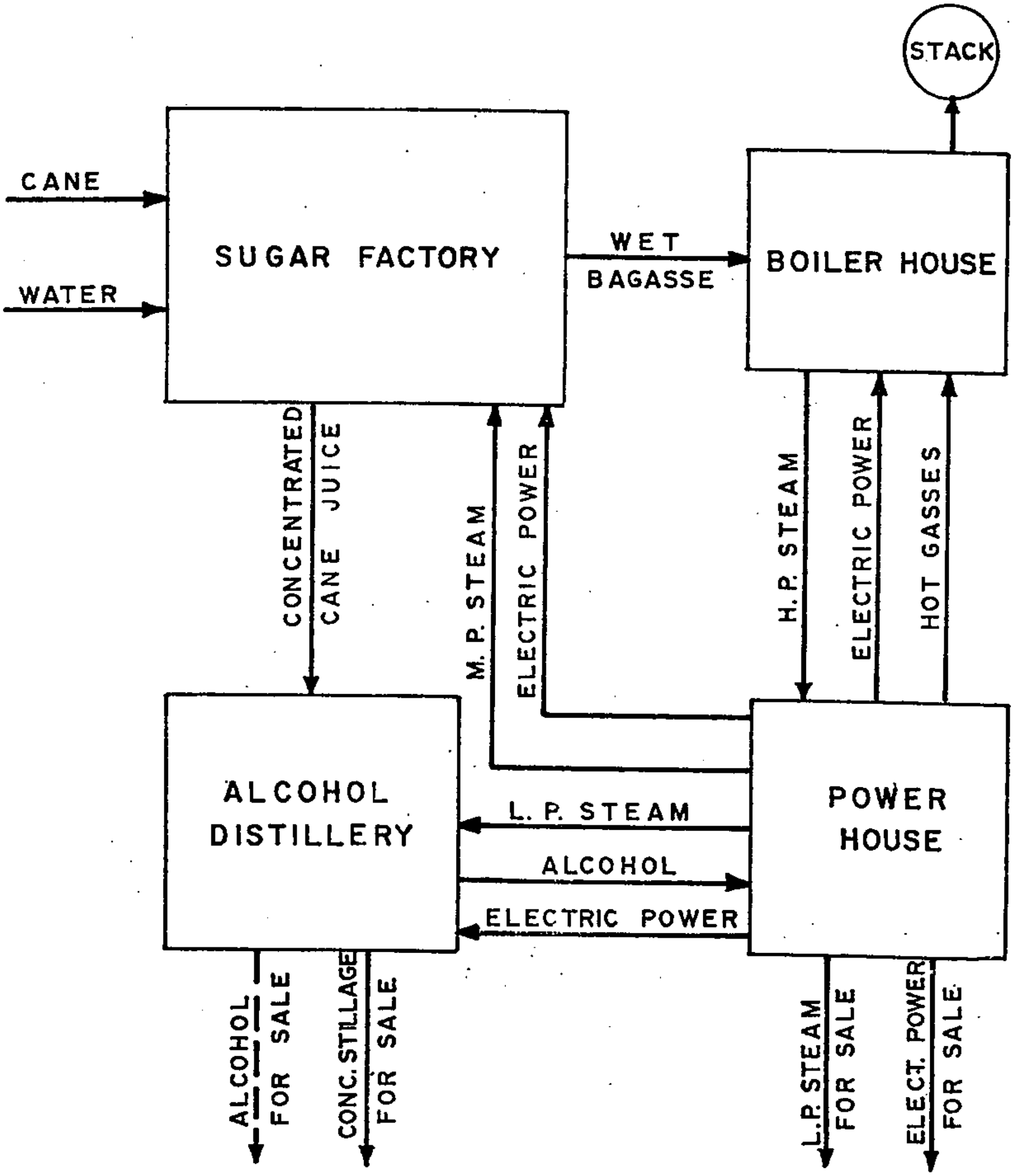
BASIS: ONE SHORT TON 4.82 MILLION BTU.- H.H.V.

FIG. 2



GENERAL CONCEPT

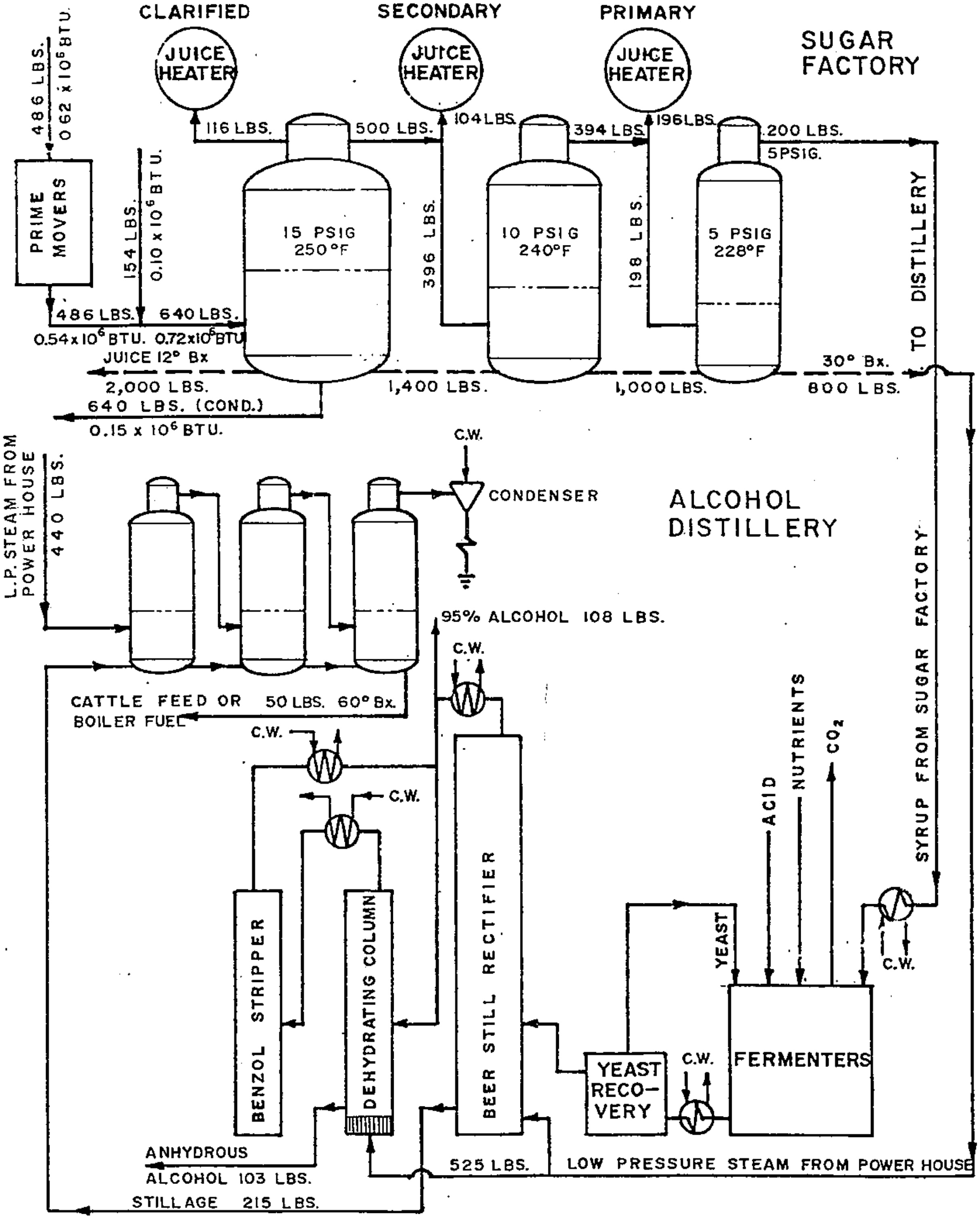
FIG. 3



SUGAR FACTORY & ALCOHOL DISTILLERY

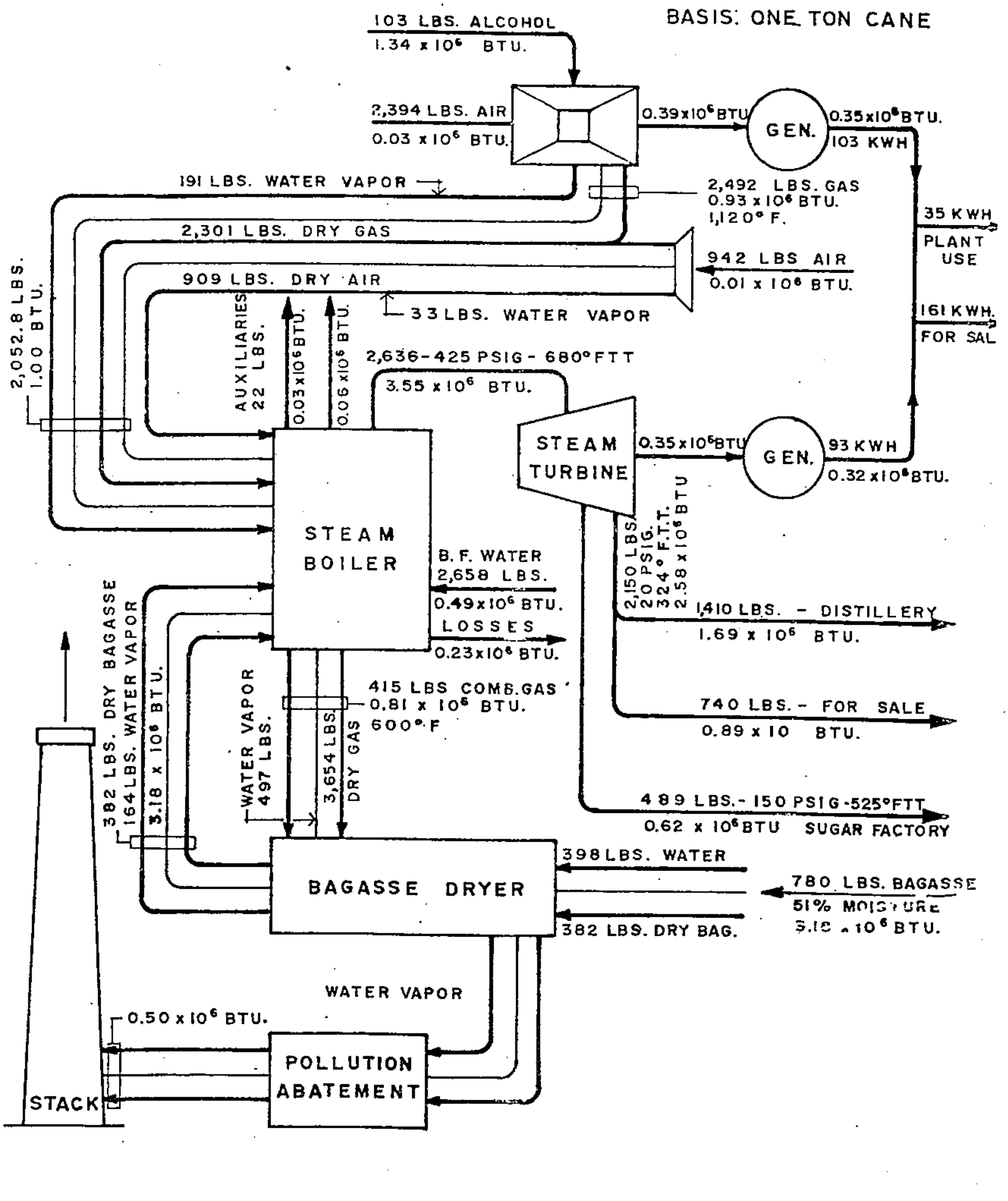
BASIS: ONE TON CANE

FIG. 4



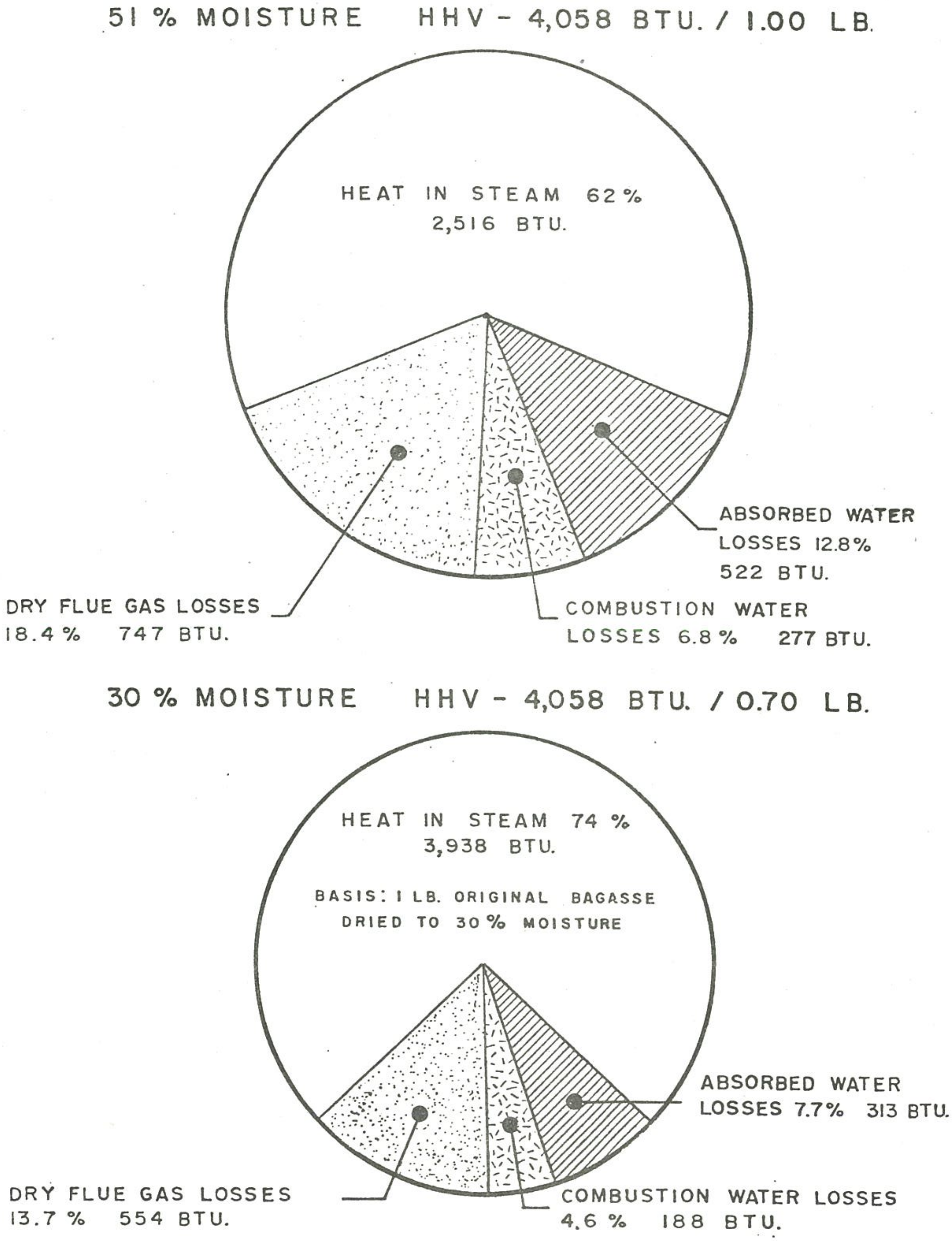
FLOW DIAGRAM: BOILER & POWER HOUSE

FIG. 5



EFECT OF DRYING BAGASSE ON BOILER EFFICIENCY

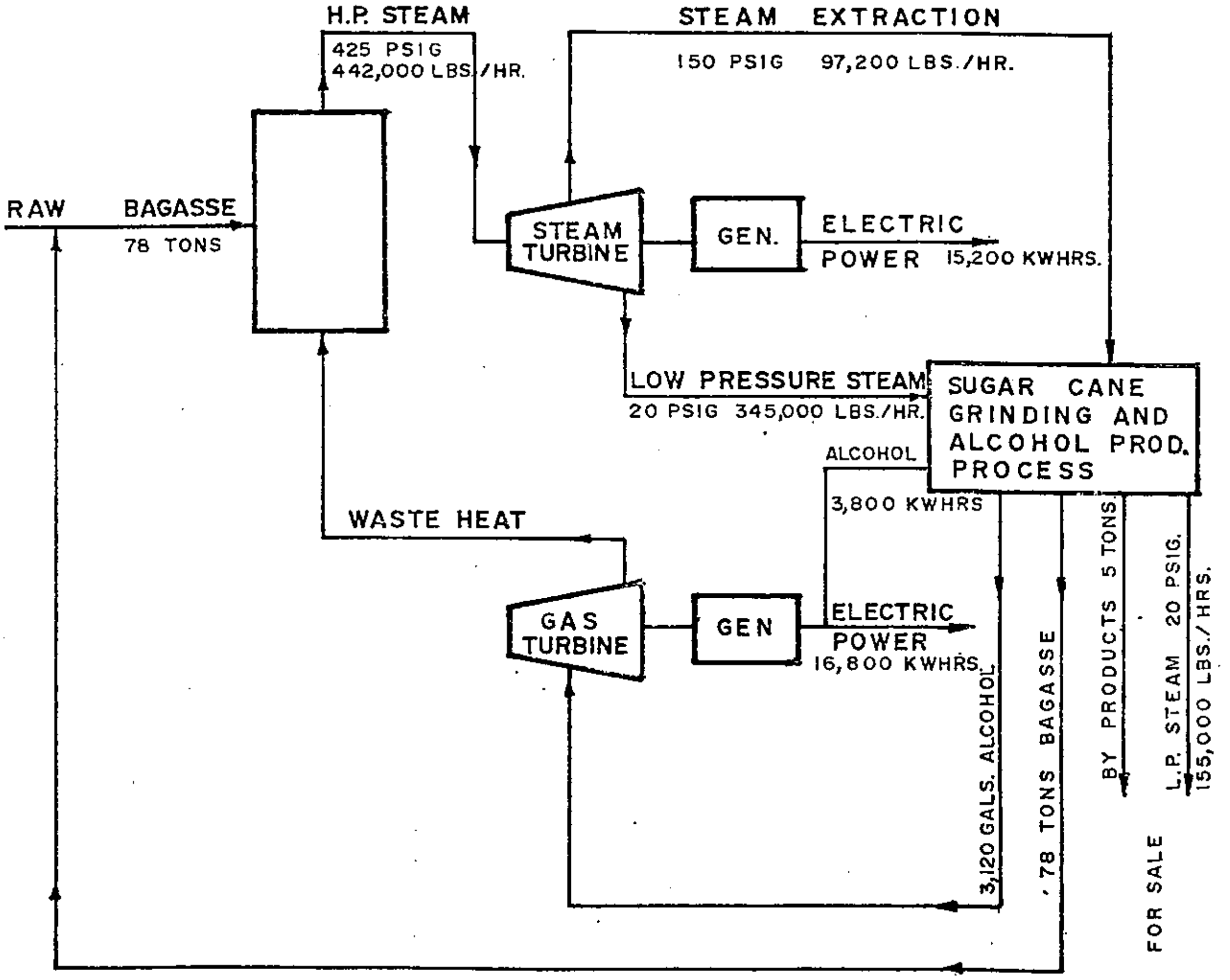
FIG.6



CO-GENERATION SYSTEM USING GAS TURBINE EXHAUST AS COMBUSTION AIR IN STEAM BOILER

BASIS: 200 TONS PER HOUR

FIG. 7



SUGAR MILL INTEGRATION WITH THE PRWRA POWER GRID

Presented To

A SYMPOSIUM ON ALTERNATE USES OF SUGARCANE FOR DEVELOPMENT IN PUERTO RICO

Caribe Hilton Hotel, San Juan, Puerto Rico
March 26 and 27, 1979

Contributed By

PUERTO RICO WATER RESOURCES AUTHORITY, SAN JUAN, P. R.

SUGAR MILL INTEGRATION WITH THE PRWRA POWER GRID

Table of Contents

SUGAR MILL INTEGRATION WITH THE PRWRA POWER GRID

A. J. Arzola[1]
Electrical Engineer, PRWRA

INTRODUCTION

The Executive Director of the Puerto Rico Water Resources Authority, Engineer Alberto Bruno Vega, was kindly invited by Dr. Juan A. Bonnet to make a presentation on this occasion on the "Integration of Sugar Mill Generators to the Power Grid of the Authority." Mr. Bruno regrets that he has been unable to participate in this symposium due to pressing matters of the Authority that need his personal attention. He, nevertheless, sends his best wishes for a successful and productive session on this so vital problem of energy conservation. Mr. Bruno has kindly delegated our Engineers, Rafael Llavina and myself to represent him. I shall do my best to do so, but with the conviction of the impossibility of fully substituting for a man of the merits of Mr. Bruno Vega.

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[1] Electrical Engineer, Puerto Rico Water Resources Authority, San Juan, P.R.

SUGAR MILL INTEGRATION WITH THE PRWRA POWER GRID

HISTORIC BACKGROUND

THE CONNECTION of the sugar mill generators to the power grid of the Puerto Rico Water Resources Authority dates back to the bonanza years of the sugar industry. I refer to the 1940's and the 1950's. In those days, the mills operated with good profits. Sugarcane was harvested by hand and delivered to the mill as clean as toothpicks. Juices were of high purity, sugar yields were high, and the fiber in cane was low. The bagasse obtained was of such good quality that burning in the furnaces was quick and efficient. This usually resulted in an excess of bagasse over the needs of the factory, which had then to be burned after storage capacity was exceeded. Consequently, the factory had to resort to blowing steam to the atmosphere while burning this excess bagasse. Those sugar mills that had excess generating capacity had then the option to inter-connect with the power grid of the Water Resources Authority. This gave birth to the practice of interconnection. Where the sugar mill generators were run synchronized with the power grid, the factory bought power from the 38 KV system at a specially reduced rate, and in turn sold back all excess generation to the WRA at the Authority's cost to produce it at its most efficient plant. In the year 1954, the cost of producing one KWH was just four mills (0.4 cents) at our Puerto Nuevo Plant. For comparison purposes, the cost of producing one KWH is now around 2.8 cents at our Aguirre Plant. This is a very good example of the co-generation concept, which, as you see, has been practiced in Puerto Rico for at least 35 years.

It is well to mention here that these inter-connection contracts were of mutual benefit in those days. The electrical demand was increasing at such a rapid pace that the WRA was hard pressed to keep pace with this growth. Some of you might remember the floating power plant bought and connected to the system just to buy time until our new Puerto Nuevo generating facilities were put on the line. Even the small amount that could be generated by the sugar factories was then welcome, and inter-connection contracts of benefit to both parties could easily be negotiated.

PRESENT CONDITIONS

It is my understanding that the sugar factories that remain operating still have this inter-connection contract. Of course, the conditions now are drastically different, and the sugar factories are deriving almost all the benefits of the inter-connection, since they are not able to sell any appreciable power to the Authority. The main purpose still in the sugar mill generators being synchronized with the power grid, is to have a reliable source of electric power immediately available whenever those generators cannot carry 100% of the load due to low steam pressure, which is frequently the case. Many factory operators prefer to buy power on these occasions rather than burning oil inefficiently in their boilers to keep up the steam supply. During these power defficiencies, the power grid will automatically pump power into the factory system keeping up voltage and frequency for the efficient operation of electric motors, lights, and equipment.

So, it is easy to see, that while in the beginning the inter-connection with sugar factories provided the WRA with a source of power, however small, now it just provides another load that must be met by the Authority during the grinding season.

FUTURE OF THE INTER-CONNECTION SCHEME

The bonanza of the sugar industry is gone, probably forever. Sugarcane is harvested and loaded mechanically and delivered to the mill with a great quantity of mud, sand, stones and other foreign matter. Even though the cane passes through a cleaning phase before milling, the quality of bagasse is poor with consequent serious deficiencies in the production of steam. Although there has been considerable improvement in this area, the problem still persists.

If the inter-connection with the power grid is ever again to produce benefits in the sale of power, the production of steam in the factory has to be re-evaluated in the light of new procedures and new approaches. The Inter-professional Service Group presentation on the conversion of a conventional sugar factory for the integral utilization of sugarcane as a source of energy proposes such a new approach.

In a factory grinding 4,800 tons of cane per day, as envisioned by the Inter-professional Service Group, the production of steam would leave an energy surplus enough for generating 160 KWH per ton of cane ground, or 4,800 x 160 = 768,000 KW hrs per day. This would represent 192,000 KWH on a 250-day year, for a yearly saving of around 320,000 barrels of fuel oil to the economy of Puerto Rico.

