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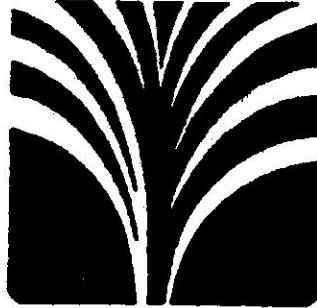
PROCEEDINGS OF UNICA WORKSHOP ON BIOMASS
AS AN ALTERNATIVE FOR THE CARIBBEAN

Caribe Hilton Hotel
San Juan, Puerto Rico

April 28-29, 1982



CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
UNIVERSITY OF PUERTO RICO -- U.S. DEPARTMENT OF ENERGY



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CONTENT

	Page
Foreword -----	1
Acknowledgments -----	3
WORKSHOP ON BIOMASS AS AN ENERGY ALTERNATIVE FOR THE CARIBBEAN -----	4
Words of Welcome -----	5
Biomass Opportunities for the Caribbean -----	9
Why Worry? -----	10
What is Biomass? -----	14
Energy in the Caribbean -----	15
Energy grasses -----	25
Energy trees -----	25
Upgrading biomass -----	25
Municipal solid wastes (MSW) -----	26
Wood and Wood wastes -----	26
Anaerobic digestion of animal wastes ---	26
Anaerobic digestion of municipal sewage sludge -----	27
Ethanol -----	27
Methanol -----	29
CARIBBEAN ENERGY ACTIVITIES SUPPORTED BY THE U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT -----	35
Overview of Aid Programs in Energy -----	36
Additional Resources from the Energy Office -----	37
Simple, Low-Cost Energy Technologies for the Rural Poor -----	38
Caribbean Energy Programs -----	38
New Research Funds -----	40
Central Program on Bioresources -----	41
Energy Studies -----	42
EL CONCEPTO DE INTEGRACION DE SISTEMAS DE ENERGIA A LAS GRANJAS AGRICOLAS -----	43
Introducción -----	44
Etapa evaluativa de las granjas -----	45
Guías y factores importantes en la fase de diseño -----	49
Aplicaciones y limitaciones -----	51
Aspectos económicos -----	54
BIOENERGY FROM ANAEROBICALLY TREATED WASTE WATER -----	56
Introduction -----	57
The USAB-System -----	60
Energy Production -----	66
Applications and Importances of Anaerobic Waste Water Treatment -----	71
Arrangement of Test Equipment USAB Reactor Processing Domestic Waste Water -----	78

CONTENT (cont.)	Page
Results -----	80
Conclusions -----	83
Acknowledgments -----	83
References -----	83
 EL I.N.R.A. DENTRO DEL DOMINIO DE LA ENERGIA BIOMASICA -----	 85
 BIOCONVERSION OF STRONG ORGANIC WASTE STREAMS TO METHANE GAS: THE BACARDI CORPORATION'S ANAEROBIC TREATMENT PROCESS -----	 91
 BIOMASS - A POTENTIAL ENERGY SOURCE FOR JAMAICA -----	 99
Jamaica and the World Energy Scene -----	100
Biomass - A Potential Source? -----	102
Works Consulted -----	107
Appendix I-A -----	108
Appendix I-B -----	110
Appendix I-C -----	112
 ALCOHOL FUELS FROM AN INTEGRATED BIOMASS SYSTEM: TECHNOLOGY AND ECONOMICS -----	 114
Introduction -----	115
Data and Results -----	116
Alcohol Properties -----	116
Ethyl alcohol (Ethanol) -----	117
Coproducts -----	117
Market for Coproducts -----	118
Ethanol as a Fuel and as a Chemical -----	118
Butyl Alcohols -----	122
Acetic Acid -----	124
Economy of Alcohol Production -----	128
By-Product Credits -----	131
By-Product Prices -----	132
Technology of Alcohol Production and By-Products -----	 136
Sweet Sorghum or Sugar Cane Juice -----	136
Sweet Sorghum -----	137
Alcohol from Molasses -----	138
Butanol-Acetone -----	138
Review of Solar Distillation -----	144
References -----	145
 REPORT ON BIOMASS AS AN ENERGY ALTERNATIVE FOR THE CARIBBEAN WORKSHOP -----	 147
 LIST OF PARTICIPANTS -----	 160

FOREWORD

By

Dr. Juan A. Bonnet, Jr.
Project Principal Investigator

These are the Proceedings of the Workshop on Biomass as an Energy Alternative for the Caribbean that was held on April 28-29 at San Juan, Puerto Rico, as part of the UNICA Science and Technology Commission Project on Development of Alternative Energy Science and Engineering in the Caribbean. The second workshop in the series, this project uses the unique institutional resources of the Association of Caribbean Universities and Research Institutes (UNICA). By these means an unrivaled network has been established to make this project a rare experience: Caribbean talent is being used to establish, at an early stage, wind and biomass research.

The first Workshop on Wind as an Energy Alternative for the Caribbean was held on December 6-9, 1981 in Bridgetown, Barbados. The Proceedings were also published by UNICA.

This project was already underway when President Ronald Reagan announced his Caribbean Basin Initiative on February 24, 1982. As a forerunner for analyzing Caribbean energy alternatives, the initiative has foreseen the importance of the project and especially the recommendations from the three workshop sessions on education and training, research and development, and demonstration needs.

The conclusion reached has been that biomass as an energy alternative for the Caribbean offers a unique opportunity to produce large amounts of energy. Relative to Caribbean island needs, biomass could help in the economic recovery of the region. Both

energy and food crops could be complementary, especially the production of bagasse/fiber from energy cane.

Specific demonstration projects are now needed in the Caribbean in order to implement the use of biomass as an energy alternative. The only resource lacking is funding. Also important is the development of a tropical biomass institute. UNICA is in a unique position to play an active role in developing regional programs, technology transfer activities, and information dissemination. All these recommendations are discussed in the presentations and workshop results.

This workshop followed immediately upon the Fuels and Feedstocks from Tropical Biomass Seminar II, also held in San Juan, Puerto Rico, April 26-27, 1982. This seminar was organized by the Center for Energy and Environment Research (CEER) of the University of Puerto Rico. Proceedings have also been prepared and may be ordered from CEER.

Finally, thanks to all the members of the Commission and the CEER Staff who helped make this project a success.