The savings to the Island's economy would actually be higher, in the measure that the Factory can supply its own load during the grinding season and thus liberate PRWRA generating capacity to supply other customers. If this excess power generated were to be sold to PRWRA at a rate of $.028/KWH, the income to the factory would be 192,000 x $.028 = $5,376,000. We give the rate of $.028 only as a guide in computing the estimated earnings of the factory. Actually, this figure would have to be negotiated with PRWRA as part of the inter-connection contract.

From the point of view of the power grid of the WRA, the connection of one 32,000 KW machine to the system would not affect much the trend for the installation of new power plants. However, in the case that at least four of these generators were connected, then a more serious scrutiny of the situation would have to be made, since we would have then a generating capacity of 128 MW to consider. Such a scheme might permit a one-year delay in the Authority's generation-expansion plan, which calls for additional generation capacity by the mid-1980's.

We wish to state emphatically, that new approaches for the preservation of energy must be made. This novel idea of using the renewable resources of biomass for the production of energy should be explored to the maximum and implemented wherever there is a chance, however slim, of being successful. The Puerto Rico Water Resources Authority is not only willing, but desirous to provide any aid, technical or otherwise, requested from her for the accomplishment of such projects.

FACTORY MANAGEMENT CONCEPTS FOR AN INTEGRATED SUGAR-ENERGY INDUSTRY

Presented To

A SYMPOSIUM ON ALTERNATE USES OF SUGARCANE FOR DEVELOPMENT IN PUERTO RICO

Caribe Hilton Hotel, San Juan, Puerto Rico
March 26 and 27, 1979

Contributed By

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FACTORY MANAGEMENT CONCEPTS FOR AN INTEGRATED SUGAR-ENERGY INDUSTRY

Table of Contents

FACTORY MANAGEMENT CONCEPTS FOR AN INTEGRATED SUGAR-ENERGY INDUSTRY

Mariano A. Romaguera[1]

ABSTRACT

A general picture is presented of Puerto Rico's sugar industry as it exists today, and as a potential instrument for future energy and by-product sales on the Island. Increasing energy expenditures imposed on the sugar factory during the past two decades are reviewed together with Puerto Rico's mill potentials to produce electricity with existing low-pressure steam installations. In relation to alcohol production, emphasis is given toward development of salable by-products of distillery residues. The effects of local EPA and EQB offices on present and future developments within the sugar industry are pointed out. Potential developments in the use of bagasse, and in the development of a PR-based sucrochemical industry are also discussed. Drawbacks are pointed out in plans to use Puerto Rico's existing sugar mills as co-generation plants. The ultimate salvation of Puerto Rico's sugarcane industry is seen to be in the total resource development of alternate cane uses, in the context of a future electrical power co-generating industry.

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FACTORY MANAGEMENT CONCEPTS FOR AN INTEGRATED SUGAR-ENRRGY INDUSTRY

THE PRESENT status of world energy shortage has put the sugar industry in the spotlight. There are great expectations pertaining to the possibility that the sugar industry might be one of the answers among the many alternatives for producing energy in the form of alcohol, or co-generating electricity for our people.

The idea that the sugar industry could generate added kilowatts for consumption other than processing is not really a new one. Before anyone ever thought up the word "co-generation," the world's sugar industry was producting electricity over and above the required capacity for its basic operations.

Here in Puerto Rico, in the heyday of our production, sugar mills provided extra electricity during their seasonal operation. In the year 1952, a peak year for Puerto Rico's sugar production with over 1,300,000 tons of sugar, our mills contributed an estimated 12,096,000 KWH[1/]. What has happened since? Well, for once, this business of selling electricity was not so hot after all. You see we were selling electricity at 1/6 the price we were being charged for it during the dead season and during emergency needs. What this condition brought was a laxity on behalf of our mill management for efficient operation of our generating plants... and with oil so cheap, our operators became "oil addicts."

We all know what happened afterwards; not enough labor at our fields, and finally a hurried mechanization which created havoc with our milling equipment. Our solution? Cane washing plants... huge contraptions that require energy, lots of energy, just to prepare the cane in order to be able to grind it.

An example of this is the cane cleaning plant in Coloso, constituting 1,500 added horsepower installed to be able to grind about 6,000 tons of cane/day. All of a sudden, our mills had to reevaluate their capacity for generating electricity just to cope with this new energy outlay. The rule of thumb of 1/2 KW/ton of cane ground/day was suddenly increased to about 0.7 KW/ton of cane.

[1/] Charles Lang data compilation.

On top of that the environmental protection agency stiffened the rules and set limits of effluents–not only in air but in water also. This meant a greater need for additional energy. Yes, in order to clean the air and the water we need energy, lots of it.

In order to separate particles in the gases leaving our boilers we needed large pressure drops which meant larger fans and more energy to handle the same amount of gas. We also needed to scrub or clean our gases. In our Sugar Industry we are utilizing impingement type and venturi type wetscrubbers, and for that we need pumps, water, etc., in other words, we need still more energy.

In order to get our liquid effluents down to the minimum requirements we need large extensions of territory, lakes, chemical control areas, pumps, dosifiers, and aerators, all of which require more energy. If we add all this up, we can get staggering figures of added energy required just to produce that same pound of sugar. This added requirement implies an additional 0.3 KW/ton of cane, thereby placing our energy needs at close to one KW/ton of cane ground/day.

This means that in Coloso, for instance, we would need a generating capacity of 5,500 to 6,000 KW just to be able to grind the same 3,000 KW amount of cane where formerly we needed only 3,000 KW. If we are to proceed with the installation of air and water leaning equipment we must install added generating capacity or face the fact that we must buy more energy from WRA and thereby add to the energy problem.

Fortunately, we are being told that the field operations have incorporated the latest generation of mechanical harvesters that deliver cleaner cane and thus we can gradually eliminate the cane cleaning contraptions. We all hope this can be true!

In the meantime there are many things we can do. Our existing power plants are capable of generating about 30,000 KW if operated properly. With the exception of La Plata, our other sugar mills are operating below capacity. This means we have low power factors in some of our substations due to low load operating equipment. Our steam lines are not insulated properly. Rough estimates of economies of fuel run about 10% to 15%.

If we are to have an integrated sugar-energy industry our power plants must be brought up to date. We have boilers, turbo-generators, conveyors, you name it, to handle bagasse or similar hog fuel. The more efficient our plants become, and we are trying to achieve this, the more electrical we can generate for use other than in sugar factory processes.

Hopefully, we will be phasing out our cane cleaning plants, thereby releasing an immense amount of energy in the form of electricity. The same can be said of the water requirements.

What makes this step interesting is the fact that our sugar industry is already investing heavily into scrubbers to clean the air, and in lagoons and aerators to control the quality of water. In other words, we already have installed the technology as well as the means to comply with EPA and EQB regulations. And if I may say so, in this step we are ahead of WRA plants. In principle our boilers are capable of burning refuse fuel, biomass, etc., in addition to our bagasse for cogeneration purposes. If we can handle the cane we are receiving and have received in the past three years, we can handle practically anything.

Our plant managers could now investigate future economics of energy by turning to alternate means of sugar processing. We could use more sugarcane to produce rich molasses for conversion to alcohol. The main problem in the distilling of alcohol, utilizing molasses, is the residual substances. Factory management could look into the utilization of the nutrients in this by-product. Another approach would be the processing of hi-test molasses for world market consumption.

UTILIZATION OF RESIDUES FROM THE DISTILLATION PROCESS

If we are to utilize sugarcane as a principal source of alcohol and as a boiler fuel we must consider the final residue of this process, or "mosto" as we call it in Spanish. This is the end product of the biological fermentation, and, as such, presents a grave social problem owing to the high pollution effects of its organic components.

Factory operations must necessarily take into account this matter and managers must realize the importance of minimizing the adverse of distillery residues. At the same time our managers should take advantage of the potential of this material as a possible source of income when properly treated.

It is evident that, in order to perform economic evaluations, one must know the composition of this residual material and how we can utilize it. In the Republic of Brazil, where extensive work has been done on utilization of alcohol and its derivatives, recent experiments have indicated the following composition of distillery residues[1]:

Organic matter	7.56%
CaO	0.52%
MgO	0.15%
K_20	0.78%
N	0.16%
P_20_5	0.03%
SO_4	0.81%

There are known means of reducing the basic volume of residues by the process of evaporation. This presents the problem of excessive corrosion of the equipment and the constant incrustations of the heat exchangers.

To gain an idea of the quantities of residue components we are talking about, let's assume an average distillery producing 90,000 liters of alcohol/day.

This factory would produce a residue, concentrated to 60° Brix, which would contain the following important nutrients:

Concentrated residue	170,000 Kgs.
Organic Matter	78,000 Kgs.
Nitrogen (N)	1,500 Kgs.
Potassium (K_20)	9,600 kgs.
Phosphorus (P_20_5	150 Kgs.

The way to handle this material would be by either:

1) Using it as irrigation water applied through channels on neighboring land.
2) Distribution, by means of tank trucks, for cattle consumption or land dispersion.

In the first instance we have the problem of diluting this material to its proper consistency, leveling of terrain, and installation of pumps and channel systems. We must also consider its

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[1] Nadir, A; Da. Gloria. Consultant for Planalsucar. Brasil Azucareiro, No. 11, 1975.

dependency on climatological conditions and soil conditions and its eventual arrival at a body of water where the danger exists of pollution and non-compliance with the clean water act. In Puerto Rico this is critical.

In the second instance, and once again basing our figures on our basic distillery producing 90,000 liters/day of alcohol, we will have a residue of 14 liters of vinaza, or mosto, per liter of alcohol (assuming all residues from the process are brought together, thus eliminating the possibility of water pollution). This constitutes a daily production of 1,260,000 liters of residue (1,260 cubic meters). Assuming delivery on tank trucks carrying seven metric tons/load, we would require 180 trips/day to haul this material away.

If the average distance of travel is around 10 kilometers from our distillery and assuming 1.5 hours for round-trip loading, transport, and distribution, we could possibly get 16 trips/truck/day. A more logical figure would be 10 trips/day. This means we would require 18 trucks traveling a full shift (24 hours) every season day. Our normal zafra or season runs 100-120 days. Two drivers/truck are required. We now have in our hands all the data for analyzing the cost of labor, fuel, repairs, and basic investments required for this type of project.

We can evaluate the utilization of this by-product as a nutrient for cattle feed. In Brazil, this material is widely used. They have the advantage of not having to cope with the EPA and EQB agencies as we here in Puerto Rico have to.

At present the problem presented by the local rum distilleries is still unsolved. This is on the basis of 96° alcohol. If we talk of absolute alcohol (99.9°) as the one proposed for fuel utilization, we must take into consideration the added problem of the handling of benzene residues (Copersucar report, Dec., 1977).

In Brazil the sugar industry is installing an average of four new distilleries/year, each capable of producing a daily average of 150,000 liters. Their aim is to produce by 1985 all the ethanol required to mix on a 20% basis with local gasoline for local consumption. This is quite a feat in itself. The main idea is to keep the mills operating at peak capacity but diverting some of the sugar production into alcohol. These distilleries are mostly attached to existing sugar mills. The process differs somewhat in the fact that only rich juices from the first extraction are used for sugar production, with high-test molasses or meladura being sent to the distillery. This results in an economy of steam utilization and thus the steam balance of the total complex is minimized. This in turn releases steam capacity for co-generation of electricity which is distributed to the local housing enclave, and in some instances to the public power system.

First-strike sugars are readily sought by all sugar consumers. High-test molasses, not utilized for the fermentation process, have a very high demand at present for the sucrochemical complexes and as feed.

The need for bagasse as fuel, on a steam blanace for the integrated factory, would be less, and consequently some bagasse would be available as extra fuel for co-generation, or as a by-product for fiber board or paper manufacture. The success of the utilization of this by-product for other uses rather than as fuel has suffered somewhat due to the exhorbitant price of oil, the former natural substitute required to release large quantities of bagasse for commercial utilization. In Puerto Rico we have experienced attempts to use bagasse as a manufacturing feedstock. The most recent plant, unfortunately has not even been able to start operations! The BTU exchange concept simply did not work properly here!

The sucrochemical industry appears to be an increasingly viable option now that the rising cost of oil has made sugar an alternate building block for many organic compounds. Some of the alternatives our sugar managers could consider include the production of organic acids for use in food and plastic products. Another application is the hydrogenation of invert sugars to sorbitol and mannitol. Personally, I have used a sucrose surfactant as a detergent. It was made in Cuba; it is non toxic, and works very good in actual washing machines. Additional processes include hydrogenolysis to glycenol and glycals and acetylation (alcohol denaturants) and esterification (plasticizers)1/.

Why am I talking of a sucrochemical complex? Because our generating plants in sugar mills are designed to generate electricity and exhaust steam. If we are thinking of co-generation and utilization of our boilers and power plants we must necessarily utilize somewhere else the process

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1/ Cane Sugar Handbook. Tenth Ed.

steam resulting from this process. Another drawback in our existing installations is the fact that the majority of our sugar mills generate steam at 150-175 PSIG and 50°F superheat, and our turbine-driven generators produce electricity at 480 volts. This means our energy-producing equipment is not as efficient as we would like it to be. And our turbines are non-condensing, with back pressures of 15 PSIG saturated.

In Hawaii, at Honokaa, boilers operating at 900 PSIG and 200°F superheat process steam, and produce electricity on generators at 13,200 volts, which is more suitable for distribution without so many transmission losses. In this specific instance the sugar mill utilizes about 60% of its generating capacity and sells the extra 40% to the local power company. In Río Haina, in the Dominican Republic, the sugar mill generates 50% of its energy requirements for use, and the remaining 50% sells it to the local power company. In Río Haina, the mill has similar equipment installed, but due to its large capacity there is enough bagasse left over for this type of generation (they do not require costly or energy-consuming pollution control equipment as we do).

We cannot try to match these performances due to the limitation of our existing equipment and our uneven grinding season, but we can generate at a more efficient rate than at present. We need qualified personnel to operate our equipment and at the same time be ready to coordinate an integrated sucrochemical industry with our existing capabilities. At the same time, if we can afford to operate our boilers and power plants, even at our existing possible efficiencies (after due improvements) with a longer than normal grinding season, we could process sorghum, biomass, and other fibrous materials after we finish our regular season. We are thinking of utilizing our equipment for ten months or possibly eleven months of the year. We would be co-generating electricity—first as a by-product of the sugarcane grinding process (four months), and second as a by-product of the operation of a sucrochemical industrial complex.

From management's point of view, we could provide full employment to more personnel, and thus be able to offer a good salary to attract better personnel, both at the professional and technical levels. In order to make viable plans, management must study alternate products of sugarcane and be capable of utilizing to its maximum (as indicated with our example of distillery residues) its residual by-products. This, of course, requires intensive feasibility studies and preparation of future operations aimed at those specific industries.

We have the equipment to handle sugarcane, and logically, all related fibrous materials. The alternatives presented are interesting and should be analyzed first separately, and secondly as a total group within the context of the sugar-energy industry as it can rightfully be called. This total utilization of our resources will be our goal.... and the ultimate solution for a commercially-viable sugar industry in Puerto Rico that also can serve as a power co-generator for the future.

NEW CONCEPTS FOR THE FUTURE OF PUERTO RICO'S SUGAR INDUSTRY

Presented To

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March 26 and 27, 1979

Contributed By

José A. Masini, Member of the Board of Directors
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NEW CONCEPTS FOR THE FUTURE OF PUERTO RICO'S SUGAR INDUSTRY

José A. Masini
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In a seminar presented at Caracas, Venezuela, during August of 1973, with the purpose of revitalizing agricultural development in that country, the philosopher Arnold Toynbee stated that

> "Nowadays there are a few countries that possess vast natural resources, and there are some which are densely populated that have been poorly endowed in natural resources by nature. Whatsmore, in some rich countries, the 'gross national product' at present is distributed unequally between the different classes into which the society is divided. There is a marked contrast between the poor and rich countries; and in both the rich and poor countries there is an even more marked difference between the local rich population and their poor compatriots who are oppressed by misery. Even in the rich countries there is a minority which is indigent."

Mr. Toynbee's observations obligate us to evaluate our own situation, in Puerto Rico, where we are not endowed with Venezuela's huge petroleum resources, and where we have an overwhelming population density compared to Venezuela. We realize that, having limited land resources, we should use these resources intensively and to the utmost, in order to absorb the population growth and the immigration of second-generation Puerto Ricans from the U.S. mainland. Moreover, these resources must be used in such a way that the contrasts between the different social classes (the very rich and the very poor) shall not be augmented significantly in our country.

In relation to this topic, Toynbee warns:

> "If these inequalities in the distribution of world riches have not been leveled or at least notably reduced by the year 2003, it is probable that the present tension in the world will have reached by then a limit which is dangerously high."

The present world circumstances, in relation to the energy reserves and their costs, should produce a profound anxiety among all who live in Puerto Rico. This is particularly true upon visualizing the future, when Toynbee's predictions, instead of being reduced, will tend to be even more dangerous owing to inflation and our having to assume more austere life styles as a result of the over-all scarcity and over-use of energy in our society.

This seminar, sponsored by three entities united in the desire to find alternatives to our grave energy problem, should serve as a stimulus to other entities, not represented here today, to join this mission which is of such importance to the destiny of all who live in Puerto Rico.

Sugarcane has been selected in this symposium as the chosen domestic resource for obtaining energy, because it has superior biomass qualifications and can produce renewable energy through the accumulation of our tropical sun under our Island's ecological conditions. Upon mentioning sugarcane, we have to defer to the sugarcane industry, with all of its present problems of deficits in the sales of sugar and an extenuating background of struggles and problems that appear not to have an end.

The technicians dedicated to this industry need stimulus and motivation in new dimensions that will place them within a new technological framework and will shake them out of the inertia and routine to which they have been subjected by the industry, never having an opportunity to renew it and eliminate the great deficits and losses that this means to the public budget.

I wish to point out that, owing to Puerto Rico's scarcity of land (270,000 acres of mechanizable soil) the possibility of harvesting biomass from that soil should have a relation with, and be in harmony to, the evaluation of the government's political agricultural policy. It should state (in its priorities), that our policy is to produce the greatest part of our food in Puerto Rico, and thus be able to get the best possible use of those mechanizable lands in an economical and social context based on the number of jobs it will be able to provide. A large portion of these lands (at least half) are now used for the cultivation of sugarcane.

At present, the nation's input of kilocalories for every kilocalory of food produced at the consumer's table has a ratio of 6 to 1 with the scarcity and mounting costs of energy, we should admit that food costs will augment progressively; and, in our case, the long distances between production and consumption sites further agravates the problem. Therefore, we should carefully explore the use option for our 270,000 acres, in order to obtain their best and maximum possible productivity in terms of our proper and most elemental necessities.

The production of biomass on these lands could be one alternative, and we should keep a watchful eye on a world full of rapid and dramatic technological changes. We should be receptive, and the public agricultural policy should be directed toward an effective exploitation of our soil in order that we can cover the rising necessities of food or energy, as the case may be.

Within this same line of thought, Professor Toynbee backs our contention upon stating:

> "Within this mark of parameters, risks, and possibilities, each country should trace its own route and condition its situation; there is none, and each day there will be less possibility of isolated growth and individual salvation."

Food, energy and the protection of our environment are the three most important items among the forces which control or move the streams of leadership, be it in scientific, economic, or political circles. In some countries the intensity of these items varies, but they are of universal importance.

To us, it is a great satisfaction having in Puerto Rico such a great scientist as Dr. Alexander, to whom, in a large measure, we owe the organization of this symposium. He is also distinguished by his findings in the field of investigation of biomass, in which he has determined that Sordan 70A has been identified as the first authentic biomass resource for a short rotation crop, yielding an average of five tons per acre of dry material in ten (10) weeks. We are sure that new findings will be accomplished in the next few years in which the genetical qualifications of the *Saccharum* species are revised, finding improved expectation in the role of biomass as a renewable energy resource. We feel that biomass should be included in Puerto Rico's energetic plan, and should be directly related with Puerto Rico's public agricultural policy.

Both should be considered as a whole, firm and decisive, as a possible answer to our future energy problems, not only from the energetic viewpoint, but also with regard to economic, agricultural, and social considerations.

Our sugar industry, at the same time, would have to respond by obtaining the maximum possible production per acre, in accordance with the known potentials for our land and climate, given our best management efforts. There must be a motivation of our technical personnel in order that the industry may respond to our necessities, including the indispensable food production within the framework of the best possible use of our mechanizable 270,000 acres. We must admit that our role as an exporter of sugar to the continent is no longer possible or desireable owing to the rise in prices of our imported foods. These are prices which will keep on rising progressively, while, on the other hand, the decline in sugar prices have converted the industry into a losing business in our community.

Without a doubt, the progress obtained by other countries is impressive, especially that of Brazil, where they obtain 20 gallons of ethanol per ton of cane. In Brazil at present they have increased their production and use of sugarcane in a manner corresponding to the favorable conditions existing in permitting in turn that country, Brazil, to confront her energy crisis and to favorably adjust her balance of payments.

The Brazilian approach is permissible in that country due to its potentially large agricultural regions many of which are still unexplored. During mid-1978, a firm by the name of Verago formed a partnership between the Brazilian government and a private American entity. They have dedicated their business to the production of ethanol using as a base the crop known as cassava (mandioca), cultivating 182,000 acres at mina gerais. Based on a yield of 533 gallons of ethanol per acre, this firm will produce the tremendous yield of 97,006,000 gallons of ethanol, and this is only one of seven firms that are cultivating cassava for this purpose.

When we have seen a firm with exploits agriculturally 182,000 acres (which is nearly all of Puerto Rico's mechanizable land) our attitude towards renewable energy resources becomes contagious; we are filled with admiration and we are stimulated to imitate the process. Our question to you, is, can we and should we do it without first revising our realities and our resources?

I must answer for myself, that in an Island whose populational density continues growing, we necessarily have to draw a balance between the government's objectives, and an intelligent use of the land. Land which has a high potential for a determined use should consistently be destined to that use; and every piece of land should be used as intensively as possible in consonance with other objectives of our community. This means that units of exploitation should be more compact and more intensely developed than they are at present.

I still have in my mind the thoughts voiced by the distinguished writer Uslar Pietri, who warned us:

> "At the growing rate of our capacity for consumption and destruction of our natural resources, and breaking the irreparable ecological balance that made possible our life in this terrestrial globe, we could, in two or three centuries to come (at the most), convert the planet which we are inhabiting into a steril globe which would wonder through the dark solitude of space and carry the hardly noticeable traces of a civilization fatally extinguished by its own inunderstandable impulse towards growth."

It is up to you, distinguished technicians and scientists, to draw your conclusions, and, from the pragmatical approach to which you reach the same, will emerge the changes in the priorities which up to now we have established.

We are truly grateful for the presence of all the distinguished visitors who are giving such interesting and profound presentations in relation to a subject which is of universal importance.

SUGARCANE AS A SOURCE OF FUELS AND CHEMICAL FEEDSTOCKS

Presented To

A SYMPOSIUM ON ALTERNATE USES OF SUGARCANE FOR
DEVELOPMENT IN PUERTO RICO

Caribe Hilton Hotel, San Juan, Puerto Rico
March 26 and 27, 1979

Contributed By

Fuels from Sugar Crops Program
Battelle Laboratories
505 King Ave., Columbus, Ohio 43201

SUGARCANE AS A SOURCE OF FUELS AND CHEMICAL FEEDSTOCKS

Table of Contents

SUGARCANE AS A SOURCE OF FUELS AND CHEMICAL FEEDSTOCKS

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ABSTRACT

Fuels from sugar crops concepts are reviewed in the context of U.S. National requirements for alternate motor fuels and motor fuel additives. Strategies are presented for motor fuels research and production as presently perceived by the U.S. Department of Energy. Together with a series of conversion alternatives for sugarcane juice and fiber, the various states-of-the-art are updated in the context of on-going research by both private and DOE-sponsored research organizations. Special emphasis is directed toward ethanol yield increases and cost reductions, and toward the roles to be filled by sugarcane as a direct source of fermentable solids and of fermentation substrates eventually to be recovered from the cellulose-hemicellulose-lignin complexes of bagasse.