ACKNOWLEDGMENTS

The UNICA Science and Technology Commission acknowledges the work done by Mr. William Ocasio, CEER-UPR, in organizing this Second Workshop on Biomass as an Energy Alternative for the Caribbean. The Commission also thanks Eng. Pedro A. Sarkis, CEER-UPR, who collected and organized these Proceedings.

The Commission acknowledges with thanks the funding support received from the National Science Foundation, the Exxon Educational Foundation and the UNICA Foundation. It gives thanks to the UNICA Staff for their cooperation, for the simultaneous translations, and for other services during the workshop.

The Commission is, of course, also grateful to all UNICA contact persons who participated in and actively supported Commission members in this project.

UNICA SCIENCE AND TECHNOLOGY COMMISSION

Dr. Juan A. Bonnet, Jr. Chairman	CEER, University of Puerto Rico
Dr. Howard P. Harrenstien	University of Miami
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October 6, 1982

WORKSHOP ON BIOMASS AS AN ENERGY ALTERNATIVE
FOR THE CARIBBEAN

APRIL 28, 1982

WORDS OF WELCOME

By

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

Good morning, ladies and gentlemen, friends and colleagues. It is my pleasure to extend words of welcome to this group of dedicated professionals attending the UNICA Workshop on Biomass as an Energy Alternative for the Caribbean. This activity is co-sponsored by the UNICA Commission on Science and Technology, the Exxon Educational Foundation and the National Science Foundation, to all of whom we express our thanks. We must also express thanks to the Caribbean Development Bank for sponsoring the attendance of five representatives of five different CARICOM countries. Thank you all.

During the preceding two days we heard two dozen carefully prepared papers on various aspects of the biomass/energy problem. For the next two days we shall be concerned with the practicalities of finding means whereby our accumulating knowledge--research and technology transfer capabilities and the results obtained--might be applied to the current and future problems of the Caribbean, and especially to biomass as a Caribbean energy resource.

It is fitting we should be doing this in the Caribbean and particularly in Puerto Rico for two reasons: first, we have been doing much research in biomass, and, second, our natural resources themselves demand we do so. As most of you already know, Puerto Rico's mere 3,435 square miles of land contain six ecological zones and 26 soil classifications. These are representative of southern Florida, the Caribbean in general, Central America, northern South America and large regions of Africa and Asia. Thus a wide range of land and water and plants and animal

variables may be studied. Altitudes range from sea level to mountainous. At El Yunque the tropical Luquillo Forest averages a rainfall of over 200 inches a year; yet within a two hour drive there is desert region at La Parguera where one of the world's few phosphorescent bays may be found and where the rainfall seldom exceeds ten inches a year. Just few miles off the north shore lies the abyssal Puerto Rico trench, one of the world's deepest. Dwarf forests, lush valleys, volcanic karsts, wetlands--these phenomena multiply Puerto Rico's ability to provide naturally occurring environments for interaction not only with laboratory-created experiments but also with the impact of an industrialized and technologically advanced society on a densely populated island with few mineral resources of its own.

These characteristics, unique to Puerto Rico, can be found and duplicated in varying degrees on other islands and regions in the Caribbean.

It is therefore fitting that UNICA should be the sponsor of these two days of our four day program. Not only do we share a common geography, and, in spite of linguistic differences, a greater commonality of human heritage and economic needs than are generally realized, but we also share a common range of problems. It is for this, for exchange and common effort, that UNICA was created in 1968 and has since grown to 45 member institutions. In these 14 years UNICA has organized more than 200 meetings of various kinds, including workshops such as this, focusing on regional needs and regional abilities and resources.

Energy is such a regional need. Energy is such a regional resource. The need is present, as it has always been; the resource continues to be largely potential. Always abundant as sunshine, wind and vegetation, energy has also been in short supply since the advent of industrialization and modern technology. Now

a promise is opening up for us again--the promise and potential of energy here and now, constantly renewing itself--without our having to rely on imported fossil fuels to develop our modern societies.

Biomass is such a constantly self-renewing form of energy. It offers certain, almost immediate, short-term substitute possibilities for reducing the reliance on fossil fuels; it also heralds a potential promise of substantial proportions in the long term.

Essentially a mechanism for collecting and storing sunlight in organic form, biomass has numerous attributes particularly favorable to Puerto Rico and other developing Caribbean nations. Of particular note are these factors. Its varying forms are adaptive to the region's special climatic and botanical resources and divergent land and water resources. As an already integral component of the Caribbean historical experience, it can be produced and processed with existing technologies. A rapidly deployable and broadly applicable substitute for petroleum fuels and feedstocks, it is also potentially the least expensive substitute for the petroleum fuels and chemical feedstocks in temperate regions. Finally, the world's most productive biomass forms are found in the Caribbean region, including both herbaceous species, such as sugarcane and other tropical grasses, and a broad range of woody forest species.

Therefore, as Director of the Center for Energy and Environment Research of the University of Puerto Rico where we have been working on these problems for five years now, and as Chairman of UNICA's Commission on Science and Technology through which we take steps to spread our good works, it gives me great pleasure to welcome you to these proceedings.

It is my hope--and I am sure yours too--that they will become a step to furthering our mutual understanding of our common needs

and problems and, even more significant, a major step in working toward resolving these needs and problems with shared scientific and technological solutions.

BIOMASS OPPORTUNITIES FOR THE CARIBBEAN

Presented at

UNICA WORKSHOP ON BIOMASS AS AN
ENERGY ALTERNATIVE FOR THE CARIBBEAN

San Juan, Puerto Rico

April 28-29, 1982

By

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WHY WORRY?

In a report dated March 17, 1982, Daniel G. Snow of A.G. Becker Inc., states:

"We believe OPEC will hold its official \$34-a-barrel price at its March 19th meeting, but lower the price to \$29 a barrel at its late May meeting... and possibly even to \$25 a barrel at its year-end meeting... Moreover, we believe there is substantial risk that, as prices move down, OPEC may lose control in a downward, leapfrogging price spiral to \$25 a barrel (sic)... depending mainly on whether the U.S. economy has a robust second-half recovery...." (1).

Herbert W. Krupp, vice-president of Banker's Trust Company, New York, has even predicted a world surplus of oil, with stable prices, through 1990 (2). These reports are illustrative of many which have been published this year by knowledgeable authorities forecasting a significant decline in crude oil prices over the short, intermediate or long run, depending on the inclinations of the analyst. Such forecasts and current developments in the oil industry (3) are in partial or total contrast to those published a year or more ago, sometimes by the same authorities (4) (5).

There is no doubt, of course, that we are experiencing a temporary glut in oil supplies. Contracts for delivery of No. 2 heating oil in May of 1982 are selling on the New York Mercantile Exchange for 91.4 cents per gallon, almost 22 cents or 19 percent below their lifetime high of 113.0 cents. Moreover, the glut is expected to last for some time because contracts for delivery in every month through October 1982 are also selling below their life-time highs (6). With winter gone, these figures from a regulated, open market in the U.S. confirm newspaper reports of significant reductions in the price of crude oil sold under regular contracts between oil companies and producer governments.

Accurate information on such crude prices is not regularly available, especially when changes in FOB cost are affected by varying non-price terms. For example, the average FOB cost of Venezuelan crude oil imported by the U.S. is believed to have declined by \$4.84 per barrel or 15 percent between January and December 1981, from \$32.87 to 28.03 (7). More recently, Japanese companies have agreed to buy on spot basis at least six million barrels of Iranian crude at \$26 per barrel, some \$6 per barrel below Saudi Arabian crude of the same variety, in violation of the OPEC pricing structure (8).

Under the circumstances, one may ask, why worry about alternatives to petroleum fuels? And then, what are we doing here?

We stand by the forecast which we made last fall. Averaged over periods of several years, the prices of petroleum fuels will escalate at a rate at least one or two percentage points above the general rate of inflation for the Caribbean region. Over a decade, at only two percent per year, this means an increase in the real (i.e. inflation-adjusted) cost of these fuels of 22 percent. To get an idea of the impact, think of your own country and what could happen if suddenly, tomorrow, petroleum prices increased 22 percent, other domestic prices changed only enough to pass on this increase, but export prices changed not at all.

Despite the relief given oil consumers by the current price decrease, petroleum conservation and import substitution are as urgent as ever. The present decline is only a small piece of good luck which gives us a little more time than we thought we had. We would be foolish not to take advantage of it. Our reasons for saying this are as follows:

- (1) Since the first oil crisis of May, 1970, the history of crude oil prices has been precisely what we are observing

today--periods of declining (or stable) real petroleum prices followed by sudden increases which give the appearance of "steps" when plotted on graph paper.

- (2) The current oil glut appears to be caused primarily by transitory factors: simultaneous recessions in many industrialized countries, both marxist and non-marxist; overestimates of the effectiveness of President Reagan's economic programs and consequent over-production; and efforts to adapt a particular structure for oil prices and a particular mechanism for escalating them.
- (3) World oil consumption will continue to increase, despite the success of efforts to conserve energy and replace petroleum fuels (9). Even if this increase is only one percent per year compounded, the net increase in world productive capacity required at the end of twenty years will be over 13 million barrels per day, or 26 percent more than the present maximum capacity of the largest OPEC producer.
- (4) In addition, a very substantial amount of new capacity must be added to compensate for exhaustion of, or declining production from, existing wells. For the United States alone, this requirement could reach 10 million barrels per day by the year 2000, close to the present maximum capacity of OPEC's largest producer (9).
- (5) New oil fields are becoming more difficult and more expensive to find and develop, so even a slow increase in consumption insures a relative inflation in oil prices in the long run. For example, during 1975-1978, a period of relatively stable oil prices, exploration expense in the U.S. increased at an average annual rate compounded of

and lifting costs, at 9 percent, for a weighted average of 11 percent (5). In addition, recent technological advances and high oil prices make it profitable to spend relatively more, per foot drilled and per well, to find oil than in the past (10,11,12).

(6) Nearly half the world's crude oil is supplied by OPEC countries. Moreover, outside of China and the Soviet Union, about 75 percent of the world's proven reserves are controlled by these same countries. The middle eastern countries in general, and the largest OPEC producer in particular, dominate OPEC pricing policy. Indeed, this producer has a maximum capacity equivalent to roughly one-sixth of normal world consumption. Since its own needs are substantially less, it has a "swing capacity" equivalent to almost 7 percent of world consumption (13) and has repeatedly demonstrated its willingness to use this swing capacity to attain foreign policy or oil price objectives.*

(7) Middle-eastern politics differ from politics elsewhere. Political and religious considerations often prevail over economic ones, sometimes in a manner that is entirely logical within the historical context, but which catches westerners, both marxist and non-marxist, by surprise. Conflicts between nations, ethnic groups, religions and sects are often centuries old and may have the nature of hereditary feuds or holy wars. Finally, some countries in the region have, or will soon have, nuclear bombs (14).

*Neither praise nor blame is intended here. However, oil producing countries may not always be able or willing to consider the needs of small, oil-importing countries!

Sooner or later we must expect new conflicts in the Middle East or elsewhere which will adversely affect the price and supply of crude oil (15,16).

Under the circumstances, the only prudent course is to develop alternate sources of energy as quickly as practicable. The fact that we cannot predict the timing or cause of the next energy crisis is not really relevant. Its consequences are likely to be severe and, to some degree, permanent. Within this context we will now proceed to examine biomass opportunities with specific reference to the Caribbean.

WHAT IS BIOMASS?

Defined broadly, biomass consists of terrestrial vegetation (e.g. crops, weeds and trees), aquatic vegetation and the residues of such vegetation. It also includes animal wastes, wastes created by processing animals or biomass and municipal wastes of biomass origin.

Biomass is a renewable and indirect form of solar energy. It is sunlight which powers the chemical reaction that converts carbon dioxide and water into solid green matter and oxygen.

The sub-tropical conditions which characterize the Caribbean are often ideal for biomass. Due to warm (or mild) nights and winters, plant growth is usually possible on a year-around basis. Soil fertility may be greater than in the tropics while rainfall, even where abundant, is normally not so heavy as to drown crops or leach away most soil nutrients. As a result, high yields per acre of fiber and other solids may be achieved, frequently superior to those attained in other climatic zones.