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SUGARCANE AS A SOURCE OF FUELS AND CHEMICAL FEEDSTOCKS

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UNDERSTANDING of the magnitude of the energy problem is growing slowly because the residents of the United States have been protected from the full impact of international price increases. As gasoline and natural gas prices become deregulated and as the impact of the Iranian production cutbacks become apparent, interest in alternative fuel sources will accelerate. Because Puerto Rico has virtually no fossil fuel reserves, and much solar insolation, fuels from biomass is especially appropriate for this Commonwealth.

The mission of the U.S. Department of Energy is to bring the supply and demand for energy in the United States into reasonable balance, with emphasis on domestic sources of supply. The nature of U.S. energy demand is such that the highest priority is assigned to transportation fuels, the petroleum for which is increasingly imported from OPEC countries. Clean gaseous fuels that can be used as substitutes or extenders for domestic natural gas also have high (but not the highest) priority. Electricity is of high priority, but domestic fossil sources appear likely to be the major sources of this form of energy.

DOE and sugar growers/processors have different goals, but they can be reconciled to the benefit of both parties. The sugar industry needs to obtain more profit, and fuels production is one route to this goal. DOE makes distinctions among alternative uses for ethanol and other sugar-based products that profit-oriented growers/processors cannot make. For example, ethanol for industrial uses is economically attractive for sugar processors who have molasses available at low cost. Ethanol from molasses fails to meet DOE's criterion for high volume fuel production.

The Fuels from Sugar Crops Program of the Department of Energy started in 1975 with a systems study by Battelle Columbus. Since then, a multi-faceted, cooperative program has been built up which involves many of the major elements of the U.S. sugar establishment. The major

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thrust of DOE's program is the development of economical transportation fuel extenders and improvers. Substitute natural gas and electricity are not excluded, but the characteristics of sugar crops and the economics of the alternative fuel goals render transportation fuel applications the most long-range promising DOE goal at this time.

STRATEGIES

The major transportation fuels are gasoline and diesel fuel. The three major strategies that may be employed to convert sugar crop biomass to chemicals for combustion in these engines are:

1. Ferment simple sugars to fuels
2. Convert nonsugar fractions to fuels
3. Upgrade nonsugar fractions to reduce the net cost of fermentable sugars.

The most well-known example of fermentation of simple sugars to a fuel extender is the production of ethanol for blending with gasoline to make gasohol. Thermochemical conversion of bagasse to methanol would be an example of making fuels from the nonsugar fractions. Separation of rind fiber from sugarcane so that pulp for papermaking could be produced along with fermentable sugars is an example of upgrading the nonsugar fractions to reduce the net cost of fermentable sugars. Each of these strategies has been explored in some detail and has its merits.

ALTERNATIVES TO ACHIEVE GOALS

Implicit in the transportation fuel goal of the United States is the need for large quantities of liquid transportation fuels at selling prices that are politically viable. The high prices (approximately $2 per gallon) of gasoline in Brazil, Japan, and other countries are not politically acceptable at this time in the United States. Therefore, economic considerations are very important in selection of specific gasoline extenders and raw materials from which they are made.

JUICE AND FIBER CONVERSION ALTERNATIVES

As illustrated in Figure 1, sugarcane stalks can be squeezed to produce juice consisting primarily of water, fermentable sugar, and a mixture of salts, proteins, and nonfermentable polysacchrides. The fibrous residues of this juice extraction (bagasse) consists primarily of cellulose, hemicellulose, and lignin. Sugarcane juice is readily fermented to ethanol or other chemicals. Sugarcane juice is a more desirable fermentation substrate than either molasses or starchy grains. Molasses includes degradation products that arise from harsh thermal treatments of sugars in the crystallization process. Starchy grains require enzyme treatment to produce fermentable sugars. Serious mechanical problems arise in conducting the fermentation and subsequent distillation operations in the presence of ground corn. The output of the fermentation of sugarcane juice is sufficiently expensive, due to the cost of sugarcane, that it must be used either for motor fuel or for such high-quality fuel markets as cooking or peak power generation.

The bagasse from sugarcane juice extraction traditionally has been used for generation of steam and electricity. Conventional bagasse combustion units have been run as incinerators as much as energy generators. With the development of a market for electricity derived from bagasse, the engineering challenge is to consume as little steam and electricity as possible within the sugarcane processing facility and to be able to sell as much as possible into the electric grid. This opportunity is much greater for Puerto Rico than it is for the mainland United States because of the high selling price of electricity in the commonwealth and because of the lack of viable alternative fuels.

The production of synthesis gas (carbon monoxide and hydrogen) from fibrous residues is old technology that is undergoing improvement. Synthesis gas can be sold as a medium BTU gas, converted into methane for cooking and other high value gaseous fuel uses, or into methanol for liquid motor fuel markets.

Ethanol, methanol, methane, and synthesis gas may be employed as chemical feedstocks, a market that has higher economic returns that does the fuels market. However, chemical markets yield higher returns only for those organizations that have access to marketing skills, technical service, and other elements required for success in a chemical venture. In practice, fuels markets may be superior because there are many more fuel buyers than there are chemical buyers.

The production of chemicals and fuels can be used to control the supply of table sugar, as shown in Figure 2. Thus, when the price of table sugar is relatively high, greater profits are made by selling as much crystalline sucrose as possible. When sucrose prices are low, the otherwise burdensome inventory is reduced, before it is even crystallized, by direct conversion of the sugarcane juice into ethanol or other fermentation-derived chemicals.

ALTERNATIVES TO CONVENTIONAL JUICE EXTRACTION

Realistic estimates of the cost of a facility integrated to produce ethanol, electricity, and the distillers by-products indicate that the total inestment of approximately $60 million is divided as follows:

1. $36 million for preparation of the sugarcane for fermentation
2. $12 million for fermentation and distillation
3. $12 million for the facility to manufacture steam and electricity.

Reduction in the cost of obtaining fermentable sugars from sugarcane is of great importance. Richard Andersen (1) of Ander-Cane, Inc. has described the Tilby process for obtaining low-cost sugarcane juice and additional salable by-products. The reader is referred to this companion paper for details. This process is the front runner in cost reduction in ethanol and electricity production at this time.

An alternative concept for reducing the cost of ethanol production from sugarcane is the Ex-Ferm process under development by Dr. Rolz (10) and his associates at ICAIITI (Figure 3). Sugarcane is crushed by hammer mills or similar crushing equipment and exposed to yeast in a fermentor. No attempt is made to separate the bagasse from the sugarcane juice. The fermentation conditions resemble those of grain fermentation in that there is a high concentration of inert solids that cause materials handling problems. However, these problems are offset by the significantly lower capital investment involved. The fermentation is slower and repeated additions of fresh crushed cane are needed to achieve commercially significant ethanol concentrations. This process clearly merits evaluation because it saves on capital investments and operating expenses that are known to be high for juice extraction.

ETHANOL YIELD IMPROVEMENTS

The yield of ethanol from sugarcane at first appears unimprovable. The ethanol-producing yeast converts virtually all the sucrose, glucose, and fructose that it encounters into ethanol. Small losses occur in fermentable sugar consumption for replacement of yeast cells, but elimination of all such losses would be a small improvement. Nevertheless, significant opportunities exist for increasing yield of ethanol from sugarcane. The opportunities arise from the possibility of making simple fermentable sugars from the five-carbon and six-carbon sugar polymers known as hemicellulose and cellulose.

Considerable progress has been made in recent years in the conversion of lignocellulosic materials into simple sugars for conversion to fuel and chemical feedstocks (Figure 4). The principal problem with conventional technology to convert cellulose to glucose is that treatment with mineral acids yields glucose degradation products while enzyme hydrolysis proceeds at unacceptably slow rates and results in low overall yields. Research on the Purdue process (11) and the Iotech process (8) has shown two approaches for facilitating cellulose hydrolysis. In the Purdue process, the cellulose is rendered amorphous, which facilitates either enzyme hydrolysis or acid hydrolysis. In the Iotech process, lignin is stripped from the cellulose and microfibrils are produced that are readily hydrolyzed. Although much development still is needed on these concepts, approaches to rapid, controlled hydrolysis of cellulose now appear much more feasible than previously.

Unlike cellulose, hemicellulose is relatively readily hydrolyzed to monomeric five-carbon sugars without much degradation and reasonable hydrolysis rates are achieved. However, conversion of five-carbon sugars into ethanol or other fuel molecules by conventional fermentation technology results in relatively low yields and requires lengthy fermentation cycles. Recently, micro-organisms that are said to be capable of making 2-3 butanediol and ethanol from five-carbon sugars at reasonable rates and yields have been evaluated in small scale experiments (3). Although many research and development hurdles must be overcome, there is hope in this area also.

Successful development of processes to make fuels and chemical feedstocks from the fibrous portions of the sugarcane plant can almost double the yield of this resource. Thus, the availability of fuel increases, and the revenue per acre of sugarcane increases.

ALTERNATIVE CHEMICALS FROM ETHANOL

Numerous alternative chemicals can be manufactured from primary fermentation products of sugarcane, though none of the chemical markets are anywhere near the size of the fuel markets. However, some of them have attractive profit margins. In addition, the replacement of petrochemicals with sucrochemicals is a means of indirectly manufacturing petroleum because the petroleum that is not used for petrochemical manufacture can be used for fuel manufacture (4).

Because ethylene has a market of about 25 billion pounds per year and is readily made from ethanol by well-known dehydration technology, it is a superficially promising target for manufacture from fermentation ethanol (Figure 5). However, closer examination shows that ethylene is not such a good choice. When one pound of ethanol is converted to ethylene, only 0.6 pound of ethylene is made with the remaining being 0.4 pound of unsalable water. If the ethanol costs $0.15 per pound, the raw material cost of ethylene is $0.25 per pound. The current selling price of ethylene is only $0.13 per pound and it has risen only a few percent since 1975, which means that its selling price in real dollars has declined dramatically during that time.

As shown in Figure 6, the situation gets better when oxygen, water, or other inexpensive ingredients are added to ethanol, because then the arithmetic works in favor of ethanol. Both conventional catalytic processes and enzymatic processes are known for conversion of ethanol to acetic acid. The source of the extra oxygen ultimately is air. In theory, ethanol could be converted either to ethylene oxide or ethylene glycol. Straightforward processes to accomplish this feat are not available at this time and would be a promising area for research. When ethanol is $0.15 per pound, the raw material cost of ethylene glycol made from this raw material would be approximately $0.11 per pound. This is approximately one half the present selling price of ethylene glycol.

The production of 2,3-butanediol from fermentable sugars (Figure 7) is under development (3). This four-carbon product has the advantage that it may be possible to solvent extract it from the fermentation mixture rather than use energy-consuming distillation. 2,3-butanediol is a source of methyl ethyl ketone (MEK) and butadiene which are major petrochemicals. MEK is an important solvent with a present market of approximately 0.5 billion pounds. This market could increase substantially, especially since MEK has a high energy content and desirable volatility for fuel applications. Butadiene has a 3.2 billion pound per year market in rubber products. The usefulness of simple arithmetic can be illustrated by comparison of the opportunity to convert 2,3-butanediol into MEK and 2,3-butadiene. If butanediol were $0.15 per pound, the raw material cost of butadiene would be $0.25. Whereas, the raw material cost of MEK would be slightly under $0.19 per pound. Yield calculations are not the only criteria, however, because butadiene may be more readily separated from the reaction mixture than would be MEK.

ETHANOL COST REDUCTION

Aside from sugarcane processing improvements, the four major elements in ethanol costs reduction are:

1. Cost of fermentable sugars
2. By-product credits
3. Length of fermentation season
4. Steam requirements for distillation and stillage processing.

In sugarcane growing areas where the season is relatively short, narrow-row spacing can help reduce the cost of fermentable sugars (5). As described in Mr. Andersen's companion paper, by-product credits can go far toward reducing the costs of ethanol. Studies conducted by F. C. Schaffer and Associates compare the costs of ethanol from fermentable sugars available for 90 days, 180 days, and 330 days. The shortest fermentation season leads to an ethanol selling price of nearly $2.00 per gallon, while the 330-day season leads to a selling price of approximately $1.20 per gallon. Thus, long seasons are favorable.

A dramatic improvement in ethanol cost reduction has been in the area of steam consumption for distillation. Conventional ethanol distillation that was incorporated in World War II facilities requires about 50,000 BTUs per gallon of ethanol. When one considers that ethanol contains only about 84,000 BTUs per gallon, it is clear that this distillation is not only costly but also injurious to the energy balance. In recent Schaffer studies for Battelle/DOE, it has been shown that more modern technology requires only about 30,000 BTUs (7).

Still more modern technology (12) involves further optimization and use of diethyl ether in the pressure distillation approach. This technology can distill ethanol for 21,000 BTUs per gallon on a demonstrated basis. There are conceptual designs that have not been translated into functioning ethanol facilities that claim to require approximately 18,000 BTUs per gallon (6). There is such dynamism in ethanol distillation technology that a 1985 goal of 10,000 BTUs per gallon of ethanol could be set.

ETHANOL VERSUS METHANOL

Ethanol has always had a cost disadvantage with regard to methanol. The superior performance of ethanol in gasoline blends has compensated for the 25-50 percent lower cost of methanol proclaimed by its advocates (9).

When methanol is available cheaply enough, it can be subjected to the Mobil process to make a genuine high octane unleaded gasoline (2). Also, when engines are designed to run with methanol, its performance disadvantage is greatly diminished. Therefore, any technology that will further reduce the cost of methanol made from trees or agricultural residues is noteworthy.

The development of multisolid fluidized bed (MSFB) technology is a method which may reduce the cost of methanol considerably. MSFB technology uses a dense fluidized bed to hold wood chips, bagasse, or other biomass for pyrolysis (Figure 8). No oxygen is required and super high processing speeds can be attained. This new approach may indeed reduce the cost of methanol by lowering the capital investment and increasing the efficiency of the process.

UNSOLVED PROBLEMS AND OPPORTUNITIES

The major unsolved problem that needs attention before many ethanol plants using sugarcane are built is the stillage problem. Enough is known from South African and Brazilian experiences to recognize that stillage from sugarcane bears little relationship to the valuable distillers dried grains with solubles (DDGS) produced when making ethanol from corn. As shown in Table 1, the sugarcane stillage product is relatively low in protein and high in salt. It might be desalted or it might be anaerobically digested to methane wihtout having to use energy to dry it.

The development of tower fermentors permits very rapid fermentation (under 8 hours), and it may be possible to achieve quite high ethanol concentrations in them. The lack of solids in clarified cane juice means that the tower fermentors can work effectively on sugarcane juice.

ACKNOWLEDGMENT

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TABLE 1. MOLASSES DISTILLERS DRIED SOLUBLES

TYPICAL ANALYSIS	
Moisture	3.5%
Protein	10.0%
Fat	0.5%
Fibre	
Ash	38.0%
N.F.E.	48.0%

MINERAL CONTENT (%)	
Silica (SiO_2)	1.7
Iron (Fe)	0.1
Calcium (Ca)	4.9
Magnesium (Mg)	1.3
Potassium (K)	10.3
Sodium (Na)	0.4
Phosphorus (P)	0.3
Sulphur (S)	2.2
Chloride (Cl)	5.3

TRACE ELEMENTS (p.p.m.)	
Manganese (Mn)	150
Copper (Cu)	90
Cobalt (Co)	1.3
Zinc (Zn)	45

VITAMIN CONTENT (gms./gm.)	
Riboflavin	12
Pantothenic Acid	90
Nicotinic Acid	50
Choline	1,000
Vitamin B_{12}	0.04

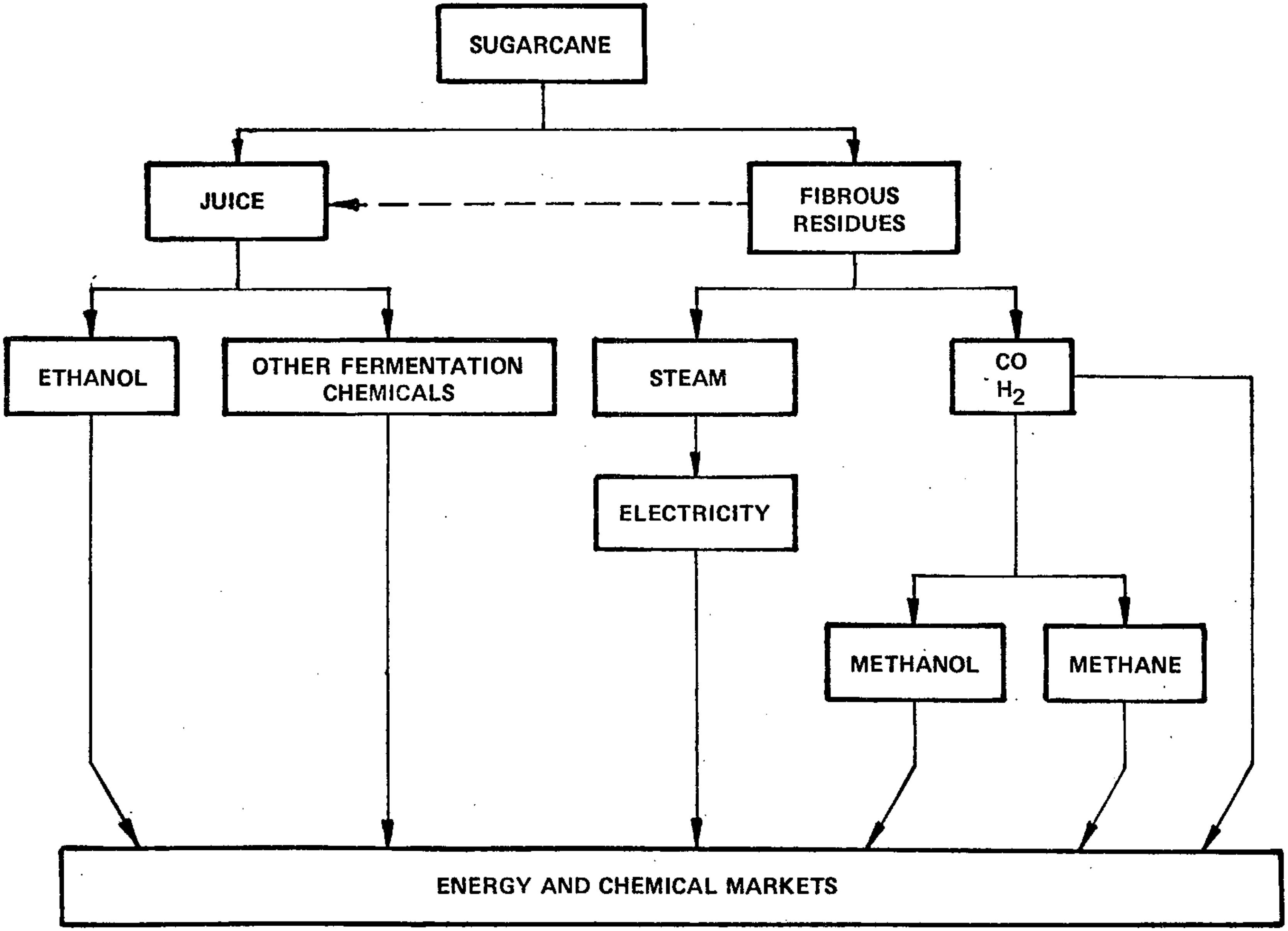

FIGURE 1. CONVERSION OF SUGARCANE TO FUELS AND CHEMICAL FEEDSTOCKS WITH CONVENTIONAL PROCESSING TECHNOLOGY.