The uses of biomass are many: to feed people and animals; as raw materials for chemicals; for lumber, decoration, shade, protective surface cover; as the source of the oxygen which we breathe; and, finally, for energy. An "oven dry" short ton of biomass (6 percent moisture) has about 15 million BTU of energy. On a steam equivalent basis, that is about as much realizable energy as there is in two 42 gallon barrels of residual fuel oil.

The ways of converting biomass into energy are also very numerous (See Table 1). A great many are still in the early stages of research or are undergoing systematic laboratory testing. Still others are operational on a commercial scale but are not yet economically feasible. Because time is of the essence in implementing alternatives to petroleum and most countries cannot afford to make mistakes, our discussion will emphasize those biomass energy systems which are, first, appropriate to several Caribbean countries, and, second, commercially feasible.

ENERGY IN THE CARIBBEAN

All of the insular Caribbean countries, except Trinidad-Tobago, are petroleum importers. Consequently, the oil price increases of the last decade have had a serious effect on their economies. In monetary terms, crude petroleum and refined products increased from less than 9 percent of total merchandise imports in 1971 to about 25 percent in 1980 for countries participating in the Caribbean Alternatives Energy Systems Project of AID, CARICOM and CDB.

The Caribbean energy situation is further complicated by the following additional problems, each of which, in varying degrees, is common to a number of countries:

- (1) The small size of the national energy system.

- (2) Low per capita income.
- (3) A population density which is too high (or too low) for optimum functioning of the economy, particularly of the energy sector.
- (4) A shortage of crop and/or forest land.
- (5) Small markets for indigenous fuels.
- (6) A tendency to replace traditional indigenous fuels by petroleum imports for a given end use and/or acquire energy-intensive consumer goods (e.g. frost free refrigerators, window air conditioners).
- (7) Few or no commercially exploitable, indigenous fuel resources.
- (8) Lack of trained personnel to carry out energy assessments, to develop alternative energy programs and to manage energy systems.
- (9) National energy pricing policies which inhibit energy conservation and the development of alternative energy sources.

Under the circumstances one cannot flip through Table 1 and blithely recommend every biomass alternative that happens to be commercially feasible and reliable somewhere in the world. Even the opportunities that one identifies as suitable for some countries may not be at all suitable for others. Hence, duly warned, let us now discuss some of the more promising alternatives in Table 1.

Energy Cane

Energy cane is cane managed for growth, not for sugar or some other single end product. There are at least two important final products, and one is a biomass fuel or a form of energy.

The cane plant came to the Caribbean on Columbus' second voyage in 1493 and has been continuously planted here ever since.

Even today it is still a major crop in Barbados, the Dominican Republic, Guyana, Jamaica and Puerto Rico, for example.

TABLE 1
SELECTED BIOMASS ENERGY SYSTEMS

TYPE	TYPICAL FUELS	COMMENTS
A. <u>Direct Combustion</u>		
Energy Cane	Bagasse or bagasse pellets (co-product) to steam boiler	Cane managed for growth, not sugar. Ready for commercial scale use. Should be very competitive with No. 6 fuel oil, if cane syrup product(s) can be sold at adequate price(s).
Sugar cane	Bagasse or bagasse pellets (co-product) to steam boiler	Long history. Used extensively in Hawaii. Will not save high-cost cane operation.
Sweet sorghum		Temperate zone crop. Dropped by U.S. Dept. of Energy after extensive study.
Napier grass	Chopped hay to boiler	Tropical grass managed for growth (two month rotation). Competitive with No. 6 fuel oil.
Sordam 70A	Chopped hay to boiler	Tropical grass managed for growth (two month rotation). Competitive with No. 6 fuel oil.
Energy trees	Wood chips to boiler	Trees cultivated as crops. Variable rotation (two years and up). Needs more study. Economics unknown.

Sources: (17) through (25).
*By a thermo-chemical process

TYPE	TYPICAL FUELS	COMMENTS
Agri-fuel	Powder manufactured from proven cellulosic raw material.* Burned in mixture with fuel oil in conventional oil-type boiler.	Combustion in mixtures up to 50 percent commercially. Only minor modification of boiler required. Economics uncertain and sensitive to raw material characteristics. Powder readily stored and transported. Investment: \$10,000/daily short ton.
Bechtel process	Mixture of chopped biomass* powdered coal burned in conventional coal-type boiler.	Commercially reliable. Economics variable. Some loss of boiler efficiency, some environmental gain. Investment: \$20,000/daily short ton.
Woodex process	Pellets manufactured from cellulosic raw material* and converted to medium BFU gas or burned directly.	Uses off-the-shelf equipment. Pellets storable. Economics variable. Investment: \$5,000/daily short ton.
Wood or wood wastes	Wood chips, scraps, bark sawdust or wood-based pellets to boiler	Commercially feasible. Numerous units in operation, up to 500 MW capacity. Require forest products operations.**
Municipal waste	Shredded combustibles to boiler	Many plants in operation worldwide. solid Degree of technical and economic success highly variable. Economics very site specific.

*By a mechanical process

**However, see (33)

TYPE	TYPICAL FUELS	COMMENTS
<u>B. Anaerobic Digestion</u>		
Animal wastes, municipal sewage sludge	Dilute solids to digester yields biogas, residual solids and effluent.	Some successful projects in U.S. using manufactured digestors, but most require large initial investment with economics sensitive to use of residual solids. Few "off-the-shelf" small systems available yet. Millions of small, custom-made digestors in use in China and India, but economics uncertain. For MSW, see (35, p. 6).
Sanitary landfills	Intermediate biogas (500 to 900 BTU/SCF)	Eight commercial technologies available. Economics site specific.
Water hyacinth	Wet plant to digester yields biogas	Plant used in primary treatment of sewage. Still experimental. Collection system critical to economics.
Giant brown kelp	Wet plant to digester yields biogas	Plant grown in sea. Affected by ocean storms. Still experimental.
<u>C. Thermochemical gasification</u>		
Municipal solid waste	Pyrolysis of shredded combustibles to yield pyrolysis gas (e.g. 120 BTU/SCF).	Used to generate lower pressure steam nearby. Few plants. Mixed results.
Steam gasification of wood	Methane, CO ₂ and CO in proportions which depend on process parameters.	Still experimental, but promising for methane and methanol production.

TYPE	TYPICAL FUELS	COMMENTS
<u>D. Fermentation</u>		
Molasses	Ethanol	Well-proven processes. Best end use of ethanol is country specific.
Corn	Ethanol	Well-proven processes. Temperate climate crop. Economics sensitive to by-product prices; source of distillation heat and process design.
<u>E. Thermochemical liquefaction</u>		
Methanol	Gasoline (40%) and light hydrocarbons (50%)	Mobil process using zeolite catalyst. 13,000B/D plant under construction in New Zealand.
Wood waste	Methanol	Several experimental plants announced for North America and Europe.
<u>F. Hydrolysis (for fermentation feedstocks)</u>		
Acid hydrolysis of wood	Sugars (for ethanol)	Old technology. Maximum yield is 55 percent starting cellulose by weight. Economics country specific.
Enzymatic hydrolysis of cellulosic raw materials	Sugars (for ethanol)	Still experimental. Offers possibility of large cost reduction through use of cheap raw material.

*May be obtained from biomass, coal, natural gas or naphtha. See (21) and (34), for example.

There are a number of excellent reasons why the cane plant is well-suited to the Caribbean:

- (1) It is a magnificent converter of solar energy to biomass (26).
- (2) It is capable of very high yields per acre (27).
- (3) It has input flexibility. That is, the degree of mechanization can be adjusted to match the labor supply available for cane industry work. Conversely, with energy cane, yields are high enough to suggest the possibility of increasing the labor supply by offering higher wages. This is particularly useful where foreign exchange and budgetary considerations put a low ceiling on the degree of mechanization. In general, energy cane will require more labor per acre and less per ton of green millable cane than sugar cane, at any given level of mechanization.
- (4) It is hurricane resistant.
- (5) It is very versatile. Possible final products include animal feed, chemicals such as ethylene and furfural, energy (in the form of electricity, steam or motor fuel), liquor, paper, sweeteners and wallboard (28,29).
- (6) If the non-energy co-product(s) receive adequate price(s), the energy from energy cane should be highly competitive with that from No. 6 fuel oil.

The possible limitations of energy cane are the following:

- (1) It requires greater water and fertilizer inputs than sugar cane, although these are handsomely rewarded by disproportionate increases in yields of commercially valuable outputs.
- (2) Like all cane plants, it must be dewatered in a large piece of machinery called a cane mill. Existing cane mill grinding capacity will therefore put an upper limit on

bagasse energy production, because new capacity costs roughly \$15 million per thousand tons of green millable cane per day.

- (3) Harvesting energy cane where yields may surpass 100 tons per acre of whole cane (23), requires expensive machinery or a substantial harvest-time labor force.
- (4) As a result of (2), one unavoidably obtains two intermediate products from the cane milling operation - bagasse and cane syrup. Present day economic conditions require that both intermediate products be converted to commercially valuable final products if a biomass energy system based on energy cane is to be commercially feasible. This means at least two final products, both of which should receive adequate prices. Finding an appropriate end use for the cane syrup may present a problem in some countries. A sure way to lose money on cane, regardless of the management system, is to grow cane with only one final product in mind and treat the remaining material as a minor by-product or waste. The key to cane economics is multi-product output.
- (5) During the dead season, one must either burn pelletized bagasse or energy grasses to continue to generate electricity.

For purposes of illustration, Table 2 shows possible harvest-season economics for a biomass energy system based on energy cane planted on 11,000 acres with an average yield of 87 tons of green millable stems, 15 tons of tops and attached trash and 8 tons of fallen trash. The green millable stems are ground in a mill with a capacity of 5,000 short tons per day. Electricity is sold at 9 cents per kilowatt hour, and high-test molasses is sold at 85 cents per gallon. The numbers are conservative yet very attractive. Certainly some countries in the Caribbean should consider energy cane. For a detailed explanation see (30).

TABLE 2
 PRO FORMA STATEMENT OF REVENUES AND ECONOMIC COST (1982 PRICES)
 BIOMASS ENERGY SYSTEMS (HARVEST SEASON ONLY)

	PERCENT OF \$(MILLIONS)	TOTAL
Revenues from sales		
Electricity (320.3 million kwhr 9.0c ea.)	28.8	62
High-test molasses of f.o.b. cane mill (21.2 million gallons 85.0c ea.)	<u>18.0</u>	<u>38</u>
TOTAL REVENUES	<u>46.8</u>	<u>100</u>
Economic Costs		
Field Costs		
Operational	7.6	
Capital Recovery on working capital ^{1/2/}	<u>2.0</u>	
SUB-TOTAL	<u>9.6</u>	21
Transportation of Biomass		
SUB-TOTAL ^{3/}	<u>6.1</u>	13
Mill Costs		
Conventional (by difference)	13.6	
Capital recovery on working capital ^{1/4/}	1.6	
Bagasse dry ^{1/5/}	1.2	
Electric plant ^{1/6/}	3.0	
Administrative and general (10% of sales)	4.7	
Contingencies (15% of sales)	7.0	
SUB-TOTAL	<u>31.1</u>	<u>66</u>
TOTAL ECONOMIC COSTS	<u>46.8</u>	<u>100</u>

1) Capital recovery at 20% over 10 years.

2) Working capital = 110% x 7.6

3) 5 miles 1.15 per ton mile of moist stems, dry tops and trash

4) Working capital = 50% x 13.3

5) Capital recovery and 20% maintenance on initial cost of \$3 million

6) Capital recovery and 15% maintenance initial cost of \$9 million

Sources: See text

Energy grasses

If one is solely interested in biomass energy, tropical energy grasses, such as Napier and Sordan 70A, are probably more economical than energy cane in many countries, mainly because they are de-watered by solar drying in the field and collected by a straightforward baling operation. However, they are also less labor intensive, do not utilize existing mill capacity and generate no coproducts. Where flat land is relatively scarce or of poor quality, some of these features may prove disadvantageous. Even in such cases, however, it may be desirable to rotate energy grasses with food crops or use the grasses with reduced inputs.

Energy trees

As indicated in Table 1, research on these is still in an early stage. However some countries may want to explore two or three year rotation energy trees on small plots as a source of charcoal for cooking.

Upgrading biomass

All three examples given--Agri-fuel, Bechtel and Woodex--require a considerable capital investment per ton of output. However, where appropriate boilers exist, they provide for intensive use of biomass in the existing combustion infra-structure without major refitting. The Agri-fuel and Woodex processes also convert biomass to a form in which it may be stored or exported. However, given the various constraints under which Caribbean countries operate, there appear to be few opportunities for the use of these processes as yet.