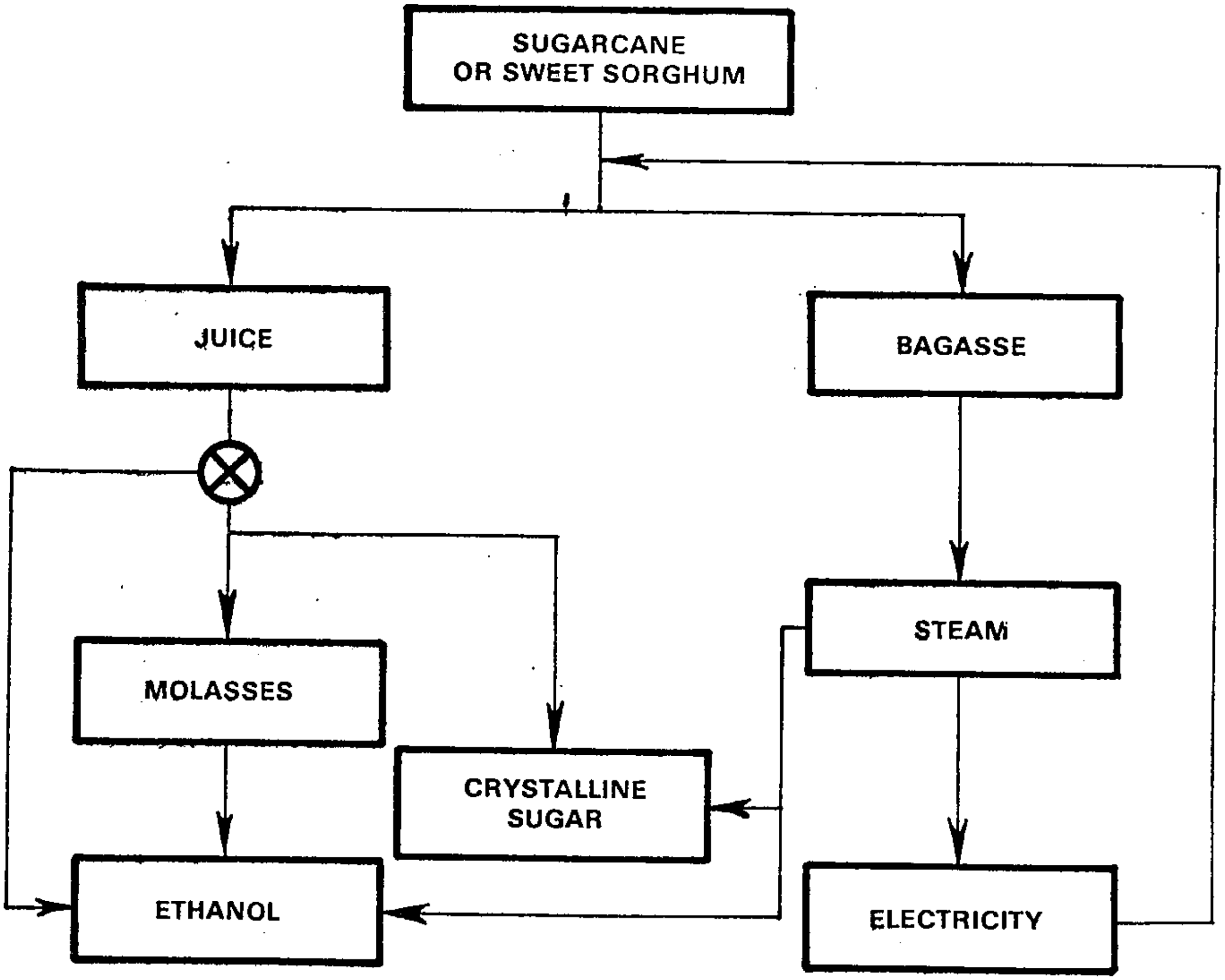

FIGURE 2. USE OF ETHANOL TO CONTROL THE SUPPLY OF TABLE SUGAR

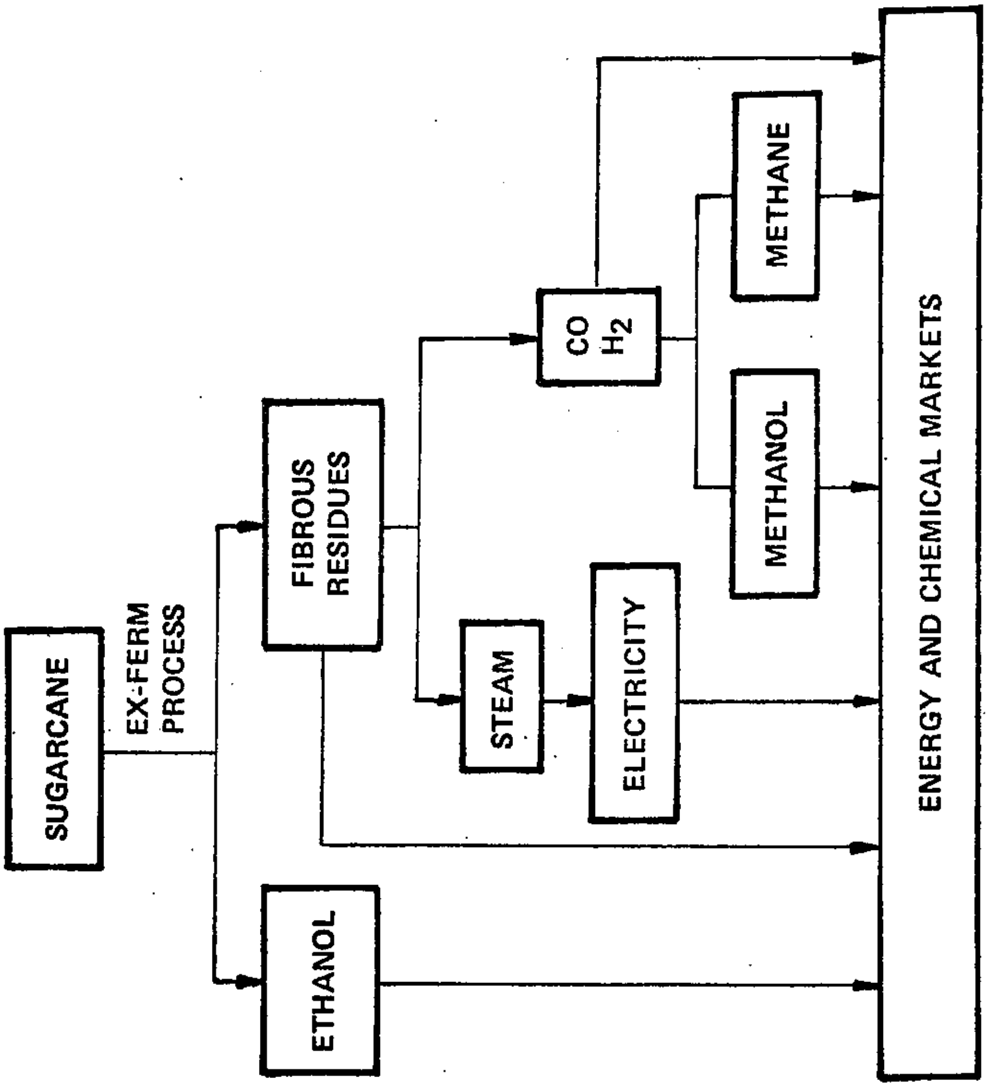

FIGURE 3. THE EX-FERM PROCESS

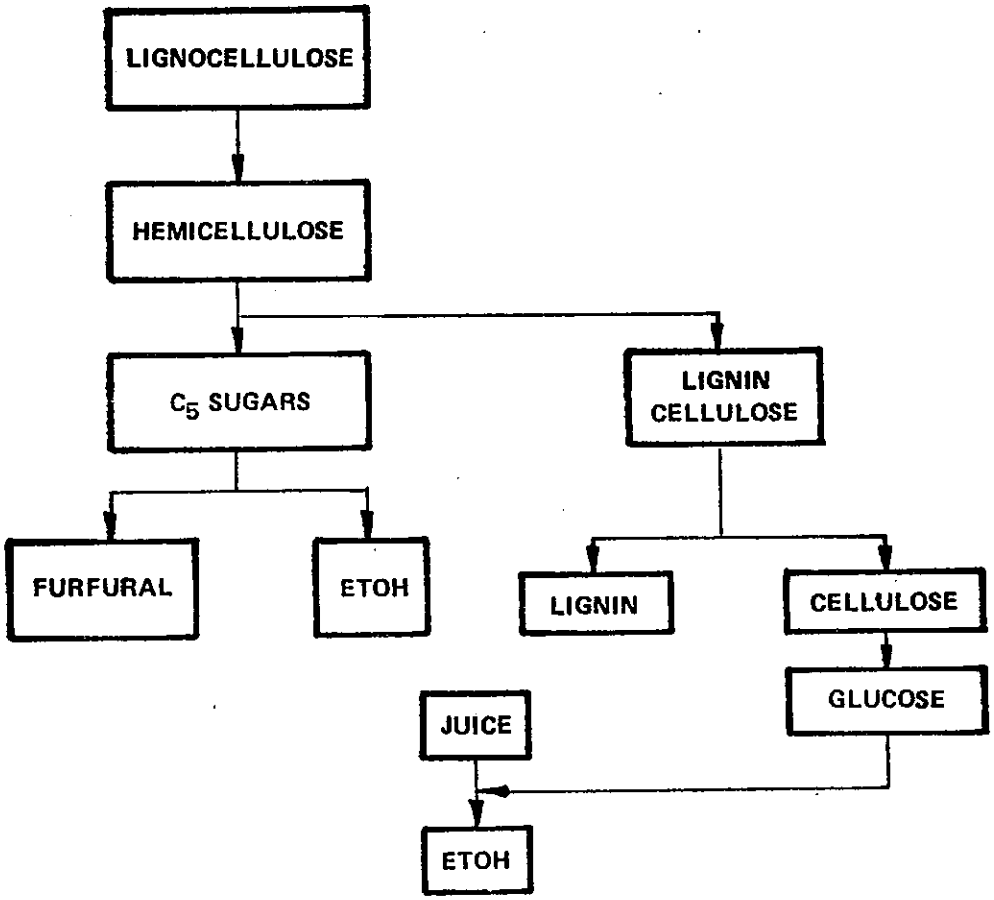

FIGURE 4. FERMENTABLE SUGARS FROM LIGNOCELLULOSE.

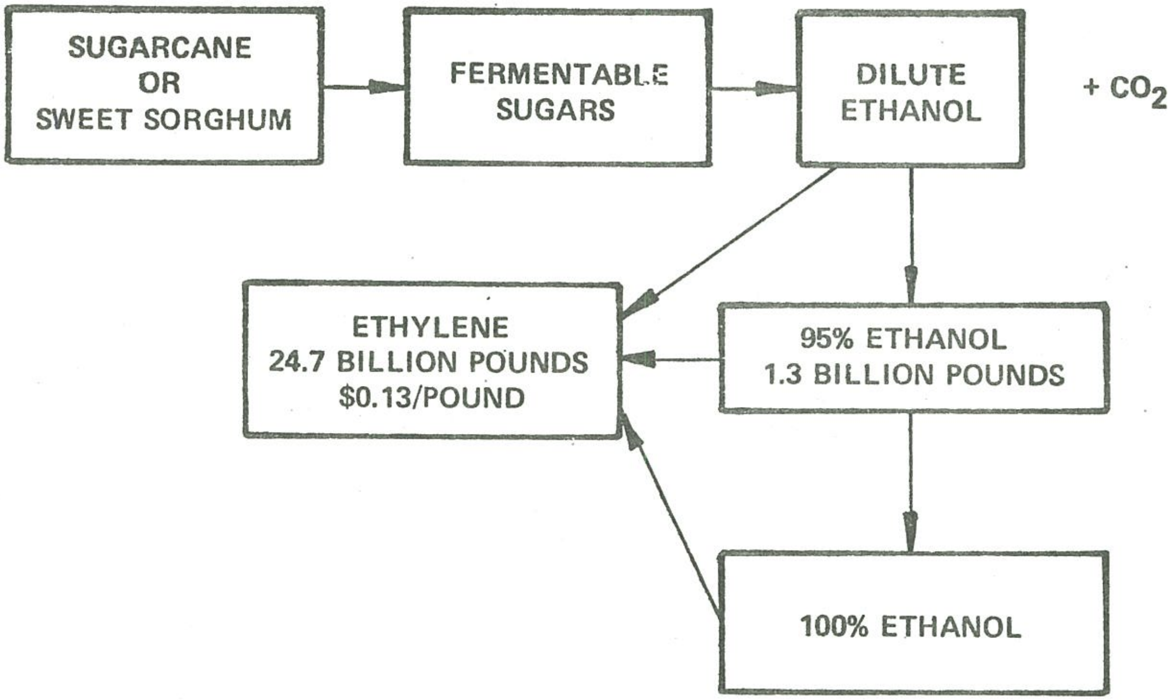

FIGURE 5. ETHYLENE FROM SUGARCANE.

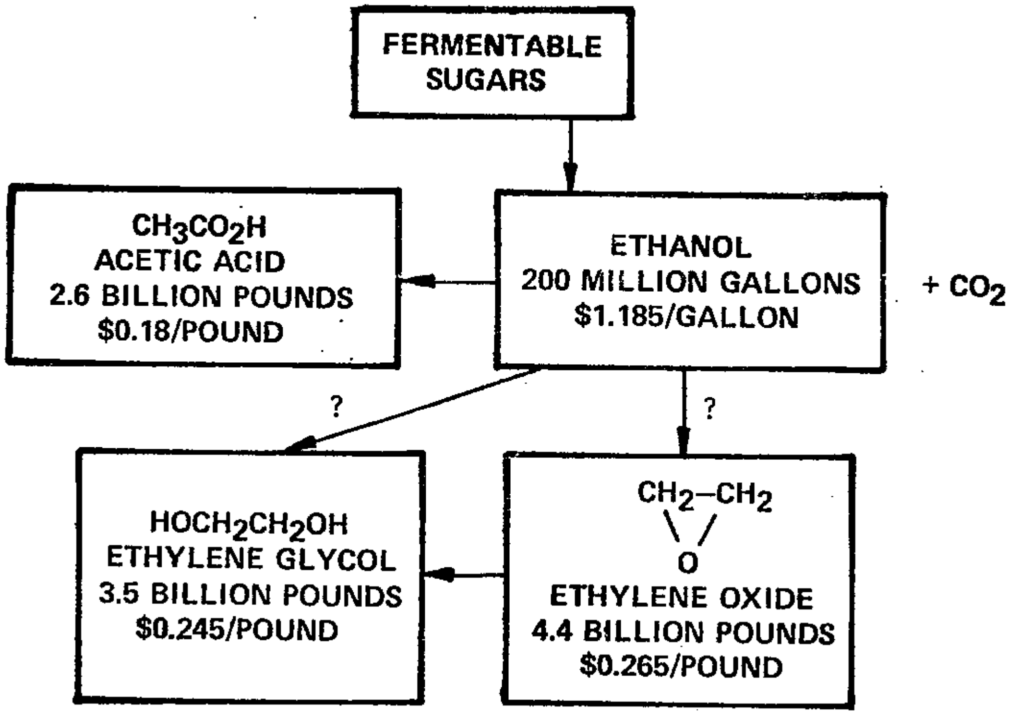

FIGURE 6. CONVERSION OF ETHANOL TO ACETIC ACID, ETHYLENE GLYCOL, AND ETHYLENE OXIDE.

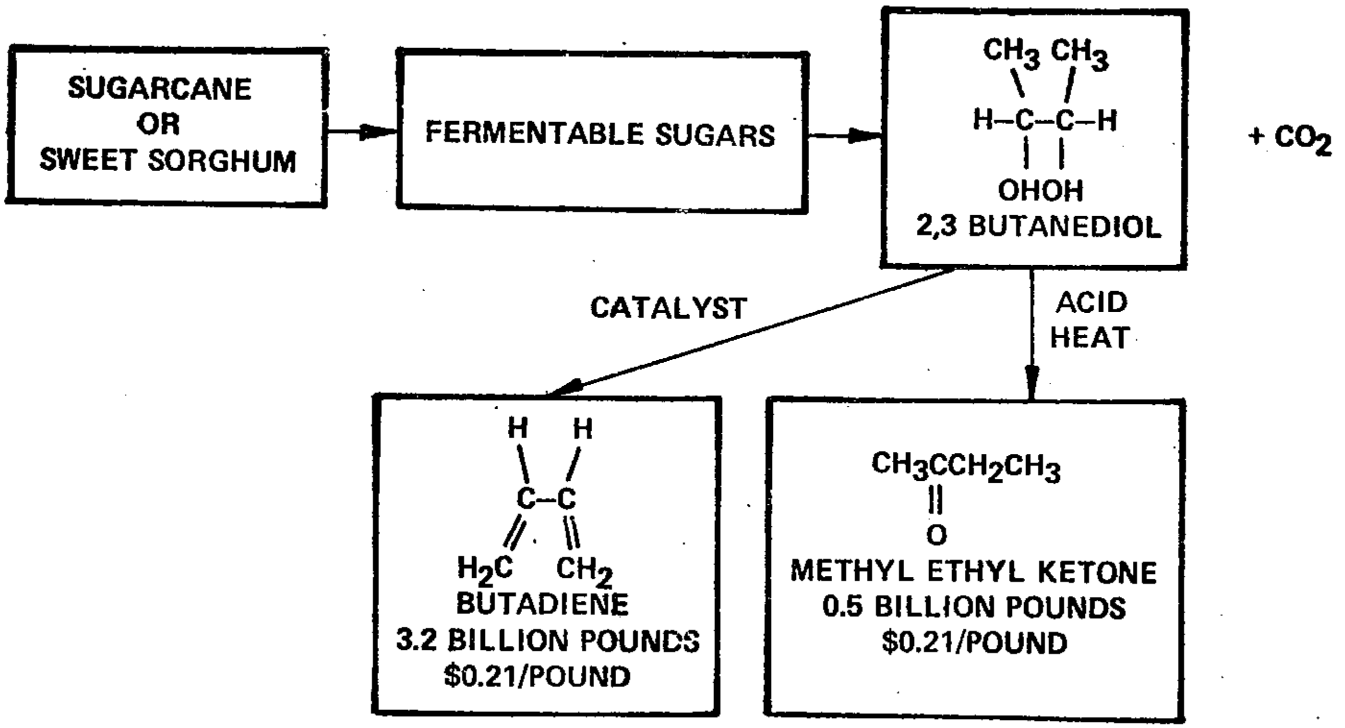

FIGURE 7. CONVERSION OF SUGARCANE INTO 2,3-BUTANEDIOL, MEK, AND BUTADIENE.

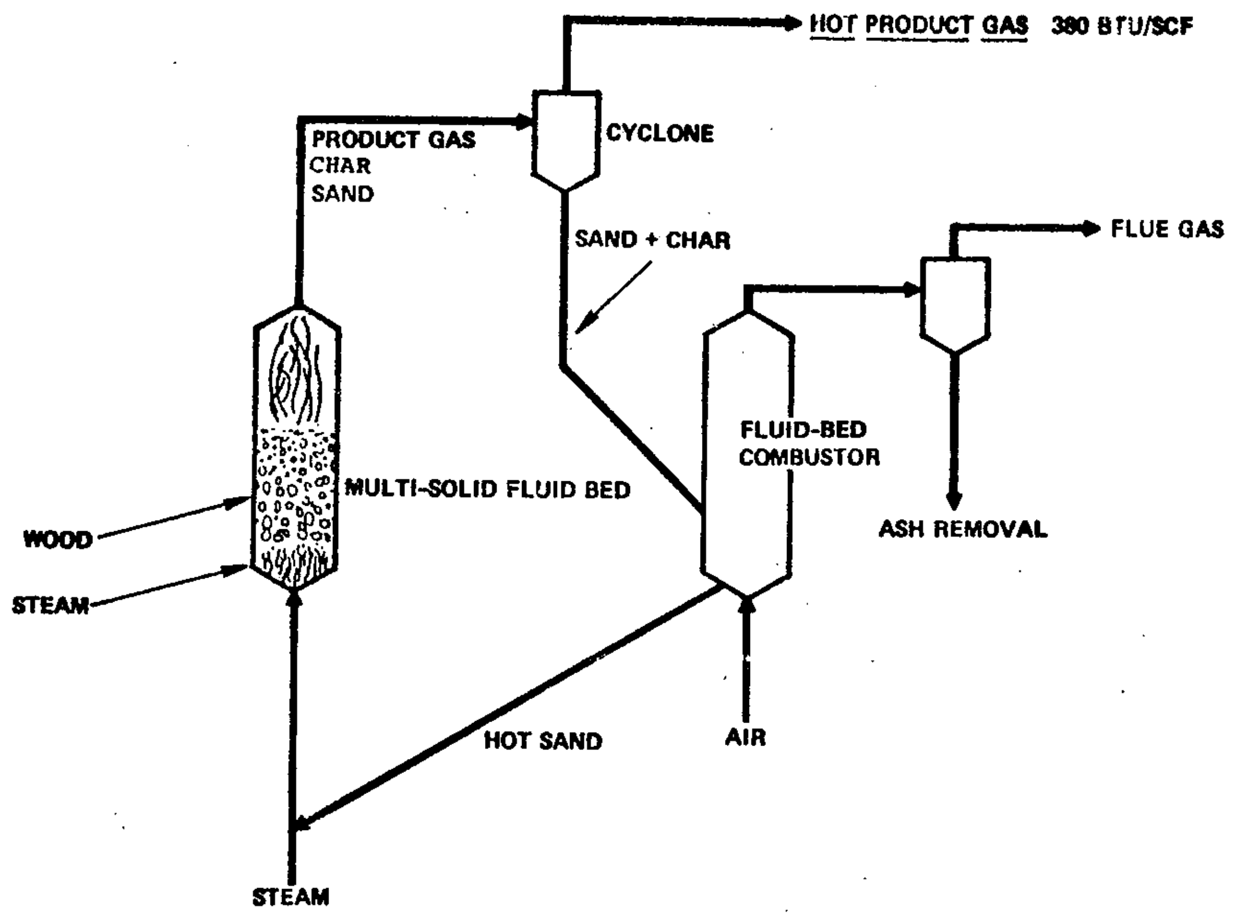

FIGURE 8. SCHEMATIC OF MSFB PROCESS

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Table of Contents

NEW PRODUCT DEVELOPMENTS FOR SUGARCANE CARBOHYDRATES

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ABSTRACT

The agricultural, processing, chemical and fermentation aspects of the use of plant storage carbohydrates (sucrose and starch) are discussed in relation to future use as food, fuel or chemical feedstock. Success of new ventures will depend on: (a) Scientific and technical feasibility; (b) the ability to produce sufficient material, and (c) political, economic and ethnic factors. Increased yields with lower inputs of energy and capital resources are essential. Priority must be given to food production. The use of carbohydrates as feedstock for speciality chemical production is likely to increase. However, the amount of material used in this way will remain low as compared with that consumed by humans or animals. Use of carbohydrates as fuel, in the production of power alcohol in particular, is feasible. However, to provide a significant part of the world's energy budget from this source will require major changes in agricultural practice or food consumption. Some of our activities in the area of plant biology, food processing, chemistry and microbiology are used to illustrate the general themes outlined above.

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NEW PRODUCT DEVELOPMENTS FOR SUGARCANE CARBOHYDRATES

INTRODUCTION

THE FUTURE exploitation of carbohydrates as renewable feedstocks will depend on three factors:

(a) The ability to grow sufficient plant material to meet all needs for food, fiber, and fuel.

(b) The scientific and technical feasibility of new processes.

(c) The influence of commercial, political, and marketing needs.

Although this paper has a very general title the content will be largely restricted to considerations of those aspects of sucrose and starch use that we are currently investigating. Obviously, cellulose will be of great importance, but this is not of immediate interest to us--and in any case it is considered in detail by other contributors to this symposium.

At present, plants containing starch and sucrose are mainly grown in order to produce food for humans and fodder for animals. The suggestion has been made that as supplies of fossil energy reserves decrease a greater proportion of chemicals, fuel and fiber requirements will again be derived from carbohydrate crops. As the world's largest sugar company, currently extended its activities into other plant based commodities, such as starch, glucose, alcohol, molasses, vegetable oils and pulses, Tate & Lyle already has the infrastructure for such activities. This includes facilities for growing, extracting, refining, shipping, storing, trading in and distributing such products on a world-wide basis. We are thus in a position to expedite the use of carbohydrates as the base for a chemical industry if and when opportunities can be identified. At present the use of carbohydrate crops for non-food purposes may appear unattractive in view of suggestions that a large deficiency of food production is predicted in the developing countries over the next decade. In other words, the use of crops as fuel or chemical feedstock will require either an increase in production or a significant change in pattern of use.

The world's plant biomass of around 2 x 10^{12} tons represents a renewable source of about

10^{11} tons *per annum* of reduced carbon. This material is largely composed of cellulose (1.4 gulcan). However, the volume of the two plant storage carbohydrates (starch d-1.6 branch points, and sucrose-D-fructofuranosyl-d-D glucopyranoside) produced by agricultural practice are extremely large. Starch in the form of grain amounts to over 10^9 tons (wheat 3.5 x 10^8, course grain 7 x 10^8, rice 2 x 10^8) with smaller quantities of root crops such as potatoes and cassava also of importance. Production of sugar from cane and beet approached 10^8 tons *per annum.* Even so, the World Bank predicts a food gap of approaching 10^8 tons of grain in the developing countries by 1985. Increased production may be expected through implementation of one or more of the following lines of action:

(a) Decrease losses, both pre- and post-harvest, due to pests and diseases.

(b) Increase yields and stability of crops in large areas which are under stress conditions (temperature or water limitations, poor soils, winds, etc.).

(c) Increase the efficiency of use of energy intensive inputs such as fertilizer, lime, and water.

(d) Increase the area of land cultivated, and decrease the rate at which good land is reverting to desert.

The effects of such courses of action may not be felt on a worldwide basis for 10-15 years, even if implemented now. The impetus to start is lacking in the technologically advanced countries as at present the problems facing producers is not one of shortage but of excess. At present, the so-called “green revolution” has its basis in breeding of high yielding varieties which are maintained by liberal use of herbicides, pesticides and fertilizers. However, the long-term effects of such applications are not known, nor are the seeds or chemicals likely to be readily available to the developing countries. Again, the establishment of high yielding but vulnerable strains over large areas where the population is critically dependent on a single crop could lead to disaster.

The prime objective in the developing countries must therefore involve increasing food production. To do this in time must involve a lot of people building rural transportation, marketing, distribution, and storage facilities before worrying about chemical or fuel production from biomass, in spite of the fact that the developing countries have the necessary conditions for the highest rates of biomass production.

In contrast, those parts of the world with a high demand for fuel and chemicals occur in regions with a lower solar irradiance and longer periods of cold which prevent plant growth. For instance, in the United Kingdom it might be possible to produce 10 kwh per year from a square meter of forest. Thus, an average household would require a land area of 1.5 x 10^3m^2 to meet present energy requirements. In turn, this would require over 50% of the land surface with a requirement to replace over 5% of the area *per annum*. This replacement would itself take up to 30% of the energy output from the forest. Such schemes are obviously not possibe, even without consideration of environmental effects. Thus in the temperate regions it is clear that agricultural activity is likely to continue to be directed towards food production, with some possibilities for the production of specialty chemicals derived from biological feedstocks.

In theory, those developing countries located between 25° north and south of the equator, where the solar radiation of over 200 $w/m^2/day$ is combined with a year round warm climate and adequate rainfall of over 1000mm *per annum*, could meet a large proportion of their energy requirements from biomass, once the food problem is solved. Our present research program is directed towards the production and use of carbohydrates as required in different parts of the world. We are thus looking at food, chemical, and energy aspects at four levels as follows:

(a) Agriculture and biology of carbohydrate crops.
(b) Processing of sugar and starch.
(c) Chemical modification of sugar and starch.
(d) Fermentation of sugars.

AGRICULTURE AND BIOLOGY

Growth of plants as a source of carbohydrate is merely one part of what has variously been termed biomass production, energy farming, or total crop utilization. The aims are: (a) to increase yields of dry matter but at the same time decrease the energy dependent inputs; (b) to use all the plant products and all wastes which arise from any processing; (c) improve use of land, water, and fertilizer; (d) identify or breed new plant species or varieties with high non-food biomass. Related studies range from fundamental work on photosynthesis and nitrogen fixation, through crop breeding, variety trials and land management.

Basic studies should be able to provide an answer to the question "how much material could be produced by photosynthesis?" The fixation of one CO_2 molecule needs a minimum of eight quanta of 680 nm light, but at least twenty quanta of solar light to provide an energy gain of 0.47 MJ mal^{-1} CO_2 reduced. However, over 40% of the carbon fixed may be lost in respiration and photorespiration. As a result, the theoretical maximum recovery of incident solar energy in plant dry matter is about 6%. In real life, in short term experiments, or in some C_4 crops with long growing seasons, values of 2 to 4% have been recorded. However, in most agricultural systems less than 1% of the available solar energy is trapped in the field and less than 0.1% is available as useful product. Table 1 shows some experimental data in which a C_4 plant (sugarcane) is compared with a C_3 plant (pea) grown over the same period (1).

The differences can be equated to various extent with differences in growing season, photosynthetic mechanism, and photorespiratory losses. Most temperate (C_3) species fix CO_2 in the reaction catalysed by ribulose *bis* phosphate (RBP) carboxylase to give a three-carbon product, phosphoglyceric acid (PGA). Oxygen may also react at the same binding site to produce one molecule of PGA and one molecule of the two-carbon phosphoglycollate. The phosphoglycollate is then oxidized, giving off CO_2, in the process of photorespiration. As a result, between 15 and 30% of the carbon fixed initially may be lost. In the C_4 plants an additional mechanism exists in which the CO_2 is first trapped into a four carbon acid (oxaloacetic acid - OAA) in the cytoplasm. This is then "pumped" to the chloroplasts where the CO_2 is released and refixed as in C_3 plants. As a result of this pump the CO_2 level is kept high in the region of the RBP carboxylase. Hence, the oxygen effect and photorespiration is reduced. However, this is only achieved at a cost in terms of energy as the C_4 process required at least 15% more energy to drive it in the direction of net synthesis.

As a result of the long growing season in many regions and the possession of the C_4 pathway, sugarcane is one of the highest net producers of biomass (Table 2). The figures presented in Table 2 can be compared with the theoretical maximum suggested by Bassham (2), amounting to 70g of starch produced per square meter per day—equivalent to 263 metric tons per hectare per year.

The net energy gain of any crop system will depend on the extent to which mechanical or hand labor is used. Again, figures are available (3) for the sugarcane plantation which suggests that this may represent the optimum agricultural system for energy production. The other possibility is cassava production. Although cassava is a C_3 plant, high yields of starch may be obtained. At present in many areas cultivation methods are poor and considerable room for improvement exists. However, the sugarcane crop still represents the best means of harvesting solar energy by higher plant photosynthesis. The formation of ethanol by fermentation of cane juice is one of the few systems with a favorable ratio of energy recovered in useful products to fossil fuel imputs. Increased production of sugarcane for such purposes requires large capital inputs (at a time when both sugar mills and refineries are being closed due to political and economic factors) if it is to be realized by the creation of new plantations or extension of existing facilities. However, costs of increasing the production rates of existing crops by better management or chemical modification by use of cane ripeners are much lower. Our studies on cane ripeners range from observations of the effects of known commercial compounds, on the levels of enzymes and biochemestry of the cane plant, to the identification of novel compounds—in particular those which could produce their effects by inhibiting the assimilation of nitrogen.

Carbon assimilated by photosynthesis may be used for growth requiring the incorporation of nitrogen into amino acids and lignin for protein and cell wall synthesis. The mechanism whereby atmospheric nitrogen is reduced to ammonia in both free-living and symbiotic bacteria is known, as are the major routes of nitrate reduction and subsequent assimilation of ammonia through glutamine synthetase or glutamate dehydrogenase. However, what is not known is the importance of factors such as regulation at both the enzyme and cellular levels, which ultimately control the size and composition of the crop. For instance, in a legume, is the substrate-sparing effect of added synthetic N-fertilizer favorable in terms of cost and energy, when compared with the alternative of a possible lower total yield produced by many crops relying on symbiotic N-fixing bacteria? In this context, of particular interest are reports that a symbiotic association may occur between roots of certain C_4 plants and some N-fixing bacteria (4). The significance of such association in relation to cane is being investigated. At the next level of association there exists the possibility of increasing fertility of soils by the addition of free living bacteria such as *Azobacter*. This is of particular interest to us since large quantities of such cells amy be available as a by-product of one of the microbial polysaccharide fermentation processes mentioned below.

At present much of this work remains at the laboratory level. However, it is hoped that such studies will be extended to complement field trials leading to greater productivity or better use of existing resources to raise production nearer to the theoretical levels.

PROCESSING

Traditionally, sugar is produced from cane in a two stage process–row sugar production in the country or origin followed by refining, often after export. Milling of 100 tons of cane stalks produces about eleven tons of raw sugar (98.6% sucrose), 2.7 tons of molasses, and three tons of filter mud. In addition, a variable quantity of bagasse, excess steam, or electricity will be produced depending on the efficiency of operation. In theory, an excess of five tons of bagasse and 1300 kwh of electricity should be available. However, in practice these figures are often not realized, mainly due to problems in adequately dewatering the bagasse to the 40% moisture necessary for use as boiler fuel.

The three main stages, juice extraction, clarification (removal of impurities) and crystallization, have all been examined by us. The most striking advance has been in clarification where the traditional methods of precipitating impurities with lime followed by CO_2 or phosphoric acid have been supplemented by new processes in which either polyacrylamide or quaternary ammonium compounds are used to flocculate the impurities and colorants (5). These processes marketed under the Talo trademark, may be applied either to row juice clarification (TALODURA) or to the refinery situation (TALOFLOC). The TALODURA process is for the clarification of thick juice from the evaporator in a raw sugar factory. It is a flocculation process which removes nearly all the suspended insolubles from the pan feed syrup, following addition of a charged polyacrylamide gel at low concentrations. This leads to a substantial improvement in the quality of raw sugar produced, and more important to a significantly higher (1 %) overall raw sugar recovery from the factory.

The TALOFLOC process is essentially similar but of importance in the sugar refinery where simultaneous clarification and decoloration of refinery liquors may be achieved at reduced cost (both operational and capital). In this process high molecular weight anionic colorants and other impurities are precipated by complexing with dimethyl dialkyl quaternary ammonium chloride. The precipated color and other insolubles are flocculated by phosphate ion and then separated by flotation using polyacrylamide floation aid (TALOFLOTE) similar to that used in the raw sugar process. Advantages of the system are again in terms of operational and capital costs. With the high flotation rates the clarifier retention time can be reduced from hours to minutes, hence the actual size can be reduced to about one-third of conventional clarifiers. Lower operating temperature and short retention time lowers heat requirement and at the same time reduces sugar loss due to thermal degradation. Such sugar loss will also be lower than those of the conventional carbonation process due to the lower operating pH preventing alkaline degradation reactions. Again, due to removal of color and impurities, the use of both filter aids and carbon or char for decoloration is also reduced, or abolished. The possibilities of extending this technology to starch processing are currently being considered.

As far as juice extraction is concerned most factories operate what is essentially a roller mill. Alternatives include the use of a hammer mill, possibly preceding extraction by diffusion or as feed to a roller mill. One development which could be of importance especially in relation to smaller scale processing is the Comfith process developed in Canada and now under development by Hawker Siddeley (Canada) Ltd. In this, the cane is cut into short lengths, split lengthwise, the pith removed from the rind and wax, and three separate products—wax, rind and pith—are collected.

Originally this was developed for animal feed production. More recently interest has been renewed in respect to juice production. Problems arise, however, in feeding cane at the proper alignment at a high rate, and in extracting the sugar efficiently from the pith. Sugar is also lost in the rind fraction. However, the possibility of this type of approach producing savings in capital cost remains. It has also been suggested that the color content of juice obtained in this way should be lower than that produced by conventional means. Although the level of color is in fact higher in the rind of the cane than in the pith, we have found that in both cases the juice must still be processed in order to remove high molecular weight impurities. During such clarification, using lime, the difference between the two types of juice disappears. On the other hand the Comfith process could have advantages in systems for the direct production of alcohol from cane (7).

The third area of sugar processing which we have investigated is the crystallization stage. This is traditionally both a recovery and a purification step as it results in a ten-fold reduction in impurities in the crystal relative to the mother liquor, with a crystal yield of some 50%. However, for many purposes dehydration of the sucrose syrup without purification is quite satisfactory. Since sucrose has a positive heat of crystallization it is possible to evaporate an aqueous solution until it is super saturated yet unnucleated and of such a concentration that when all of the sucrose is crystallized there is sufficient heat liberated to evaporate the remaining water. The only other requirement is that crystallization and therefore heat liberation is fast enough to be effectively adiabatic, avoiding heat loss other than from water evaporation. These conditions can be met by a 90% sucrose solution boiling at about 125°C. The phenomenon in itself is not new. However, the process required careful control in order to produce sugar in the form required. We have now developed such a process which has passed pilot trials and awaits commercial development. The advantages over conventional crystallization are again in lower capital costs and energy requirements.

As far as the processing of starch is concerned, our efforts so far have been directed towards improvements in methods for the production of glucose syrups from refined starch, rather than production of starch feedstock itself. The major form to which starch is modified for the food industry is as glucose syrups, which are products in which the starch has been hydrolyzed to a varying degree using either acid or enzyme methods, traditionally using batch methods. Again both capital and operating costs can be reduced by running continuous processes which in the case of enzyme hydrolysis means the use of immobilized enzymes. Of particular importance, especially in the U.S.A., has been the use of immobilized glucose isomerase, which will convert a high DE glucose syrup to a mixture containing about 45% fructose. A second enzyme of interest is amuloglucosidase, which saccharifies thinned starch to glucose. In collaboration with AERE Harwell a process has been developed in which the enzyme is immobilized on a rigid innert inorganic support material. Studies using a 25 liter pilot column of this enzyme have demonstrated that its productivity and longevity are such that it will be cheaper to use than the soluble enzyme, as well as requiring only a small fraction of the present volume.

CHEMICAL MODIFICATION OF SUGAR AND STARCH

At present the extent of further modification (or use in non-food manufactured articles in a modified form) of plant based carbohydrates is in more or less reverse relationship to their natural abundance. For instance, plant gums, alginates, carragenans, etc., find uses as adhesives, thickeners, binders, suspending agents, sizes and emulsifiers. The bulk of sucrose is refined to a high degree of purity (over 99%) for consumption by humans. In contrast, much of the starch produced is consumed as grain or tuber, or with little processing other than milling to flour. Cellulose as cotton, fiber, wood chips, or as paper, card or pulp retains both its fibrous and cellular integrity.

Apart from serving as a substrate for fermentation very little sucrose is used directly as an industrial raw material. There are several reasons for this. The sucrose molecule is not chemically an ideal starting material although a wide range of products may be formed from it by degradative reactions such as shown in Figure 1 (8). However, so far only catalytic hydrogenation to form sorbitol and manitol have gained any commercial importance. In general, the degradative products will be of lower molecular weight and accordingly readily synthesized from cheaper carbon sources or waste carbohydrates. It is also possible to produce a wide range of derivatives of sucrose in which the basic disaccharide molecule remains unchanged, but in which one or more of the hydroxyl groups are substituted for by an alternative chemical group (Fig. 2).

Of the eight hydroxyl groups, three (C-6, C-1' and C-6') are primary and the remaining five are secondary. In most reactions the primary groups react preferentially, and a wide range of substituted compounds have been prepared. These include two classes of compounds of particular interest, the sucrose esters and the chlorosugars.

The surface active properties of sucrose monoesters of long chain fatty acids have been known for many years. Conventionally the mono- and higher ester of tallow and coconut oil fatty acids are produced by transesterification between sucrose and the methyl fatty acid ester in dimethyl formamide-synthesis. Separation and purification of the sucrose esters formed in this way is costly. However, in a new process we have been able to react sucrose and triglyceride in the absence of a solvent to give a mixture of sucrose esters, glycerides, and potassium soaps. All these products have surface active properties. The complex mixture may thus be used as a basis for the formulation of detergent type products. Alternatively, the sucrose esters may be extracted and purified for use in the higher value specialized markets such as food and cosmetics. The product has many advantages, being fully biodegradable, non toxic and non allergenic. At present it has passed from the research laboratory, through development, and approaches commercialization. Under the trade name of TAL it will be one of the first specialty chemicals, based on sucrose, to be produced in a new factory complex being built at Liverpool, U.K. A new subsidiary company, ALRES Developments Ltd. has been set up to market this invention.

Although not as advanced on the commercial front, the second class of compounds, the cloro deoxy sugars, promise to be of even greater interest. A number of derivatives already synthesized are presented in Table 3 [from Hough and Khan (9)].

It was reported that the 1', 4, 6, 6'-tetrachloro galacto sucrose molecule was several hundred times as sweet as sucrose (10). Subsequently, investigations established that the 1', 4, 6'-trichloro compound was 2000 times as sweet as sucrose, opening the possibility of a new class of low calorie sweeteners. These compounds are currently undergoing the necessary toxicology tests prior to chemical development.

Closely related to the chlorosucroses are the 6-chloro deody monosaccharides. It has recently been shown that such compounds, when administered to male rats, can induce a fully reversible infertility, apparently due to a depression of sperm mobility. The use of these compounds, of the general type shown below, is the subject of a British patent application. Such compounds obviously may be derived from either sucrose or starch.

FERMENTATION OF SUGARS

Microbiological processing of carbohydrates has been practiced for centuries in the production of foods and drink. Over the last fifty years it has become increasingly important in the chemical industry, generally in production of high-value specialty products. The advantages of microbial conversion systems are many. They are able to carry out complex multistep and stereospecific reactions with high conversion efficiencies. They can grow on substrates of low purity—often what would otherwise be regarded as waste. In particular, many microorganisms are able to hydrolyze complex polymeric carbohydrates to simple sugars. At the same time there are disadvantages—the most significant of these is the need to use dilute aqueous systems, often under closely controlled conditions, which leads to high capital investment and high costs of recovery of the product.

Our interests at present fall into three categories: (a) The treatment of wastes, (b) power alcohol production. The waste streams and mother liquors from sugar and starch processing, such as molasses, hydrol, corn steep liquor, etc., although unsuitable as human food, are widely used as fermentation substrates. The broad substrate specificities that can be achieved with mixed cultures of microbes makes them effective in water purification and in anaerobic digestors where production of methane enables recovery of energy from the waste treatment process.

Our most advanced project, which nears commercialization, concerns production of a novel group of products, the microbial exopolysaccharides. These are used as gelling, thickening and suspending agents in a wide range of applications. In general, the market for such specialty products is not very large; however, an exception is the use of xanthan gum in the tertiary recovery of oil.

Microbial production involves the fermentation of the appropriate bacteria, such as *Xanthomonas* or *Azotobacter*, with a carbohydrate source, usually sucrose or glucose obtained from starch hydrolysis. Conversion efficiencies of between 50 and 90% can be obtained by strain selection and control of the environment. The polysaccharide is then precipitated from solution by addition of salts or alcohol.

Our interests in waste treatment originated with investigations of the possibilities of producing microbial protein from agricultural processing wastes such as citrus canning, olive oil production, etc. However, demand for such protein is limited at present. Hence, the direction of this project has been changed to concentrate on effluent treatment. In particular, a process for removal of BOD from low concentration carbohydrate waste streams has been developed. A pilot plant study is currently being carried out.

Ethanol has been produced by fermentation as a drink for centuries. In some countries such as Pakistan fermentation ethanol is used as a starting point for chemical processes. Particular publicity has been given to the possibilities of using ethanol as a liquid fuel, particularly for use in motor car engines (power alcohol). In general, the fermentation processes used for the industrial product differ little from those used for the production of potable alcohol. In most cases ethanol concentrations of less than 10% v/v are produced in 20 to 30 hours with conversion efficiencies of hexose to ethanol around 90% of the theoretical maximum 51%. Our work in this area is centered on the production of alcohol at a higher energy efficiency by (a), increasing the concentration—hence reducing distillation, and (b) decreasing investment costs. We can not produce concentrations of ethanol well in excess of 10% v/v with holding times in a continuous reactor of less than 10 hours with no decrease in conversion efficiency. These improvements will lead to smaller fermenter and still sizes, lower capital costs, and lower steam (energy) costs in the recovery of the ethanol.

CONCLUSIONS

At present the world situation with respect to carbohydrates of commercial value is complex. Excess production capacity and stock piles exist in the developed world. At the same time large deficiencies of food demand over production are predicted for the developing countries in the next decade. An increase in the use of sugar and starch for the production of specialty chemicals is experctec. However, the actual volume of material diverted from food to chemical use is not likely to be large enough to either reduce present stock piles significantly or to affect the world food situation.

In the developed countries changes are occurring in the pattern of use of sucrose and starch as sweeteners. For instance, in the USA the *per capita* consumption of sucrose is falling (Fig. 3) as glucose syrup derived by hydrolysis of corn starch becomes more widely used. Predictions suggest that this will in turn be supplanted by glucose/fructose mixes derived from isomerase-treated corn syrup. Acceptance of chlorosucrose as a low calorie sweetener could further depress the total consumption of sucrose making this available for both chemical and fermentation use without affecting food supply.

FIBER AS AN ENERGY RESOURCE: SHORT AND LONG TERM OUTLOOK

Presented To

A SYMPOSIUM ON ALTERNATE USES OF SUGARCANE FOR
DEVELOPMENT IN PUERTO RICO

Caribe Hilton Hotel, San Juan, Puerto Rico
March 26 and 27, 1979

Contributed By

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FIBER AS AN ENERGY RESOURCE: SHORT- AND LONG-TERM OUTLOOK

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ABSTRACT

Consideration of the potential utilization of sugarcane or related fibrous species of grasses as biomass for the production of energy in Puerto Rico leads to the necessity of analyzing production and conversion systems on a near- and far-term basis. While much work has been done in concept development and demonstration projects to prove the feasibility of the system it apparently is not recognized that the needs of this Island are critical enough to preclude lengthy research programs without immediate and effective application of current available technology to ameliorate somewhat the rapidly exacerbating energy crisis. Since at the present time the primary need is for biomass production, a generalized plan is outlined for integrating current sugarcane production with proposed fiber-cane production eventually resulting in an optimized energy and sugar plantation which makes maximum use of readily available land while keeping intact the social, economic and political constraints inherent in sugar-producing cultures. Additional generalized proposals are made for incremental development and utilization of the different conversion technologies presently still at various stages of development.

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FIBER AS AN ENERGY RESOURCE: SHORT- AND LONG-TERM OUTLOOK

THE TITLE of this paper suggests that it would be appropriate at this part of the symposium to deal in some generalities on a more philosophical level than a technical one. The papers which have preceeded this discussion, and the two which will follow, present a variety of concepts, proposals and detailed technical analyses of the *means* by which the tremendous biomass potential of Puerto Rico can be exploited. Perhaps then it may be profitable to view the situation from a somewhat different perspective and examine the *ends* lest the two become inextricably fused and we lose sight of the real goal—not research *per se*—but its rapid and pragmatic application to our real and immediate need and its subsequent refinement for future improvement of our energy scenario. Using that perspective the various options can be related to time, place, and finances, and developed as evolving but functional operations rather than concepts waiting for future refinement while contributing nothing to present needs. Otherwise, following the slope of our current learning curve, the first operational biomass plantation may greet a Puerto Rico which will be either unpowered or bankrupt; the first commercial gasohol station may fuel a vehicle whose driver has long since forgotten how to drive!

Let us first examine the often used phrase "short term" and "long term," or "near term" and "far term," which is extremely popular jargon in both mainland and insular energy scenarios. As generally accepted (1), "near" or "short" term means 1985 to 1990 and "far" or "long" term means something between 2000 and 2025. Yet our 1978 fuel bill, already over a billion dollars, will increase again in 1979 and certainly the OPEC prices will not remain fixed for the next five years until we arrive at our near term solutions (2). It would seem logical then to consider that our "near term" has arrived and begin implementation of biomass technologies to at least start to offset the exacerbating energy crisis while our other far-term solutions, e.g., coal fired and nuclear plants, and OTEC, with their longer lead times, are being considered, planned, and built. It should be pointed out that while this discussion is restricted to the topic of sugarcane fibers, both the hyperbole and the arguments are equally adaptable to solar, solid waste utilization, and perhaps OTEC as well. The concept of "far" or "long" term seems to be equally meaningless and really serves only to provide guide posts with which to saddle the next generation as the majority of us will either no longer be here or will be in no condition to implement the scenario we are presently improvising. Further, unless some action really is taken in the so called "near term," the "far term" may be an entirely different world. One need only contemplate the Mid East situation to realize the precarious position most of the industrialized world is in. What is being said, essentially, is that we need to resolve our near term problems now and the far term solution, based on the laws of economics, political expediencies and practical technology will evolve as required.

Within the context of this sugarcane symposium there are a number of options for the conversion of fiber to energy and these can be discussed in general terms. Before doing that, however, it will be valuable to review the more limited production alternatives.

There are three possible options for the production of sugarcane fiber for energy. They are:

A. Present method: 95,000 cuerdas of sugar-producing cane yielding 950,000 tons of dry bagasse (3).

B. Energy Plantation method: 300,000 cuerdas of high-fiber cane producing 10,500,000 tons of dry fiber for direct energy production equal to Island's entire energy need (4).

C. Combination Method: 100,000 cuerdas of mixed cane. Enough sugarcane to supply domestic consumption of sugar and molasses for rum industry. Balance to be fiber cane for energy. Estimate is that this would provide approximately 15% of Island energy needs, supply required domestic sugar and molasses and cut the 60 million dollars/year sugarcane industry loss appreciably. (In passing it should be noted that the loss could be cut even more by producing brown sugar instead of white.)

Under the present fuel pricing situation *alternative A* would keep approximately $100,000,000 in Puerto Rico, *alternative B* would keep nearly $1 billion dollars in Puerto Rico, and *alternative C* would shift our balance of trade favorably by about $150,000,000. All these are, of course, on a per year basis.

Viewed from the "near term" pragmatic basis mentioned earlier the solution is perhaps simplistic but obvious. With an investment of something less than a subsequent year's repatriated dollars, alternative A could be implemented to immediately begin producing energy, with a minimum of dislocation of agricultural, labor, or cultural prerogatives. Given the success of this venture, an expanded version of alternative C could evolve and in the so called "far term" reach a limit based on land use considerations, future energy needs, and domestic sugar (preferably brown) and rum production. In the limit, energy needs beyond the capacity of fiber production would be met by far-term available alternate sources such as coal, nuclear and OTEC plants.

Effective and immediate action, with adequate financing, could then implement a near-term solution. The collateral problems often mentioned as "needing more research," such as genetic manipulation, logistics, fertilization and irrigation, and improvement of the Centrals' boiler systems, can be probed simultaneously and improvements incorporated into the system as it develops, and, most important, while it is providing needed energy.

While there appear to be only three reasonable options in the production phase of cane fiber for energy, there are considerably more alternatives in conversion (5, 6). We may consider direct combustion, pyrolysis, gasification, anaerobic digestion, fermentation and co-product conversion. All of these processes are in varying stages of development or demonstration ranging from bench model operations to pilot plant production levels. With other substrates, many of the processes are proving to be economically and technically feasible and are presently in use for energy generation. For example, methane production by anaerobic digestion using animal wastes is currently being developed on a large scale basis in Colorado (7) and Florida, and on a somewhat smaller scale here in Puerto Rico (8). The emphasis in the design and sizing of these plants is on energy independence at the producer/user level (e.g. individual farm or ranch) and not on production of energy for grid distribution. Ethanol is currently being produced in Brazil as a gasoline additive on a relatively large scale and is contributing to that nation's overall energy needs. Going back to sugarcane, the mills in Hawaii burn bagasse and are energy independent as a result. Certainly there is no doubt that efficient direct combustion is a realizable goal and that pyrolysis, gasification, and fermentation are processes which are becoming economically more viable with every petroleum price increase or shortage. The only process which seems to be inherently more suitable to decentralized and smaller operations, and different substrates than cane fiber, is anaerobic digestion for methane production.

The near-term, far-term point of view which was applied to biomass production needs to be somewhat modified in considering the energy conversion of cane fiber. It would appear reasonable that, since the primary objective of immediate near-term action is to develop a source of energy as quickly as possible, the utilization of cane fiber as fuel in a direct combustion mode, or converting it to a supplementary fuel combined with oil, would be the most effective approach. Starting out in this way, the near- to far-term operations might follow this sequence:

First: Immediate utilization of bagasse as primary or supplementary fuel for direct combustion.

Second: Gradual improvement of boiler systems to optimize use of cane fuel.

Third: Integration of cane fiber into biomass fuel mix.

Fourth: Construction of intermediate size pyrolysis and gasification plants based on data from presently operating systems elsewhere.

Fifth: Construction of intermediate size ethanol plant based on Brazilian system.

Sixth: Integration of pyrolysis fuel product and ethanol into local market.

Seventh: Concurrent research and development program to refine technology and improve yields.

Again, the near term or immediate needs can be met on a functional basis while the system is being improved rather than waiting for the development of more efficient and more sophisticated technology. The evolution of the cane fiber/biomass fuel system will reach its limit of practicality based on the biomass available under the previously cited parameters and the far-term technology will be available at that time.