Municipal solid waste(MSW)

This is a vast and complex subject. We have dealt extensively with its economics in a paper now under revision (31). However, the following points must be mentioned:

- (1) The economic and technical feasibility of an energy system based on municipal solid waste is very sensitive to local site conditions.
- (2) The design of the collection system is critical to the success of MSW energy, especially if citizen collaboration in sorting waste is required. Socioeconomic variables are important. Once a system is established, it should not be changed often.
- (3) MSW is not an agreeable raw material for energy production. It is not homogenous and may vary frequently in moisture content, solids composition, etc. The MSW energy system must be designed with these variations in mind.
- (4) The end product is typically low pressure steam or low-BTU gas. Neither travels well, so the MSW energy facility and its customers must be located close together.

Wood and Wood wastes

Wastes are already being used in Guyana, but for pyrolysis gas rather than for direct combustion. This may be good for many countries. Economics appear to favor direct combustion for wood - electric units of 10MW up; pyrolysis, 3MW down.

Anaerobic digestion of animal wastes

Given the problems noted in Table 1 and the number of small waste generators in the Caribbean, the best solution for many

countries is probably to obtain proven U.S. designs but build as much of the system as possible from local or regional materials. Except for large operations (30,000 birds or 450 head of cattle), it is probably more economical to use the biogas produced to heat a still or to refrigerate by absorption than to generate electricity. Note that the economics of these energy systems are sensitive to the end use for the residual soil. By weight, these are the most important product of the digester. It is helpful if they can be used as an animal feed supplement to replace imported ration. The typical alternate use as a soil conditioner or mild fertilizer usually has much less value. Use of the digester effluent is highly site specific. Biogas-fired distillation of ethanol is promising.

Anaerobic digestion of municipal sewage sludge

From the point of view of economics, health and marketing, it is vitally important to kill pathogens in the sludge, remove metals and avoid the accidental passage of raw sludge through the digester without transformation. A feasible solution might be to combine a first-stage treatment using water hyacinths with a second-stage digestion process, using a UASB or a through-type, end-feed digester. The hyacinths would be harvested and digested separately.

Ethanol

For the Caribbean, the only immediate way to produce fuel-grade ethanol is to ferment cane molasses. However, this begs the question - what is the best use of the cane syrup? For some countries, sugar, molasses for cattle feed, molasses for export and/or ethanol for rum are obvious answers. However, given the poor prospects for cane sugar (32), countries with cane mills will definitely want to look at the generation of electricity by ethanol-fired gas turbines.

Note that high test uses 32 percent less material than black-strap to produce a given volume of ethanol. Also non-fermentable solids are reduced by 76 percent. Since these constitute the major component of distillery slops, there are substantial savings in distillery operating costs and a large reduction in environmental problems (30).

We doubt, however, that ethanol as motor fuel, either alone or in gasohol, is an attractive option for small countries. Even small, on-the-farm fermentation facilities are expensive (e.g. \$25,000 and up for corn-based ones of 10,000 gallon annual capacity). Also "considerable time and skill are required to operate an efficient facility... Rather close supervision is required during certain phases of operation... Many precautions must be observed in plant operation... vapors may ignite... there is the possibility of explosion" (33). Large facilities have the following drawbacks:

- (1) An extensive distribution system must be established and closely supervised to avoid contamination of the fuel. If the fuel is pure ethanol, the system must be larger than the gasoline system it replaces because of the lower energy content per volume of ethanol (21).
- (2) For ethanol-gasoline blends over 10 percent ethanol, modifications to automobile motors may have to be made. If pure ethanol is used, carburetors and certain other parts will have to be modified (21).
- (3) Any blended fuel may or may not lower the motorist's operating costs but it does not increase his security of supply so long as the gasoline is made from imported crude oil.

Methanol

Methanol is currently produced from naphtha and natural gas via synthesis gas, a mixture of carbon monoxide and hydrogen. About 90 percent of world consumption is as a solvent or as a chemical intermediate (34).

Coal and biomass are potential sources of methanol, by the same route. In the latter case, biomass is gasified, the ratio of carbon and hydrogen adjusted, and the mixture cleaned and then pressured in the presence of a catalyst to produce methanol (21). At present, no biomass-to-methanol plants exist, but several based on wood wastes have been announced for Europe and North America.

Methanol fired gas turbines look even more promising than ethanol fired ones (21,35). Given their sizable forest resources, continental countries will definitely want to investigate this alternative. Moreover there is also the possibility of methanol exports. Finally, if technical and commercial feasibility is proven, Mobil's zeolite process can be used to convert methanol to gasoline. Unfortunately, methanol-from-biomass facilities require an investment of about \$2.00 per gallon (21) and do not yet give a very good return on investment unless the biomass feedstock is quite cheap.

As a motor fuel, methanol suffers from the same kind of problems as ethanol, only to a greater degree. In particular, the separation problem is more acute (21). Moreover, expensive motor modifications are required for methanol based fuels, although the 90 percent variety has excellent operating characteristics (36).

SUMMARY

Despite the constraints limiting the options of Caribbean countries, there are a number of promising biomass energy options which have potential for several countries:

- (1) Energy Cane, for the production of electricity from bagasse and one or more products from cane syrup. Ready for trial on a commercial scale with a good probability of success.
- (2) Energy grasses, for the production of electricity from chopped solar-dried grass. Excellent possibilities.
- (3) Direct combustion of wood wastes. Commercially proven.
- (4) Anaerobic digestion of animal wastes or sewage sludge. Tricky but probably feasible on a small scale in a number of countries.
- (5) To be investigated carefully - electricity generation by gas turbines fired with ethanol or methanol; pyrolysis of wood.
- (6) For further investigation - charcoal for cooking from energy trees.