The primary objection which can be raised at this time to the immediate application of cane fiber biomass for energy is the factor of cost. With the present technology of biomass energy production there is no doubt that cane fiber-produced energy will not be competitive with present fuel sources. This, however, is a transitory argument. Economies of scale, improvement of technology and, most of all, the rapidly escalating price of petroleum will combine in the very near term to invalidate this objection. It should also be pointed out that even if cane fiber biomass energy is just competitive, or at worst more costly than petroleum, the money spent will stay within the economy, provide jobs, and help maintain a favorable balance of trade. The more intangible but important aspect of this energy independence has considerable political and social value as well.

One more factor should be discussed briefly. Serious thought should be given to the development of biomass energy plants and operations as producers of a number of products along the operational chain to offset costs. For example, sugar, molasses, and fuel are clearly part of a sequential operation and on that basis could be profitable. To this could be added levulinic acid produced as a by-product to pelletized fibers for fuel (9). Undoubtedly there are others.

In conclusion it may be well to repeat the basic premise of this paper. The opportunities exist to make a beginning effort in the solution of our Island's energy problem. "Near term" is a phrase that can be better translated as *now*, and "far term" will either take care of itself or never arrive.

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ETHANOL AS A MOTOR FUEL FOR PUERTO RICO

Presented To

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Caribe Hilton Hotel, San Juan, Puerto Rico
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The AES-UPR Rum Pilot Plant
Río Piedras, Puerto Rico

ETHANOL AS A MOTOR FUEL OR PUERTO RICO

Table of Contents

ETHANOL AS A MOTOR FUEL FOR PUERTO RICO

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ABSTRACT

Ethanol is a valuable product whether used as a beverage, as a motor fuel, or as a chemical feedstock. Its production by fermentation processes in Puerto Rico is becoming desirable and economically feasible owing to large increases in petroleum prices since 1973. This paper describes the facilities for ethanol research in Puerto Rico and a proposed method for production of ethanol as motor fuel, utilizing sugarcane juice and high-test molasses as direct sources of fermentable solids. This method describes the production of ethanol by utilizing bagasse as a source of distillery heat, and by optimization of milling, fermentation, and distillation-extraction operations. Studies center on reduced milling expenditures, direct fermentation of raw juice, improved fermentation efficiency and process modification, and distillation processes. The utilization of excess steam to dry bagasse to appropriate levels is discussed.

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ETHANOL AS A MOTOR FUEL FOR PUERTO RICO

ETHANOL has been recognized as a fuel energy source for more than 70 years (17, 26). However, except during periods of low grain values, interest in fermentative ethanol as a fuel has remained academic owing to the low price of gasoline and low costs of synthetic ethanol production from the petroleum derivative ethylene. Abrupt changes in this scenario began during the autumn of 1973. By the end of 1976 petroleum prices had nearly quadrupled and the costs of synthetic alcohol doubled. During this interval the costs of ethanol production via fermentation were only marginally affected by price changes for petroleum and raw materials. In the meantime there has been mounting interest in the production of alcohol as fuel from sugarcane juice, high-test molasses, and blackstrap molasses. Brazil has used surplus molasses from sugar manufacture to produce ethanol as a motor fuel and as an additive to gasoline (1, 2, 19, 27). In addition, it has been claimed that ethanol could be produced at a competitive price by direct fermentation from sugarcane juice and other agricultural products (13, 25).

Within this overview the ERDA Fuels from Biomass Program identified ethanol as a potentially valuable fuel and chemical feedstock (14, 15). Workers at the Batelle-Columbus laboratories found sugarcane juice to be a superior source of fermentable solids, as opposed to cellulose, hydrolyzable grain starches, and the poorly-hydrolyzable polysaccharides of other plant materials (14, 16). On the other hand, the U.S. fermentation experience has centered largely on grains and ethyl sulfate, and on the blackstrap molasses remaining after sucrose has been crystalized from evaporated cane juice. High-test molasses (in which sucrose is partially inverted and retained) has also been used as source of ethanol during periods of surplus sugar or when the supply of blackstrap molasses is insufficient to meet demand (21, 29). But there is relatively little information on process efficiency and cost reductions utilizing raw sugarcane juice and high-test molasses. Moreover, there is little hard data on the use of cane refuse and bagasse as process heat sources for ethanol production processes.

Puerto Rico, an insular, densely-populated land mass is totally reliant upon foreign fuels to meet its energy needs. From 1950 to 1974 agricultural activities were transformed from a labor-to-machine orientation with a vastly greater dependence on fossil fuels. During the same interval the Island's industrialization program grew rapidly within the framework of "Operation Bootstrap." Fossil fuel consumption was enormously expanded.

Puerto Rico imported about 80-million barrels of petroleum in 1977 and more than 90 million during 1978. This represented a total payment of more than $1.2 billion for 1978 alone. A proposed increase in petroleum prices of 15% will amount to about $250 million in increased expenditures for 1979, while the gross amount to be paid for oil could be as high as $2.0 billion. Gasoline consumption in Puerto Rico for 1978 was 15.8 million barrels at a total cost of $500 million. Due to the proposed large increases in petroleum prices the cost of a gallon of gasoline will jump from an average of 70 cents to $1.00 in less than a year. This is an additional payment of more than $150 million annually. The impact of mounting fuel costs since 1973 is aggravated by the Island's lack of fossil fuel resources. In contrast to the U.S. mainland, there are no domestic coal or petroleum reserves to be developed or conserved.

The production of ethanol from sugarcane for use as a motor fuel has been proposed and is one approach toward partial substitution of fossil fuels with a clean renewable fuel. Ethanol in its most attractive medium, as rum, has been a blessing for Puerto Rico. Ethanol as a motor fuel could represent a new industry here equally important as that of rum. Ethanol, as such, may be produced from different sources, including the fermentation of crude juice, low-grade molasses, high-test molasses, farinaceous products, bagasse, paper, and industrial urban wastes.

The purpose of the present paper is to discuss the facilities that the Rum Pilot Plant of the University of Puerto Rico has to conduct ethanol research. In addition, an outline of the approach for the economic production of ethanol intended for fuel and industrial feedstock is also given. The main route is to produce ethanol using sugarcane as a source of fermentable solids, where all the operations are integrated in a system using dried bagasse as sole energy supplier at the plant site.

DESCRIPTION OF THE AES-UPR RUM PILOT PLANT

In 1952 a special law of the Legislature of Puerto Rico established the Rum Pilot Plant at Río

Piedras. It is owned and operated by the UPR Agricultural Experiment Station. Its operations are organized in a number of divisions to deal with analytical chemistry, fermentation chemistry, distillation technology, rum waste utilization, and technical services (23). These facilities are shown in various slides.

In the Analytical Chemistry Division equipment is available for virtually any class of chemical or biochemical analyses (4). There are facilities for chromatographic analyses, atomic absorption and emission spectrography, total organic and inorganic carbon analysis, and ultraviolet visible spectrophotometry. Additional items include an infrared spectrophotometer, a precision polarimeter, and a refractometer. There are incubators, large-size chemical hoods, medium- and high-speed centrifuges, and constant-temperature baths. Numerous other items of equipment are available to support ethanol research.

The Fermentation Chemistry Division deals with yeast strain selection and evaluation, and demonstration studies in fermentation. The pilot plant facility for the demonstration of fermentation technology includes equipment for both batch and continuous processes. The main equipment includes six 1000-gallon fermentors, two 250-gallon fermentors for yeast preparation, and a pre-seed 50-gallon fermentor. Equipment is also available for laboratory work in foermentation. This includes two magnaferm fermentors, incubators, microscopes, a rotary evaporator, comparative fermentation equipment, an autoclave, a lyophilization system, a large-size centrifuge, and an industrial compressor. The plant possesses a 10,000-gallon tank for molasses storage and a complete control panel for the pilot plant fermentation system.

The Distillation Division consists of a three-column system capable of distilling 600 gallons of ethanol per day. In addition, there is a small pot still, several ethanol stainless steel storage tanks and drums, large- and small-size boilers, and a control panel for continuous distillation.

Rum Pilot Plant research deals with all phases of rum production, including the selection of raw materials, fermentation of blackstrap molasses, distillation, product aging, and processing (5, 10, 6, 23). The fermentation and distillation systems are sufficiently flexible so that research in the various fermentative and distillation processes can readily be conducted. Facilities suitable for research on the selection of superior yeast strains are also available. Laboratories are well equipped for investigations on all aspects of the manufacture of rum, ethanol, and allied products. Information derived from the studies conducted in the Rum Pilot Plant are provided to the rum industry and to interested organizations through publications and technical meetings. Reports and publications include work on raw materials and yeast, pretreatment of raw materials, fermentation control, distillation, rectification of crude rum, control of chemical and biological reactions, correct equipment selection and usage, product aging, rum processing, and waste treatment.

A very adequate cane milling facility is located at the UPR Agricultural Experiment Station adjacent to the Rum Pilot Plant in Río Piedras. It was developed to accommodate experimental sugarcane samples from substations throughout the Island. The key implement is a two-mill tandem consisting of two sets of 18 x 12 inch rollers with circumferential grooving. Its operational capacity is about 300 tons of unprepared stalks/day. Essentially custom-built with Squier and Falk brand components, it is driven by a 15 hp electric motor at a continuous operating speed. Cane and juice samples can be withdrawn between the roller sets. Longer multiple-mill tandems are simulated by reintroduction of the crushed materials. Various mill support facilities are located in the same building. These include cane weighing equipment, a small laboratory for juice processing and analysis, and storage space for incoming cane, juice samples, or equipment. There is suitable space for installation and operation of the cane preparatory units. The Experiment Station also owns a pilot-scale cane shredder (hammer mill). It is a mobile unit and can be located either at the cane harvest site or at the milling facility in Río Piedras.

Facilities for machinery and equipment repair, servicing, and a variety of other research support facilities are located with AES-UPR in Río Piedras. These include greenhouse and laboratory installations, a central analytical laboratory, a data processing center, a library oriented to agricultural research, and a centralized service department responsible to the entire Experiment Station network.

DESCRIPTION OF A PROPOSED ETHANOL PRODUCTION PROCESS

A modified process for proposed ethanol production from sugarcane is presented in Figure 1. This system is intended to use steam generated by burning dried bagasse at the plant site. The main operations to be carried out are: Milling of the cane and extraction of the juice, bagasse combustion for steam generation, preparation and fermentation of the mash, distillation, and a secondary ethanol recovery using regular gasoline.

1. Cane Milling and Extraction

Conventional extraction operations employ a tandem series of roller mills which remove a progressively diminished percentage of recoverable sugars, while multiplying the cost of sugar extraction. These operations are sometimes supplemented by a variety of diffuser systems. The latter operate to remove sugars by a combination of washing (lixiviation) and dialysis (diffusion) following the addition of water or dilute sugar solutions to the initially-extracted cane (8, 12). Diffuser processes are commonly substituted for three or four intermediate mills of a multiple-mill tandem (8, 28). Their advantages include high sugar recovery and a reduction of the capital and maintenance cost for mills. However, vastly greater reductions in energy expenditure should be possible for a fermentation ethanol operation based on optimized sugar extraction followed by direct fermentation of raw juice.

A decisive factor in attaining such savings lies in the pre-milling preparation of input cane. Cane preparator designs include combinations of sectioning knives (to improve mill capacity and extraction), shredders (hammer mills), and chopper-fiberizers (7, 12). In a conventional multiple-mill sequence the first extraction may recover 65 to 70 percent of the extractable sugar (7).

Shaer (24) maintains that, with cane carrier and knife modifications, cane preparation can be sufficiently optimized to exclude the mill extraction step preceeding the diffuser. It has been estimated that this operation would consume only about 12% of the energy expended in attaining a conventional 92 to 96% recovery (22). This estimate also recognizes that only one or two milling steps will be allowed for extraction of fermentable solids.

Proposed extraction experiments are designed to optimize recovery of fermentable solids within a context of net energy balance. The objective is to remove the maximum possible sugar with minimized milling operations. This is predicted upon a fine preparation of the input cane, but specific trials will include non-prepared cane as a reference point upon which the improvements in sugar recovery can be gauged. Utilizing the pilot-scale milling facility located at the UPR Agricultural Experiment Station, extraction tests will include the following: (a) Optimized mill speed and carrier capacity settings for variously-prepared material; (b) sugar extraction performances by mill one, and by mills one and two of an existing two-mill tandem; and (c), evaluation of the relative recovery proficiencies for sugar and water, with special reference to the second milling step.

2. Bagasse Drying and Burning Trials

This phase deals with the development of bagasse as the fuel source for process heat in ethanol-production operations. The bagasse to be used immediately will be dried directly in the mills to a moisture content of about 48 percent, using hot flue gases under pressure. For the fraction of bagasse to be held in storage, the moisture content will be reduced to 12-20 percent, starting with partially dried material from a commercial mill (48 percent moisture). This dry bagasse would be suitable for use as a boiler fuel and as a feedstock for other commercial applications.

3. Preparation and Fermentation of the Mash

Even the modest amount of 25 metric tons of sugarcane per acre year, having a net yield of 8.3% sucrose, is equivalent to 450 gallons of 95% ethanol per acre year. This is readily attained in Puerto Rico with present-day production, harvesting, and processing operations. Increases in sugarcane tonnage could be attained through intensive propagation and by modifying other agricultural practices, but the percentage of fermentable sugars obtained for each harvest would probably be lower than the percentages obtained from conventional sugarcane plantings. On the other hand, the output of total sugars per acre year would be increased by more than 100 percent while the average yield of bagasse would be more than doubled. Under these conditions, the ethanol yield would be in the order of 900 gallons per acre year. Unfortunately, this increase will not be realized unless the agricultural improvements are accompanied by changes in juice extraction and processing methods, and by introducing new fermentation and distillation practices.

This must be accompanied by a more effective use of surplus bagasse for milling operations, for the subsequent clarification of crude juice to be used for production of high-test molasses, and for sucrose crystalization processes. In the traditional Puerto Rican system fuel oil is usually added to the green bagasse to attain a suitable combustion for generating steam. Although some pre-drying of bagasse is done, no serious attempt has been made to establish formal cogeneration systems in Puerto Rico's sugar mills.

With respect to the time-course for fermentation, substantial reductions could be attained by the Melle-Boinot technique (20), or by tower fermentation (3), employing crude juice as a source of fermentable solids. This offers an added advantage in that the stillage by-product would be free of suspended solids. This minimizes the pollution problems stemming from disposal of the final wastes.

Major energy savings would accrue by direct fermentation of the crude juice, in effect by-passing all subsequent energy expenditures attending the production and storage of molasses. Hugot (12) and others (18, 22) have noted the high energy levels consumed or wasted outright in these processes. A continuous input of raw juice is feasible in Puerto Rico where sugarcane can be harvested on a year-round basis.

The economic assessment processes using crude juice as direct source of fermentable solids, as opposed to the more costly preparation of stable high-test molasses, is to be considered. By evaporating the clarified juice to a stable syrup, a substantial cost is added to the process which could render the ethanol produced too expensive for use as a motor fuel and for most industrial applications. In the latter instance the molasses is ordinarily transported to a rum distillery site, and hence the increased shipping charges affect some of the savings expected from direct fermentation of the juice. For practical purposes it is better to perform the ethanol production operations at the milling site.

Fermentation pilot plant trials based on a range of raw juice preparations, and designed to maximize ethanol yield, will investigate the following: (a) Substrate preparation; (b) yeast sources; (c) optimal fermentation procedures; (d) bacteria control; and (e) chemical composition of cane, mash, and fermentation products.

Various substrate (mash) formulations will be evaluated by batch- and continuous-fermentation techniques, using both raw and clarified cane juice. These formulations include:

- Fresh cane juice
- Fresh cane juice plus varying proportions of juice concentrate (syrup)
- Juice concentrate (high-test molasses) diluted with water.

4. Distillation studies

The Rum Pilot Plant's distillation unit consists of three columns (Figure 2). The first is the "beer column," where fermented mash is subjected to distillation to recover a product containing more than 50 percent ethyl alcohol. The second column is a purification unit where volatile materials are removed. The third column is a rectifying unit where fusel alcohol is removed and at the same time the alcohol content is increased to about 190°P. The procedure described uses either a modified beer column (Figure 3), or the modified beer column followed by the rectifying column.

Distillation of the fermented mash by the standard continuous technique has as its objectives the purification and concentration of the ethyl alcohol content, using a three-column system (6). Waste streams, termed "slops." consist of water or water containing solids in solution or suspension. In the usual distillation process for rum (Figure 2), by-product streams include "fusel oils" (mixture of alcohols containing a number of carbon atoms per molecule greater than two), and "heads" (mixtures of aldehydes, ketones, esters, acids and amines). The intermediate separation of these components from ethanol is a cost factor which probably is not necessary in a fuel-production process.

The chief functions of the beer column are to remove all the ethanol present in the fermented mash, and to strip solids and some water from the mash. The largest part of the column is, accordingly, a stripping section containing sieve plates for suitable handling of a solids-containing stream. The upper section of the column has a small number of bubble-cap plates, and these are separated from the stripping section by an impingement plate, whose function is to prevent solids from entering the top of the column. Slops consisting of water, with dissolved and undissolved solids, flow from the bottom of the tower. This stream may be further processed for yeast recovery. Alcohol vapor of about 120-proof leaves the top of the column where it is condensed and divided between reflux and product streams in an accumulator.

The beer-column product is directed to a measuring tank, from which it may pass in measured quantities to the feed tank serving the purifying column. At this point the purifying column will be by-passed and the ethanol streams from the feed tank are to be directed either to the rectifying column or to an extraction system for further consumption.

The top effluents diverted from the beer column are preheated to the boiling point before entering the rectifying column. The purpose of the rectifying column with its bubble-cap plates is to concentrate the alcohol to remove remaining impurities and to remove additional impurities formed during rectification. The "heads" are removed from the accumulator at the top of the column and slops, largely water, are removed at the bottom. The recovered fusel oil is of two types which collect at two different points in the tower, necessitating two fusel-oil side streams.

The distilling system operating with two columns is to be modified to obtain maximum ethanol output with the least energy investment. This will be accomplished by using heat exchangers at all streams, or by employing a cooling tower where the recovered heat can be reused. This concept is to be assessed against techniques in which only the beer column or the pot still is used to extract the alcoholic product. Since in this case the alcoholic content of the distillate obtained with the beer column is far below the desirable strength, other methods of ethanol enrichment will be used. The use of selected brands of regular gasoline to enrich the ethanol-aqueous system, from the beer column or the pot still, and at the same time to obtain gasohol suitable for marketing, will be developed.

The extent to which ethanol can be recovered economically from fermented sugarcane juice is a major consideration. Many years of continuous effort have been expended at the Rum Pilot Plant investigating this problem with fermented molasses mash. In the latter instance, an alcohol content of 7 to 14 percent was to be recovered for rum processing, with the objective of obtaining a high quality product without sacrificing economy. The fermentation of sugarcane juice differs in the quality of ethanol to be recovered, and in the subsequent processing and marketing of main products and co-products. Nonetheless, the basic equipment to be used, with modifications, remains the same, and the technological experience gained through rum ethanol research is directly applicable to fuel ethanol research.

NET ENERGY BALANCE POTENTIALS

The net energy balance for the production of sugar from sugarcane, for both the agricultural and industrial phases, has been determined by Hudson (11). The net energy balance for the production of ethanol from sugarcane, for both the agricultural and the industrial phases, has been determined by several investigators (2, 9, 16). The industrial phase consistently utilizes more energy than the agricultural phase, from 60 to 75 percent more energy. The analysis of Gómez Da Silva et al (9) shows a positive energy balance of 2.4 (energy output/input = 2.4), while a very favorable energy balance of eight has been estimated (2), both using green bagasse as the only energy source for the industrial phase.

Although these data are far from typical for Puerto Rico, the trends do indicate that the development of ethanol as fuel from sugarcane is a logical step to reduce local expenditures for imported fossil energy. In any case, precise measurements of the energy expended in all agricultural and industrial processes must be determined at the local level. These estimates would be based on a year-round supply of raw juice in one extreme case, and on the preparation of a seasonal, high-test molasses at the other extreme.

One important element in the energy balance discussed above is the fact that the bagasse output is sufficient to supply the energy required for the industrial processing of sugarcane to ethanol. In an intensive industrial operation, the output of bagasse would constitute a surplus exceeding fuel needs by as much as 50 percent. Important uses for this excess bagasse are readily found. These include: (a) Further production of energy for the agricultural phase; (b) feedstocks for other industrial applications, such as paper and panelboard production; (c) a raw material for the production of glucose from cellulose; and (d), the production of furfural, linoleic acid, and other chemical products requiring large supplies of plant residues.

At the industrial phase of ethanol production from sugarcane, bagasse would be burned to produce steam, thereby making use of its calorific value. Unfortunately, bagasse will not burn easily unless its moisture content is lower than 50 percent. Systems to recover heat presently lost from mill stacks, and heat produced during subsequent processing of juice to ethanol, must be effectively designed and integrated into the actual system for drying bagasse and preheating water enroute to the boilers.

CONCLUSIONS

The goals of the Puerto Rican ethanol for motor fuel development program are bound to have tremendous implications four our Island in the long run. If ethanol production for this purpose proves to be economically feasible, it may become a significant factor in the solution of Puerto Rico's energy problems. Agriculture may be the main basis for its production, but the limited amount of land available at present could provide at most only about 20 percent of our motor fuel needs. Larger amounts of ethanol could be produced only if the Government is willing to allot larger areas for sugarcane planting.

The economics of direct production of ethanol from sugarcane is uncertain at present and the subject of much controversy. The proposed pilot-plant studies would undoubtedly help to settle these disputes. Alcohol production normally performed by the rum industry should be gradually linked to sugar industry operations. Improvement of both industrial and agricultural technologies will require extensive research and development, and management efforts directed toward large-scale production of ethanol. In this sense, improvements in agricultural and industrial technologies for conversion of sugarcane to ethanol are keys to economic feasibility and eventual success of this program.

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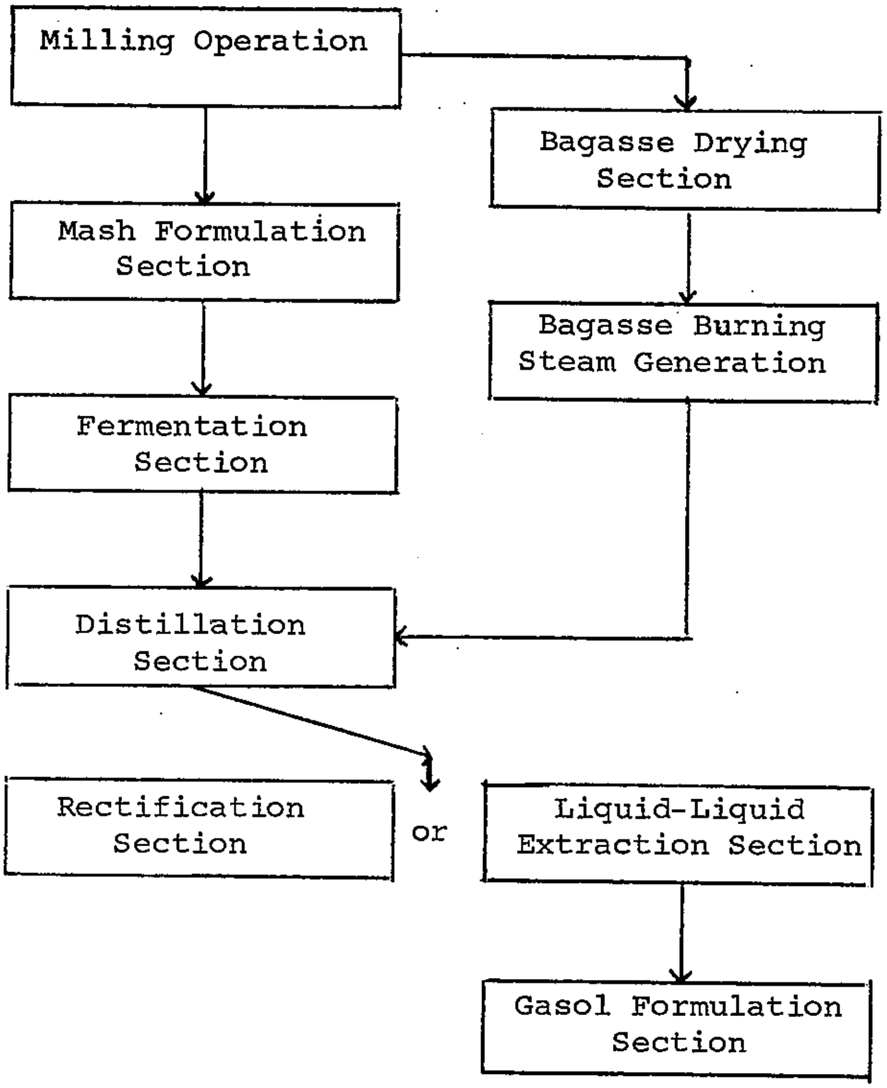

Fig. 1.-Block flow diagram of ethanol from sugarcane process.