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CARIBBEAN ENERGY ACTIVITIES SUPPORTED BY
THE U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT

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OVERVIEW OF AID PROGRAMS IN ENERGY

As reflected in President Reagan's Caribbean Basin Initiative, the countries of the Caribbean are a new major focus of the global energy assistance programs of the Agency for International Development (AID). One compelling reason for the priority assigned to energy in this region was the recognition that in many Latin American countries and in the Caribbean the price of commonly used fuels, ranging from petroleum imports to wood and charcoal, rose more than 700 percent in the past decade. In 1970 a 60 pound bag of coffee bought 30 barrels of oil; by 1980 it bought less than three barrels. In many countries of this region the poor often must spend 20 to 50 percent of their average daily wage for fuelwood alone. As a consequence of this growing crisis, AID established two major objectives for the region to ease immediate energy constraints to development and to help countries make the difficult transition to a new mix of energy sources that can sustain their future economies.

This year worldwide AID expenditures for energy will total about \$90 million. This divides into approximately one-third for conventional energy, one-third for new and renewable energy sources, and one-third to support traditional fuel replenishment and development, particularly wood and charcoal. Of this amount, energy projects in Latin America and the Caribbean are funded at \$27.4 million this fiscal year. The figure does not include a substantial component that will be allocated for new energy activities within the \$350 million supplemental appropriation that President Reagan has requested for this fiscal year or the \$900 million request for the region that the President submitted to Congress for the new fiscal year beginning in October, 1982.

ADDITIONAL RESOURCES FROM THE ENERGY OFFICE

In addition to the \$27.4 million for Latin America and the Caribbean, the central Office of Energy in AID has a budget of about \$10 million this year, some of which will be earmarked for this region. These funds and the institutions which use them are intended to provide quick-response technical assistance to individual countries and institutions in fields such as exploration and development of new sources of conventional energy, experts for energy planning assistance, decentralized hydro-power resource assessments and feasibility studies, and technical assistance in other fields of renewable energy such as biomass, wind, and solar, including photovoltaics.

In addition, the Office of Energy invests more than \$5 million each year to support three training programs. With our financial assistance the University of Florida at Gainesville offers an intensive 15-week course for 40 participants from developing countries twice each year. The course treats a wide range of alternative energy technologies in lectures, demonstrations, laboratory work and field trips. Participation is limited to those who have at least a bachelor's degree in science or engineering. We also support a seven-week course in energy planning and management at the Institute for Energy Research at the State University of New York at Stony Brook, Long Island, in conjunction with the Brookhaven National Energy Laboratory. Last year we established a new long-term \$4.5 million training program administered by the Institute for International Education which offers to 100 students annually up to two years of graduate education at U.S. universities, or equivalent internships in U.S. industry or research institutes in engineering, management and analytical experience in various fields of conventional energy. Students in this program are now at work in geology and geophysics, petroleum engineering, coal mining engineer-

ing, electrical engineering, energy resource planning and management, and hydroelectric power generation.

SIMPLE, LOW-COST ENERGY TECHNOLOGIES FOR THE RURAL POOR

The Office of Energy also focuses on the provision of low-cost energy technology for the poor in both cities and remote areas through grants to the Volunteers in Technical Assistance (VITA) and to the Peace Corps to train volunteers in simple energy technologies. These organizations are working on projects such as low-cost wood stoves, charcoal kilns, wind-powered pumps, biogas digesters, and micro-hydro installations.

CARIBBEAN ENERGY PROGRAMS

The principal focus of AID efforts in energy throughout the Caribbean is on national energy planning with special attention to the development of alternative energy systems. During the past four years we have invested nearly \$8 million with the Caribbean Development Bank and CARICOM to conduct national energy assessments and conversion studies and to design, test, finance and distribute information on alternative energy technologies. We have financed projects such as a solar/wind resources study, an assessment of Belize peat deposits, energy assessments in Barbados, Antigua and Guyana, and we have organized workshops on solar crop drying and minihydropower.

AID has just launched another Caribbean-wide activity involving about 25 separate projects designed to create employment opportunities in both the public and private sectors. Much emphasis is placed upon stimulation of private enterprise particularly in the energy field where numerous opportunities exist both for coventures with foreign investors and new small business activities for indigenous entrepreneurs. This project is concentrating on

smaller countries such as Antigua, Dominica, St. Lucia, St. Kitts-Nevis, St. Vincent, Montserrat and Barbados.

AID is channeling technical and financial support through bilateral projects with other countries in the region. In Costa Rica we are in the process of setting up a nursery to produce one million fast-growing trees each year. More than 1,000 hectares will be planted in farm woodlots by reforesting steep marginal grazing land. We are also strengthening energy planning in that country and conducting feasibility studies on alcohol fuels, industrial energy efficiency, small-scale hydropower and the use of excess capacity.

A national plan for energy is being developed in the Dominican Republic with our assistance. The management and technical skills of the National Energy Commission are being upgraded and short technical courses on energy subjects are now offered. An energy information system is being built. An additional \$11 million is projected for the Dominican Republic to help in formulating national energy investment pricing plans, to help industry change to more efficient energy conversion machinery, to exploit small-scale water resources, and to improve the management skills of the Dominican Electricity Corporation.

AID's overriding concern in Haiti is in agro-forestry and the management of rapidly diminishing natural resources. A new agro-forestry program costing \$5 million has set a target of nine million tropical trees, including five species: laucaena, neem, cassia, eucalyptus, and casuarina. Tree seedling nurseries are being planted in modern greenhouses. Tree planting is aimed at soil conservation, production of firewood and generation of income for the rural and urban poor. In Haiti this past week we observed an innovative commercial approach to the charcoal problem. Several years ago a Haitian entrepreneur purchased a briquetting machine from Chicago for about \$60,000. He discovered that a mix of 60

percent charcoal dust, which he obtains without charge from kilns near Port-au-Prince, and 40 percent molasses as a binder which he buys cheaply from the local sugar mill, makes an effective briquette which can be sold at about 60 percent of the price of equivalent charcoal. He secures bagasse free of charge to heat the ovens to dry the briquettes. Until this past year, he exported much of his production to Puerto Rico, but now the Haiti domestic market is absorbing his total production. Since charcoal sells for \$5.00 for a 30 kg bag in Port-au-Prince, he should continue to sell his full production in Haiti and make a reasonable profit.

In Jamaica AID's energy sector assistance of \$14 million is aimed at increasing the efficiency of industrial energy use, developing solar water heating, and improving the government's capability to plan and manage energy development. We are also testing species of fuelwood in Jamaica and initiating demonstration and pilot activities in various alternative energy technologies.

AID funds a number of programs in agro-forestry, rural energy technologies, small hydroelectric power and other renewable energies in Ecuador, Honduras, Perú, Guyana and Panamá.