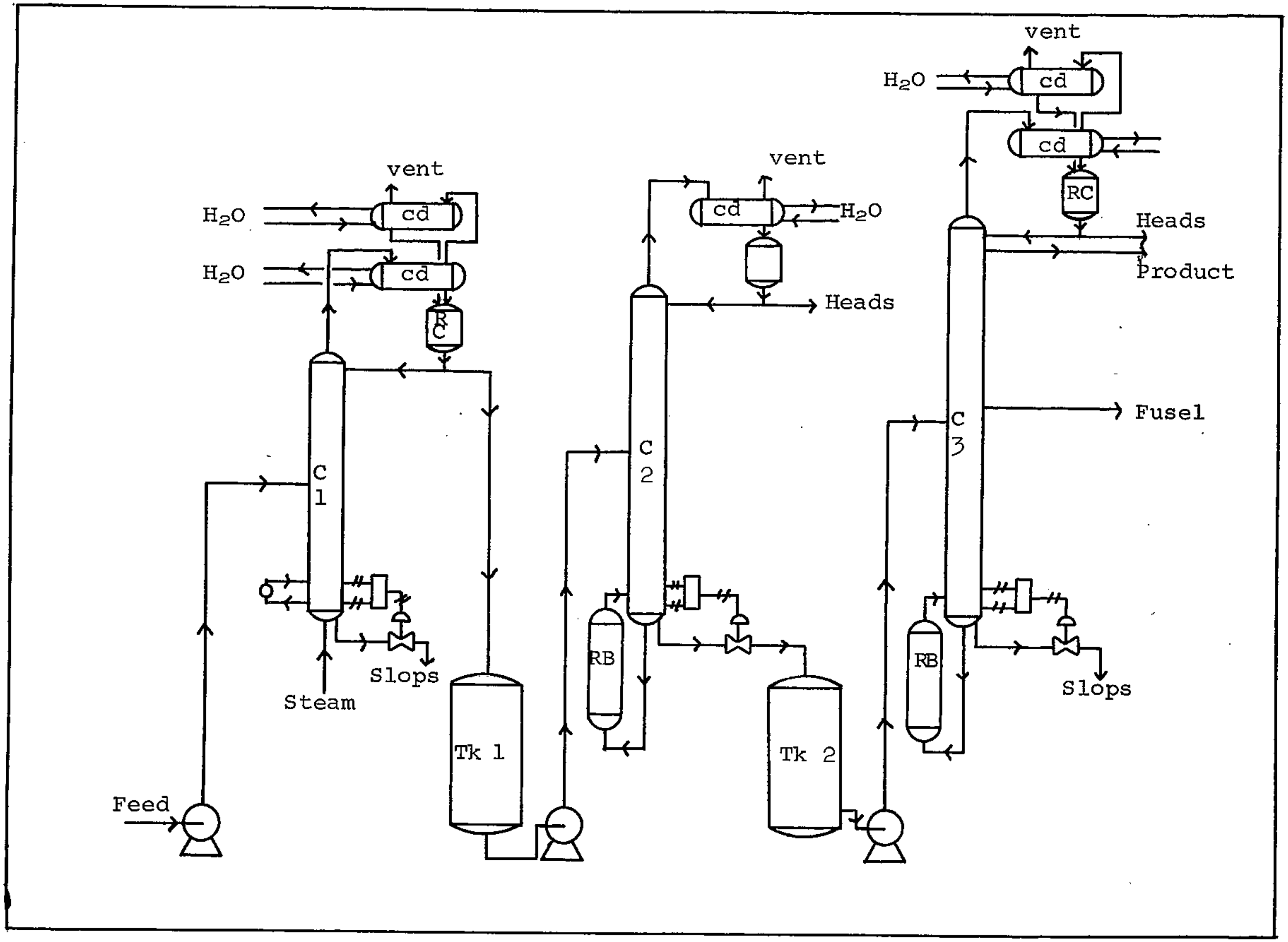

Fig. 2. - Flow diagram of 195°P ethanol distillation system

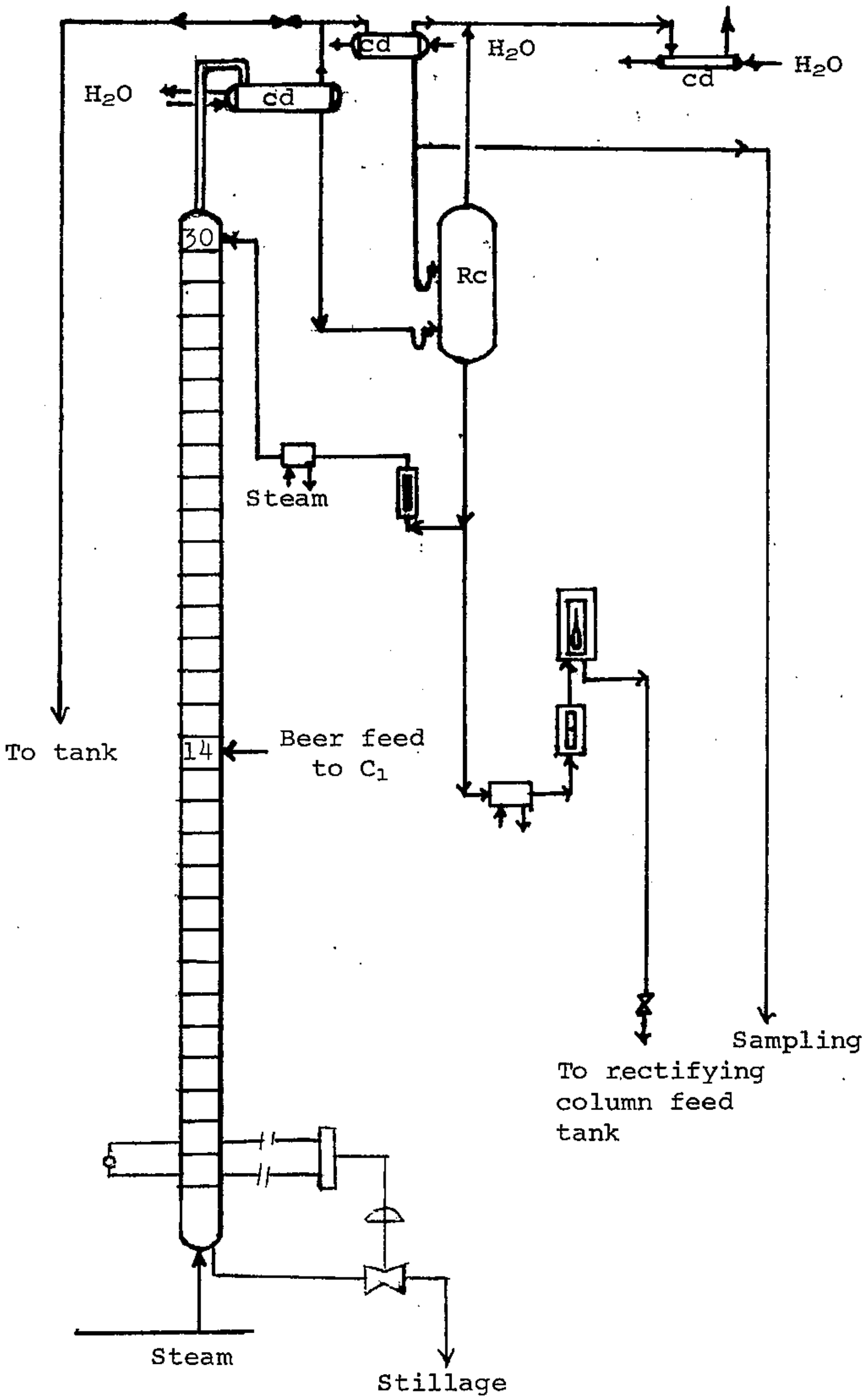

Fig. 3.-Modified beer column

MULTI-PRODUCT OUTPUT: KEY TO BAGASSE ECONOMICS

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A SYMPOSIUM ON ALTERNATE USES OF SUGARCANE FOR DEVELOPMENT IN PUERTO RICO

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MULTI-PRODUCT OUTPUT: KEY TO BAGASSE ECONOMICS

Table of Contents

Topic **Page**

ABSTRACT

MULTI-PRODUCT OUTPUT: KEY TO BAGASSE ECONOMICS

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ABSTRACT

A strong case is presented favoring multi-product development from bagasse feedstock as a partial near-term answer to Puerto Rico's energy problem. A political-economic analysis of Puerto Rico's energy dependency is presented in which the Island's energy vulnerability to foreign suppliers is underscored. Biomass utilization alternatives are evaluated in terms of social and market acceptability. A "strategy" based on multi-product manufacturing systems utilizing a flexible relationship to raw materials is proposed. Difficulties to be encountered in new-product marketing and public acceptance are also discussed. A "bagasse energy plant" (BEP) is proposed utilizing sugarcane bagasse as the feedstock for producing a compressed fuel pellet and two chemical by-products (levulinic acid and furtural).

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MULTI-PRODUCT OUTPUT: KEY TO BAGASSE ECONOMICS

PUERTO RICO'S ENERGY PROBLEM

AS IS well known, Puerto Rico must depend for 99% of its energy on imported crude oil. Moreover, by conventional means alone, the chances of substantially reducing this dependence within the next decade are remote. Coal and nuclear power—the two major alternatives with substantial histories of commercial operation—have long lead times for permits and construction and present difficult problems of environmental impact and financing for our small Island. The presence of commercially valuable crude oil off our north coast is probable but speculative. With the best of luck, it will take considerable time and money to explore and develop this nonrenewable resource.

This coal, nuclear power and/or native petroleum may be parts of the solution to our energy problem at some date in the future. But they will not provide answers which are easy, quick or cheap, in time, money or environmental quality. It is also well known that, except for small users, the cost of electricity in Puerto Rico to industrial and commercial users is about double the U.S. average and higher than for any major power company except Consolidated Edison (2, pp. 4-6).

What is not adequately appreciated is that Puerto Rico's extreme dependence on foreign petroleum makes it unusually vulnerable to interruptions in its crude oil supply. In particular, it is vulnerable to interruptions of a random nature, i.e. those due to decisions based on purely extraneous reasons and taken by foreign governments who are oblivious to the impact of these decisions on our Island, or else willing to sacrifice us to other considerations. The recent history of Latin American oil pricing is a case in point.

Consequently, there exists a significant risk that, at some time during the present decade, Puerto Rico will be unable to obtain a major portion of its crude supply and/or will be faced with crude prices so exhorbitant that their persistence would lead to economic collapse. Moreover, because a world energy crisis, for lack of economic supply, is quite possible within 10 to 15 years, the risk to Puerto Rico increases with time. [See for example: Flower (13, pp. 42-49)].

This risk arises primarily from four fundamental characteristics of the world petroleum situation:

(a) World consumption of petroleum is about 60 mm barrels per calendar day (BCD) and is expected to increase, in most projections, at an average annual rate of between 2% and 4% compounded over the next two decades (28, p. 100). This implies a minimum requirement of 29 mm BCD in additional production by 1998. During calendar year 1977, members of the Organization of Petroleum Exporting Countries (OPEC) produced more than 31 mm BCD or 52% of the world's crude oil output. Moreover, the recoverable reserves in the OPEC countries are estimated at 80% of the world total, excluding China and the Russian bloc (23, p. 28). Although the OPEC's position is slowly weakening as time goes by, for a decade or more its members will remain in a position to exercise a decisive influence over the supply and price of crude oil.

(b) Although most OPEC members, with the principal exception of Saudi Arabia and the partial exception of Iran, are "locked in" to major development programs, they are still not at the mercy of their customers and can exert a powerful influence on world crude prices, so long as Saudi Arabia does not oppose them. World demand is strong enough so that, in many cases, these countries can choose the price which maximizes their revenues.

(c) Although Saudi Arabia has also embarked on an ambitious development program (10, p. 14), it is proceeding at a very measured pace and is not locked it. In fact, Saudi Arabia has a great deal of flexibility as to the pace of its development, because of its small population, large financial and oil reserves, extensive use of foreign labor, low per capita income, strong traditions and high proportion of nomads. Hence, Saudi Arabia could suspend its development program for a few years and cut back its crude production to less than 6.0 mm BCD. On the other hand, it could also increase its crude production from the 1977 average of 9.2 mm BCD to a maximum sustainable level of 10.7 mm BCD

(28, p. 104). Thus its "swing" capacity is roughly 4.7 mm BCD or 8% of world output. Moreover, the costs and benefits of substantial variations in output are significantly lower for Saudi Arabia than for other countries. Thus, Saudi Arabia has a unique ability to cause drastic and/or rapid changes in world production of crude oil and its prices. Because of capacity limitations and financial need, the other oil producing nations can only counter this power to a limited extent. In brief, Saudi Arabia's so-called "moderate" position on oil questions is not a matter of economic necessity or external constraints, but is largely due to the *present* rulers' *own* perception of their long run *political* interests. If the rulers or the perceptions change, we have a different ball game.

(d) As the civil war in Labanon and the recent revolution in Iran so clearly illustrate, politics in the Middle East not only dominate economics but are different from politics elsewhere. Religious faith, national identity and hereditary conflicts have been deeply entwined for centuries. Such factors often overcome both ideological convictions and rational calculations of national interest. Thus it is not the limited wars between Israel and its neighbors, but the Lebanese civil war which we should keep in mind as a model of what can happen in the Middle East.

Recently, an elderly scholar-theologian sat in the studio of a Paris television station and talked to his countrymen in a far land. A few weeks later, world oil production had declined by 6.0 mm BCD. It should give us pause for thought.

POSSIBLE SOLUTIONS: THE BIOMASS ALTERNATIVE

In 1952, Puerto Rico harvested almost 400,000 "cuerdas" (157,000 hectares) of sugarcane (20, p. 37). Even in 1978, 95,000 cuerdas (37,000 hectares) were harvested (19, p. 27), and the total land in crops and improved pasture exceeded 900,000 cuerdas (20, p. 1). In fact, the Center for Energy and Environmental Research of the University of Puerto Rico (CEER) has estimated that 14.2 billion KWH of electricity, roughly Puerto Rico's present annual requirements, theoretically could be generated from biomass obtained from 90,000 cuerdas of sugarcane producing 10 tons of dry bagasse per cuerda, 211,000 cuerdas of "energy plantations" producing 35 tons of dry biomass per cuerda and over 600,000 cuerdas of other farmland producing two tons per cuerda (1), p. 5, and 22, p. 1).

While theoretical calculations are usually far too optimistic, it is nevertheless imperative to consider biomass as a major component of the solution to Puerto Rico's energy problem. We have a proven ability to produce large amounts of biomass. And, until commercially valuable oil fields are found and developed, biomass is our only significant energy resource which can be exploited on a large scale. (With all due respect to the highly desirable proliferation of solar water heaters.)

In the short and medium run, biomass means primarily bagasse. That is what we have, what we know how to produce in large quantities, and what we can burn immediately.

However, except in the short run, it is desirable to convert bagasse to some other, "higher" form of energy before using its energy content. As is well known, bagasse and most other forms of biomass are much less homogenous than conventional fuels. They are bulky, messy and cumbersome to handle, transport and store. In storage, bagasse in particular may smell, deteriorate and even catch fire or ferment, if not processed in some manner. And even then its "shelf life" is limited. In combustion, most biomass is less efficient than conventional fuels because of its high moisture content and lower homogeneity. For example, the average moisture content of the bagasse from the 1978 Puerto Rico harvest was 50.3%. Fiber content was only 43.4% (21, Table 24). Finally, the desirable features of biomass are preserved in conversion to higher forms of energy. These include: low or zero sulfur content, low ash residue, and the renewability, abundance, variety and wide distribution of the raw biomass.

Unfortunately, a review of recent research and operating experience reveals: (a) That nearly all biomass conversion efforts, including those with bagasse, have been directed at producing a single, energy-type product; (b) that the product costs (or will cost) as much or more than conventional fuels, on an equivalent basis; and (c) that there are difficult technological and/or operating problems to be overcome before a commercially-acceptable level of reliability and cost are reached. Following are a few examples:

1. A recent SRI International study for the Federal "Fuels from Biomass Program" selected 15 out of 1185 combinations of raw materials, processes and markets as worthy of further analysis. Cost estimates were made for the 15 as well as 21 cases studied by others, in $/mm BTU. While estimates for conventional fuels ranged from $1.40 for coal to $2.70 for residual fuel oil to a maximum of $9.80 for electricity, biomass conversion systems ranged from $3.67 to $52.60. Most of the latter were in the $4.00 to $25.00 range (29, pp. 25, 43-46).
2. In a paper for the Second Annual Symposium on Fuels from biomass, Wayne R. Park estimated the 1976 production cost per BTU of methanol from biomass at 1.5 times that of gasoline from conventional sources; that of ethanol at 3-4 times (29, p. 77).
3. In a 1978 report, Battelle Columbus Division concludes that, with conventional cane supply and technology, ethanol from cane juices and a little less than $1.00 from molasses, a low volume alternative not attractive to Puerto Rico. This is an improvement over Park's estimate, but Battelle warns that construction of a grass-roots facility would not lower costs much, because 75% of the required investment is for cane processing.
4. Construction costs for Combustion Equipment's garbage-to-fuel plant in Bridgeport, Connecticut, are running several million dollars over budget, and the plant is already a year and a half behind schedule.
5. At Albany, Georgia, downtime averages 50% (!) at a $3.8 million experimental, wood-to-oil plant operated by Bechtel for the Department of Energy (7, p. 60).

On a more general plane, Edward S. Lipinsky argues that energy farms are faced with a dilemma. Either they must sacrifice yield, to hold down costs and sell their output at competitive prices. Or they must find the way to sell some of their output at premium prices, to cover the cost of attaining the desired (land saving) yield of 11 dry short tons/acre (25 dry metric tons/hectare). By using only agricultural residues, one avoids some of these problems; but the yields seldom surpass 3.1 dry short tons (7 dry metric tons/hectare) and total biomass conversion is much lower than otherwise (17, p.644).

Faced with all these difficulties, Lipinsky (17, p. 645) concludes that a more powerful strategy for biomass conversion would be "a flexible, co-product manufacturing system, in which key biomass intermediates are processed *either* into fuels *or* into materials, depending on relative price levels."

The author would like to suggest still another strategy, a multi-product manufacturing system which is *flexible as to raw material* rather than process and operates in a stable manner near its optimum level, producing a variety of products simultaneously. There are several reasons why such a system may be the preferred alternative in a number of circumstances, including that of Puerto Rico. Many biomass conversion processes are relatively capital intensive. In many cases, the chemical reactions used have critical thresholds or ranges in terms of the operating conditions required to achieve acceptable yields. Most biomass-conversion raw materials have primary, non-energy uses as food, paper, etc. (Sugarcane is an obvious case in point.) Finally, current results suggest that only one cane cutting a year is desirable, even for high fiber varieties grown for their energy content. Hence flexibility as to raw material would enable *both* biomass suppliers, such as farms, *and* biomass converters, to adjust to changes in seasons, market conditions, social priorities as to land use, governmental energy policies and environmental controls.

However, the foregoing discussion would not be adequate without two additional points. In the first place, as Battelle concludes, "it is expected that solution of the energy crisis will require many small contributions, not a 'technological fix'" (4, p. 14). Let us say simply, "a variety of solutions." So it is not a question of which is best, but what is the best role for each technology or strategy.

In the second place, as indicated in the first section of this paper, time is the most critical factor in the energy situation. Consequently, in order to make a significant contribution to the solution of energy problems, both in the United States as well as Puerto Rico, the products of biomass conversion must gain *rapid and widespread acceptance* in the market place. For reasons to be explained, this is unlikely to happen unless biomass energy products are *significantly cheaper*, on an equivalent basis, *than conventional fuels.* It is not enough to be merely competitive. The procurement process in business enterprises is inherently conservative, so its built-in resistance to change must be overcome.

Much of the work of procurement officers involves the purchase of familiar items from known suppliers through standardized procedures, in accordance with written specifications or well--established industry grading systems. Reliability, product quality, performance in processing, timeliness in delivery, to name a few factors, are often as important as price in evaluating an item or supplier. Moreover, procurement decisions may involve long-run considerations of company strategy such as assuring supply over the business cycle or reciprocity for suppliers who are also customers.

Paradoxically, the purchase of a new biomass energy product from a new and unknown company may seem more risky to the procurement officer than purchase of conventional fuels refined from foreign crude oil. In the latter case, he may reduce his risk by diversity of supplier and choice of suppliers with large storage capacities. In the former, he is forced to bet on new technology and new people. Note, however, because of their multiple-generating units, electric utilities can experiment with biomass energy products at a much lower risk.

Moreover, it is a fact of life that procurement officers are not encouraged to innovate nor pardoned so readily for their mistakes as executives in advertising, marketing and new product development. Consequently, even after the procurement officer has agreed to consider a new energy product, considerable time for testing and evaluation may be required. At that, the procurement officer may have to stick his neck out and do some proselytizing among the engineering, production, and marketing personnel on behalf of the product under consideration. Recognition for a successful innovation will be slow in coming, until the new product and the new supplier have built up an adequate track record. Unsatisfactory performance in use, however, will bring quick protests from every department affected, as executives and supervisors scramble to shift the blame to someone else.

A good illustration of the difficulties which a new product faces is provided by the penetration of fructose (corn-based) sweeteners into the market for sucrose (sugar-based) sweeteners in the manufacture of food product characteristics and a price advantage.

Added to food products, fructose sweeteners are indistinguishable to the consumer from those made from sucrose. Some manufacturers even consider high fructose syrup (HFS) of good quality superior to sugar in a number of respects. In soft drinks, there may be fewer problems with haze and inversion. In baked goods, HFS may have better browning characteristics. In general, HFS exhibits greater uniformity from lot to lot (14, pp. 53-56). Moreover, acceptance and testing of HFS was greatly accelerated by discounts of from 10% to 50% from the price of sugar during 1974-75. As a result, shipping capacity in place or under construction grew from 300 mm lb in the late 1960's to 4.0 billion lb in 1978. Since the latter figure is twice 1977 shipments of 2.0 billion lb of HFS, there is no security of supply problem.

Notwithstanding all these advantages, 1977 shipments of HFS represented only 9% of the total for non-specialized sweeteners, and 1983 shipments are expected to represent no more than 24% (6.0 billion lb) of that year's total, *some 15 years after consumption of HFS began to grow* (25, pp. 16-17). In fact, as late as last fall, soft drink franchisers were still restricting their bottlers to sucrose or fructose-sucrose mixtures, out of fear of customer reaction. Yet at the time, most fructose manufacturers could break even at a price equivalent 10% below the price of sugar ($.135/lb) and quite a few were doing just that (27, p. 30).

In an effort to quantify this resistance to new products, SRI International has developed a set of formulas for estimating the growth in market share of a new biomass-derived product (28, pp. 35-38). On the average, SRI estimates that it takes 10 years for 50% of the market to accept (but not necessarily buy) the new product. Moreover, sales tend to lag acceptance by an average of four years. Only after 20 years does acceptance approach 100%. As a result, biomass energy products priced, on an equivalent basis, at the *same* price as competing conventional products, will have a maximum market share after 10 years of only 25% and, after 20 years, only 47%. (This is better than fructose, but then sugar does not have its OPEC.) Mathematically speaking, a 25% reduction in "behavioral half life," from 10 to 7-1/2 years, is more effective than a 25% cut in price, in speeding up the process of market penetration. However, acceptance is not an independent variable but in fact is heavily influenced by price, as the case of fructose illustrates.

In brief, new product promotion takes time and hard work. Sales always lag acceptance. So it is not enough for biomass energy systems to be competitive. They must price their energy products *somewhat below* the equivalent price of competing conventional fuels. Otherwise the contribution of biomass conversion to the solution of our energy problem may come too late to be much help.

The high operating costs of one-product systems and the need for attractive pricing of biomass energy products argues strongly for multi-product conversion systems.But it also argues strongly for co-products and by-products which can make a substantial contribution to joint costs, even when priced competitively. Only then can the biomass converter sell its energy product at an attractive price and still remain economically viable.

THE BAGASSE ENERGY PLANT

The author has just begun a study of a biomass conversion system, the Bagasse Energy Plant (BEP), which hopefully will meet the criteria advanced in the previous section of this paper. Since there are no results as yet, the general concept of this type of plant will be presented here.

This plant represents the combination of two proprietary manufacturing processes in an integrated facility that would convert bagasse into an alternative energy source—Woodex Fuel Pellets[3/]—and two chemical by-products, levulinic acid and furfural. These products will be discussed in inverse order.

World consumption of furfural is estimated at roughly 300 mm lb (136,000 metric tons), with an annual average growth rate of 3% to 5%. The principal uses of furfural are as follows:

(a) A binder in the production of metal-casting cores and molds.

(b) A component of corrosion resistent cements and motors.

(c) An intermediate in the manufacture of furfural resins from furfural alcohol.

(d) A solvent in the refining of lube oils.

[3/] Registered trademark.

(e) A solvent in butadiene extraction by dehydrogenation. (Such extraction may be replaced by heavy/liquid cracking by the late 1980's.)

After a shortage in the mid-1970's, furfural is currently in oversupply. World capacity is difficult to estimate but is believed to be around 400 mm lb (181 metric tons). As a result, export markets are very competitive. However, much of this capacity consists of poorly-operated, inefficient plants built without local markets, simply to take advantage of local raw materials. As a result, much price cutting may be based on desperation and subsidy rather than true cost advantages. The sole U.S. producer, Quaker Oats Company, maintains an Iowa tank price of $0.515/lb in the face of some European trades at prices between $0.45 and $0.50/lb (8).

For over fifty years, levulinic acid (LA) has been a high-cost, high-priced product with a wide variety of specialized uses such as: Food flavoring, plasticizer intermediate, agent in proprietary chemical synthesis, solder flux in chrome plating, ingredient in medicinals, and in water treatment. Current U.S. consumption is unknown, due to ambiguities in import statistics, but is conservatively estimated at between 100,000 and 200,000 pounds annually (45 and 91 metric tons), but it may be substantially more. Prices fluctuate considerably, depending on purity and other factors, but a range of $2.50 to $3.50/lb for commercial quantities is probably typical.

Ironically, LA has been known since 1870 and, together with its derivatives, has a plethora of potential uses which have never been developed, primarily due to its high cost of production. Some of these uses are: detergent emulsifier, insecticide, hydraulic fluid component, and plasticizer for various plastics (10, 26). Currently the biggest potential uses seem to be as a polyvinyl chloride plasticizer and as a synthetic rubber component.

It is estimated that use of PVC resin in the U.S. will grow at an average annual rate compounded of approximately 5% between 1979 and 1984, from 6.2 billion lb (2.8 mm metric tons) to 8.3 billion lb (3.8 mm metric tons). However, the use of PVC for pipe and pipe fittings will increase faster, at a rate of over 8%, growing from 37% to 41% of the total in the same period. PVC is displacing copper pipe in pressure uses and together the two are displacing other types of plastic pipe (8, p. 4).

Production costs of LA are high, basically because a strong acid (or a combination of salts) must be used to obtain the material by chemical reaction and then large quantities of solvent are required to extract the LA from the process liquor. For example, a typical process might use 100 lbs of methyl isobutyl ketone (MIBK) to extract 1.94 lbs of LA from the process liquor. About 3.00 lbs of MIBK would be lost in the process, or 1.54 lbs. of MIBK for each lb of LA. At $0.29/lb of MIBK, one is out $0.50/lb of LA, just for solvent losses and carrying charges. And, needless to say, strong acids and solvent recovery require expensive equipment. In addition, traditional processes present certain environmental problems. For example, among the outputs of the Quaker Oats process are a strong-acid filter cake and a solution of formic acid and water. And every known process generates much more unsalable residual matter than it does LA.

Faced with these problems, we will study the economic parameters of a process invented by Mr. Solomon Goodman, of Carolina, Puerto Rico, which produces LA and furfural without the use of strong acids or solvent extraction. We will also study the feasibility of using the residual process material as feed for the Woodex Process, in order to lower the cost of pellets. Fortunately both processes are very flexible and can use almost any cellulosic-containing material as an input. In fact, one of the operating plants which use the Woodex Process has already successfully turned 25 tons of Hawaiian bagasse into pellets.

The Woodex Process converts any organic cellular fibrous substance, such as wood waste or bagasse, into solid pellets called Woodex Fuel Pellets[4/]. This process uses standard commercial equipment to grind the raw material to size, dry it and compress it at a pressure of 10,000 lbs in a temperature range of 325 to 350°F, using the natural resins as a binder. After pelletizing, moisture content is adjusted so as to be in equilibrium with the atmosphere. A small portion of the pellets are consumed as fuel and an even smaller portion lost in manufacturing.

The pellets are 1/4 inch in diameter and 1/2 to 3/4 inch in length, with an absolute density of 65 lbs/ft^3 (1,041 kg/m^3), at 10% to 14% moisture content, and a heat content of 17 million BTUs/short ton, similar to oven-dry bagasse and some types of western coal. The pellets are easy to

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[4/] Registered trademark.

handle, not susceptible to humidity, and can be stored indefinitely in a sheltered area. With little or no modification, they can be burned in standard coal-fired equipment. Sulfur content is zero for agricultural and forest materials. Ash content is very low. Because of the pellets' uniformity, homogeneity, small size, low ash and low moisture content, steam generated per pound may equal that of coal types with slightly higher BTU values.

The woodex Process was invented by Rudolf W. Gunnerman, a West Coast physicist, and assigned to Bio-Solar Research & Development Corporation, of Oregon. Six plants using this process are believed to be in operation in the U.S. Some have been in operation for over two years[5/].

If these two processes can be economically coupled, a significant contribution to the solution of Puerto Rico's energy problem will have been made, in accordance with the criteria previously developed in this paper.

Attached, as an appendix, is a generalized mathematical model of a BEP. The principal conclusions derived from an analysis of this model are the following:

1. Given a minimum spread between product prices and input prices, an optimum mix of products exists for any number of products, even when the BEP is a price taker in *all* its input and output markets; not all the components of the bagasse can be used, due to weak demand for certain products; anything that is produced must be sold; and the waste generated cannot be sold; rather, the BEP must pay someone to haul it away. (By price taker, we mean that the BEP has no influence over the prices it obtains or pays. These are set by market conditions or other external forces.)

2. One of the most important economic criteria for an individual product is the contribution that its sales make to the joint costs of operating the BEP. Individual product profitability is not important, may not be calculable and in any case will probably depend on some debatable allocations of joint costs and joint investment (i.e. those which benefit several products).

3. If the BEP can influence the prices of some of its non-energy products, it should do so and use the increased revenue to lower the price of its energy product. If desired, this adjustment can be done so as to achieve or maintain a particular mix of physical output. Normally in economics, one would prefer an enterprise not to have such influence, and count it as a market imperfection. However, with multi-product biomass converters, the rules of the game must be different. To help resolve the problem caused by the energy price markers of OPEC, the BEP and other converters must seek to become partial price makers in non-energy fields. Otherwise their contribution to the solution of this problem may be too expensive or too late.

CONCLUSIONS

Puerto Rico's energy problem is not merely one of dependence on foreign supplies and a very high cost per BTU. The most serious aspect of this problem is that we are unusually vulnerable to random and disasterous interruptions in our crude oil supply or increases in crude oil prices. This vulnerability is independent of the possibility of a world energy crisis for reasons of economic supply. However, the probability of such a crisis means that our vulnerability increases over a time.

Thus it is urgent that we develop alternate sources of energy to reduce our vulnerability and, hopefully, at the same time reduce the cost of our energy. For well known reasons, biomass conversion, especially from bagasse—but also from grasses especially grown for the purpose—could be a major alternative for Puerto Rico. However, experience and research to date strongly suggest that single-product systems will be high-cost systems for many years into the future. Moreover, rapid penetration of energy markets requires that the biomass energy products have a *lower* price than competing conventional fuels. A possible solution to this dilemma is multi-product converting systems, such as a Bagasse Energy Plant which can use a variety of raw materials and sell non-energy products at favorable prices.

If such systems are proven to be commercially economic and reliable, an obvious strategy for Puerto Rico would be to grow more cane, much more cane than now. However, most of the varieties would be designed to maximize fiber and chemical raw materials rather than sucrose. Together with appropriate grasses, they would be the raw material for biomass energy converters. High sucrose cane would be fed to "super trapiches," producing high sucrose molasses for the rum industry and chemicals. Rice and sugar would be imported. It is better to run out of these than energy or rum which make such a vital contribution to our economy and to our government's revenues.

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Appendix

Multi-product Output - Key to Bagasse Economics

Mathematical Model of a BEP

This Appendix presents a generalized model of a multi-product Bagasse Energy Plant (BEP) which can be easily modified to describe a particular case, such as the plant under study by the author. This general model is more tractable analytically than the model of a specific plant would be, yet at the same time the results obtained will apply to most specific models. The main features of the model are first described. Then it is optimized and certain results are obtained from the first order conditions for optimization.

Following are the principal characteristics and underlying assumptions of the generalized BEP model:

(1) The BEP produces and sells m products in the quantities $y_1 \ldots . y_m$, of which y_h represents the sales of any particular product and y_i, y_j represent the sales of some pair. The product "slate" includes one energy product which is physically homogeneous and has desirable combustion, environmental, handling, storage and transportation characteristics.

(2) Initially it is assumed that these products are sold at m positive prices $p_1 \ldots . p_m$ which are not subject to influence by the BEP. I.e. the BEP is a "price taker", with prices set by external forces such as market competition, other producers, etc. Subsequently this condition is relaxed with important consequences.

(3) Output is affected by n factors, $x_1 \ldots . x_n$, of which some are inputs, such as the quantity of bagasse charged to the process, and others are operating conditions, such as the moisture content of the process material at a given stage in manufacture. Of these factors, x_k is any particular one, x_1 is bagasse and x_m and x_n are any pair other than bagasse.

(4) Inputs are purchased at competitive prices or prices negotiated under long-term contracts, so that for the purposes of optimization, they are fixed and the BEP is a price taker in its input markets as well.

(5) The quantity of any one product obtained from a given set of inputs and operating conditions does not affect the level of output of any of the other products. Instead, failure to utilize all of some component of the bagasse results in a quantity of residual waste w_k. Initially it is assumed that any quantity of such waste likely to be generated can be sold at a price which is minimally attractive to the BEP. The logic of this assumption is that bagasse is a multi-component raw material and that, in designing the BEP, we wish to extract and use each component in the most rewarding manner possible. In practice, depending on the manufacturing processes used, the output of some products might well affect the output of others. Alternatively, a certain process might unavoidably produce a variety of products as output, with only the proportions varying due to changes in operating conditions. However, such complications merely add constraints to the optimization problem without changing its basic nature and so will be ignored.

(6) All of the processes used in the BEP may be expanded in relatively small increments. This happens for two reasons. Either economies of scale are not very great beyond a certain modest size or the required equipment is available in a wide variety of sizes.

(7) Given the foregoing, we may make the following assumptions with out undue violence to the realism of the model:

(a) In the neighborhood of the optimum mix and level of output, physical "returns to scale" are roughly constant. E.g. an increase of 10% in the quantity of each input and the level of each operating condition will result, approximately, in a 10% increase in the output of each product. In more general terms, in this neighborhood, for any output y_h^*, its relation to the inputs and operating conditions may be expressed as a production function $f_h(x)$ with the property $ry_h^* = f_h(rx)$, where r is a constant > 0 and x is a vector of appropriate x_k.

(b) The incremental output dy_h resulting from a small increase in some input or operating condition dx_k, when all the other inputs and operating conditions are held constant is positive and either constant or decreasing. I.e. $f'_h(x_k) > 0$, $f''_h(x_k) \leq 0$ for all $x_k > 0$ in $f_h(x)$. In practice, because we are dealing with chemical processes, even near the optimum configuration of operations, some particular f'_{hk} might be positive and increasing, or even negative ! Theoretically such a situation could prevent us from finding such optimum pattern(s) of operation as may exist by analytical methods and could force us to resort to numerical models with hypothetical values plugged in. However, it is reasonable to assume, in the case of a BEP, that the practical effect is small and may conveniently ignored.

(c) Since capacity can be increased in small increments and only some of the processes show significant cost savings for major increases in capacity, total fixed costs can be approximated by a relatively smooth curve. Thus fixed costs per unit of output (given the mix of products) tends to decline slowly and steadily. (By contrast, in some manufacturing operations, capacity increases are not only very "lumpy", but unit fixed costs drop sharply. Hence the total fixed cost curve is a well defined step function, and the unit fixed cost curve slopes downward in a saw-tooth fashion. Needless to say, this severely complicates the optimization problem).

(d) Variable costs change more or less in proportion to output. Hence variable cost per unit of output (again given mix) is constant or slightly rising , near the optimum configuration of operations.

(8) In the light of the foregoing, we may represent the relation between costs and physical activity of the BEP by two continuous, smooth cost functions:

(a) A "direct cost" function, $D = g(y^*)$, where y^* is a vector of product outputs; $g_h'(y_h^*) > 0$ and $g_h''(y_h^*) \geq 0$. This function includes those elements of cost which vary with the level of output of each product but are not affected by changes in the mix of inputs and operating conditions alone.

(b) A "joint cost" function, $J = h(x)$, where x is a vector of inputs and operating conditions, with $h_k'(x_k) > 0$ and $h_k''(x_k) \geq 0$. This function includes those elements of cost not included in the direct cost function.

Note that, in the interest of simplicity, those cost which vary only with output, independently of the mix of outputs or the mix of inputs, have been omitted. Also, the concept of cost used here is economic cost. I.e. it includes not only interest on long term debt but also such long-run profit on risk investment (equity capital) as may be required to attract that investment in the first place.

(9) The BEP's objective is to maximize the excess of total revenues over economic cost. Given the inevitability of forecast errors in any manufacturing or other business budget this seems to be the best way to run a business, regardless of who owns it or how the excess is shared, providing certain conditions are met. The most important of these conditions are:

(a) While all real-world price systems are defective, particularly in Marxist economies, the price system faced by the firm should be relatively rational and not subject to significant manipulation.

(b) Alternative objectives can not be proven superior by cost-benefit analysis.

(c) Society has the option to tax the excess and all of the incomes earned in the firms operation.

Note that, if we assume that some or all of the suppliers of capital take the risks of the enterprise and consequently receive the excess revenue, then this objective reduces to the traditional one of profit maximization. With an appropriate estimation of the required profit, this is equivalent to maximizing return on investment.

Given the foregoing, we may express the BEP's excess revenue function as follows:

$E = \sum_{h} P_h y_h + P_w w - D - J$	subject to :
$f_h(x) \leq x_{1h}$	For each product, output does not exceed the quantity of the corresponding component available in the bagasse consumed in production.
$y_h \leq y_h^* = f_h(x) + v_{ho}$	For each product, unit sales does not exceed the sum of its output plus starting inventory.
$P_w \leq P_h^*$	The price of waste is not greater than the price of the cheapest product.

Given a stable level of operations over a sufficient period of time, we may reasonably assume that, for each product, unit sales equals production and closing inventory equals opening inventory, without undue violence to the facts. Hence the second constraint becomes $y_h = f_h(x)$, and the BEP's objective function is:

$$\begin{aligned}
\text{Max } E^* = & \sum_{h} P_h y_h + P_w w - g(y) - h(x) \\
& + \sum_{h} \lambda_h \left[x_1^* - f_h(x) - w_h \right] \\
& + \sum_{h} \psi_h \left[f_h(x) - y_h \right] \\
& + \phi \left[P_h^* - P_w - s \right]
\end{aligned}$$

where the expressions in brackets $[\;]$ are equal to zero at the optimum configuration of operations, the slack variables w_h and $s \geq 0$, And,

P_h = the price of product h ($P_h \geq 0$)

y_h = the quantity of product h sold

$y_h^* = f_h(x)$ = the output of product h

P_w = the price of waste ($P_w \geq 0$)

$w = \sum w_h$ = the total quantity of waste

$D = g(y)$ = the direct cost function, with y a vector of products

$J = h(x)$ = the joint cost function, with x a vector of inputs and operating conditions

x_{1h}^* = the quantity of bagasse component h consumed at the optimum configuration of operations

w_h = waste resulting from failure to obtain the maximum quantity of product h from bagasse

P_h^* = the price of the product with the lowest price of any product (a constant)

$s = P_h^* - P_w$

And finally, the λ_h, the ψ_h and ϕ are Lagrangian multipliers, with the following interpretations, for small shifts away from the optimum pattern of operations:

λ_h = the incremental unit value in production of component h

ψ_h = the unit value of a small change in the sales of product h

ϕ = the total quantity of waste generated

Given the nature of the inequality constraints on the slack variables w and s, there are theoretically four alternative sets of conditions for optimization. Initially we assume that there is some waste and that it sells for less than the cheapest product. I.e. $w > 0$, $s > 0$.

Following Lancaster, the first order conditions (FOC's) include:

(1) $\partial E^*/\partial y_h = P_h - g'_h - \psi_h = 0$ (for all h)

(2) $\partial E^*/\partial P_w = w - \phi = 0$ (for all h)

(3) $\partial E^*/\partial w_h = P_w - \lambda_h \leq 0$

(4) $\partial E^*/\partial x_k = - h'_k - \sum \lambda_h f'_{hk} + \sum \psi_h f'_{hk} = 0$ (for all h, k)

(5) $\partial E^*/\partial s = -\phi \leq 0$

Before obtaining results from the FOC's, we first proceed to establish that, mathematically at least, an optimum exists:

(1) Since the initial conditions include $w > 0$ and, per FOC (2), $w = \phi$, then $\phi > 0$ as well and $-\phi < 0$, as required by FOC (6).

(2) Since bagasse can either be turned into waste and sold at a price $P_w > 0$ determined by the BEP, or turned into products and sold at market prices $P_h > 0$ for all h, then $\lambda_h > 0$. Hence the BEP can set P_w such that $P_w \leq \lambda_h$ as required by FOC (3).

(3) Except for FOC's (3) and (5), all FOC's (including those omitted above) are set equal to zero.

(4) The set of prices $P_1 \ldots . P_h$ are assumed to be sufficently greater than zero to make FOC (1) feasible, if the other conditions are satisfied.

(5) We take the liberty of assuming that, since the FOC's are fulfilled, the sedond order conditions are also fulfilled. Given the mathematically well behaved nature of our cost and production functions, and the fact that they reflect operational realities, such an assumption is entirely reasonable.

Since, mathematically speaking, a globally optimum configuration of operations for the BEP does exist, one which maximizes excess revenue, we proceed to derive certain implications of the FOC's and express them in economic terms:

(1) The unit value ψ_h of a small change in the sales of product h is positive and is equal to the incremental contribution to joint costs made by the sale of that same quantity. Note that ψ_h must be positive for all h since all prices are constant and positive, including the price of waste, and what is produced is sold. Hence, per FOC (1):

$$\psi_h = P_h - g'_h > 0 \qquad \text{for all } h$$

(2) For any two products, the ratio of their unit sales values is equal to the ratio of their incremental joint costs. Per (1) above:

$$\frac{P_i - g'_i}{P_j - g'_j} = \frac{\psi_i}{\psi_j} \qquad . \quad \text{for all } i,\ j$$

The above two results illustrate what is often overlooked in in multi-product plants and multi-plant firms, with significant joint costs. One of the most important criteria for evaluating individual products or plants is their contribution to (and long-run effect on) joint costs, not their individual profitability. The latter must usually be estimated and then often on the basis of somewhat arbitrary assumptions which may be invalidated by relatively small changes in the pattern of operations.

(3) Under any circumstances, a change in the quantity of some input or the level of some operating condition, x_k , is liable to affect simulataneously revenues, output and costs. At the optimum configuration of operations, the <u>sum</u> of the changes in individual product contributions to joint costs is equal to (a) the incremental change in joint costs due solely to the change in x_h, plus (b) the opportunity cost of changing the mix of products and waste. Note that if one multiplies FOC (1) by any f'_{hk} , sums over all h and combines with FOC (4), one obtains:

$$\sum_h f'_{hk}(P_h - g'_h) = h'_k + \sum_h \lambda_h f'_{hk}$$

(4) By rearranging (3) above, we find that the <u>sum</u> of the changes in product revenues is equal to the <u>sum</u> of the changes in the different types of costs due to a change in x_k:

$$\sum P_h f'_{hk} = \sum g'_h f'_{hk} + h'_k + \sum \lambda_h f'_{hk}$$

Note that neither (3) nor (4) necessarily apply to individual products, even at the optimum. This is another reason for not overemphasizing individual product "profitability". This also contrast with the one-product case whose FOC's typically include or imply:

$$P = dC \,/\, dy \qquad \text{(marginal revenue equals marginal cost)}$$

$$P \frac{\partial y}{\partial x_k} = Pf'_k = \frac{dC}{dy} \cdot \frac{\partial y}{\partial x_k} = \frac{\partial C}{\partial x_h}$$

We now proceed to modify some of our assumptions and initial conditions, as follows:

(5) If the BEP can influence the price of some non-energy product, say product j, by varying inversely the quantity sold, y_j, then the first righthand term in the objective function is replaced by:

$$\sum_{i}^{m-1} P_i y_i + P^*_j\,(y_j)\; y_j\;,$$

where $P^*_j(y_j)$ is the price function for product j. Hence the FOC for y_j becomes:

$$\text{(1A)} \quad \partial E^* / \partial y_j = P^*_j + \frac{dP^*_j}{dy_j}\, y_j - g'_j - \psi_j = 0\;.$$

Now let us define the sensativity of the price of product j to changes in its sales volume by:

$$\frac{1}{e} = \frac{dP^*_j}{P_j} \div \frac{dy_j}{y_j} = \frac{dP^*_j}{dy_j} \cdot \frac{y_j}{P_j} < 0$$

and rewrite FOC (1A) as follows:

$$P^*_j \,\frac{(1+e)}{e} - g'_j + \psi^*_j = 0\;. \qquad (e < -1)$$

If the BEP sets $P^*_j \left(\frac{1+e}{e}\right) = P_j$, then the new price, P^*_j, will exceed the old price, P_j, but the other terms in the FOC will not necessarily change. To keep things simple, lets suppose that they dont and e is constant. Then the value of every FOC remains the same as before, but excess revenue is increased by $(P_j^* - P_j)y_j$. Furthermore, suppose that the BEP decides to use this additional revenue to lower the price of its energy product. Since, per FOC (1A)

$$P_j^* - P_j = - \frac{dP_j^*}{dy_j} y_j \quad ,$$

the total value of the price reduction on the energy product will be:

$$- \frac{dP_j^*}{dy_j} y_j^2 \ ,$$

and the new price of the energy product will be:

$$P_1^* = P_1 + \frac{dP_j^*}{dy_j} \cdot \frac{y_j^2}{y_1} < P_1 \ .$$

Since the BEP is a price taker in the market for its energy product, $P_1^* < P_1$ will help to assure a more rapid acceptance of the new product but will not affect th e prices of competing products.

(6) If $P_w > \lambda_h$, for some h, obviously the conditions for an optimum are not fulfilled. It is more profitable to generate and sell waste than produce that particular product. If $P_w = 0$, the term $+ P_w w$ in the objective function and its third constraint disappear. If the BEP must pay someone to haul the waste away and dump it, this term is replaced by $- P_d w$ and the third constraint again disappears.(There are, of course, appropriate changes in the FOC's.)

(7) If there is no waste, the objective function may be simplified to:

$$\text{Max } G^* = \sum_h P_h f_h(x) - g^*(x) - h(x) + \sum_h \lambda_h \left[x_1^* - f_h(x) \right] ,$$

and the FOC's include:

$$\partial G^* / \partial x_k = \sum_h P_h f'_{hk} - g_k^{*\prime} - h'_k - \sum_h \lambda_h f'_{hk} = 0 \ ,$$

which is analageous to FOC (4) on page 7 of this Appendix.

(8) If ending inventory, v_{ht} , is treated as a slack variable, the second constraint in the objective function becomes:

$$+ \sum_h \psi_h \left[v_{ho} + f_h(x) - y_h - v_{ht} \right] ,$$

and an additional set of FOC's, $\partial E^* / \partial v_{ht} = -\psi_h \leq 0$, for all h, must be added. $_h$ may be interpreted as the unit value of incremental supply, supply = $v_{ho} + f_h(x)$, for product h.