NEW RESEARCH FUNDS

New AID funds exist to underwrite promising research work in developing countries. Our Science Adviser's Office in AID awards several million dollars each year in research grants in a wide range of development areas including energy. We also channel about \$5 million each year to enable the U.S. National Academy of Sciences to administer a separate program of research awards. Both programs seek research topics which involve collaborative studies between U.S. and developing country research institutions and univer-

sities. Grants have been ranging from about \$35,000 to \$150,000 and usually extend for more than one year.*

CENTRAL PROGRAM ON BIORESOURCES

About \$1 million each year is provided under a Participating Agency Services Agreement to the U.S. Forest Service in our Bioenergy Systems and Technology Program. Its principal objective is to support overseas AID missions to develop projects. Bioenergy production is the product of an integrated system that involves the identification and production of feedstocks and the design and adaptation of conversion technologies.

In Costa Rica, an assessment of biomass energy options was made including production of ethanol to replace petroleum-based fuels in transportation as well as analyses of biogas, charcoal and gasifiers. In Ecuador the concentration is upon use of fuelwood, crop residues, manures and municipal wastes. In the Dominican Republic we have examined small and large-scale woodfuel planting possibilities as well as charcoal production and gasification. A study was made of the equipment requirements for construction of a wood-fueled steam electric generating plant at Yaviza in Panamá.

Under our agreement with the U.S. Forest Service a series of 14 state-of-the-art studies have been collected in the Bioenergy

* For further information on the Science Adviser's Program of Research Grants, write to Dr. Irving Asher, Deputy Director, Office of Science Adviser, AID, Washington, D.C. 20518. For details and information on submission of proposals to the National Academy of Sciences, write to Dr. Michael Greene, Director, Committee on Research Awards, BOSTID, National Academy of Sciences, 2101 Constitution Avenue, N.W. Washington, D.C., 20418.

Bioenergy Conversion Handbook for Developing Countries. Ten additional reports are in preparation which can be added to the loose-leaf binder as they are published. Copies are available without charge. The bioenergy program is also publishing a new quarterly magazine called Bioenergy Systems Report with technical data and case material. Those interested can ask to be placed on the mailing list.

ENERGY STUDIES

Many of you are familiar with the impressive series of publications on technological innovation produced by the Board on Science and Technology for International Development of the National Academy of Sciences. A number of studies on energy and bioresources have been prepared and published in recent years. They include booklets on energy for rural development with a new supplementary edition; methane generation from human, animal and agricultural wastes; leucaena, firewood crops; microbial processes; food, fuel and fertilizer from organic wastes; producer gas; sowing forests from the air; and the proceedings of a workshop on energy survey methodologies. Several new studies are in process, including the potential of alcohol fuels, and on three crop species such as acacia mangium, calliandra and casuarina.

The Office of Energy hopes that it will continue to be possible to use the outstanding technical resources and experience of the Center for Energy and Environment Research, not only for our activities in the Caribbean and Latin America, but for other regions as well. The Center deserves warm congratulations for helping to organize the symposium and workshop which have attracted an impressive number of high-quality scientific and policy papers.

EL CONCEPTO DE INTEGRACION
DE SISTEMAS DE ENERGIA A LAS GRANJAS AGRICOLAS

Presentado en

UNICA WORKSHOP ON BIOMASS AS AN
ENERGY ALTERNATIVE FOR THE CARIBBEAN

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INTRODUCCION

El incremento continuo de los costos de energía, alimento, mano de obra y costos para prevenir el deterioro del ambiente y mejorar la higiene de los sistemas de producción agrícola, han obligado a estudiosos e ingenieros en los Estados Unidos a la búsqueda de soluciones que mayormente cumplan dos propósitos básicos: (1) generar cierto grado de autosuficiencia energética con un mayor incremento en la producción y (2) el empleo de métodos económicamente atractivos que eliminen en forma efectiva los riesgos de contaminación al ambiente a un nivel aceptable dentro del esquema legal de regulaciones que lo protegen. Distintas soluciones han sido formuladas todas ellas de efectos positivos, pero sin que una en particular satisfaga las necesidades básicas mencionadas. Entre las más importantes se encuentran: (1) el uso de los desperdicios para producir energía; (2) las distintas prácticas de tipo técnico para el recobro de energía desechable; (3) renovación de algunos sistemas mecánicos en los sistemas de producción existentes; (4) la puesta en práctica de medidas de conservación y administración de energía y; (5) el recobro de materiales reusables que no comprometan la calidad de la producción. Estas soluciones por separado y algunas en conjunto han producido mejoras económicas y han facilitado la solución de problemas en los sistemas de producción agrícola. Desde luego, el grado de mejoras económicas y los logros alcanzados no han satisfecho las proyecciones hechas, especulándose que quizás la falla está en la forma poco intensa como se han implementado y coordinado en la práctica aunque se reconoce que se ha obtenido algunos beneficios.

La idea de combinar distintas fuentes energéticas imperecederas coordinadas entre sí con la utilización de técnicas propias de las áreas de ingeniería y agronomía ha generado gran interés por lo atractivo que resulta la incorporación de una serie de ventajas de tipo técnico que mejorarán la flexibilidad ya alcanzada con la meca-

nización y que revitalizarán más los sistemas de producción con un mayor incremento del beneficio económico. Esta idea se describe en el concepto conocido como "Integración de Sistemas Energéticos a Sistemas de Producción Agrícola" a nivel de pequeña y mediana escala. Se adiciona a este concepto de integración, la condición de minimizar toda energía residual disponible que pueda utilizarse. Asimismo para su implementación se establece como requerimiento, el agregar a los sistemas, ya existentes en las granjas, elementos y mecanismos eficientes ya probados en otros procesos industriales disponibles en el comercio local y ensamblados con materiales de la región.

En este trabajo se tratará de enfocar los aspectos más importantes relacionados con este concepto. Se indicarán brevemente tipo de flexibilidad y limitaciones de estos desarrollos. Se usará como referencia el modelo propuesto para la finca Ubarri, en Juana Díaz, que incluye operaciones y actividades de tipo industrial afines en sus métodos y procedimientos a las que realizan la industria avícola, ganadera, vacuna y porcina.

Entre los tópicos a considerar se incluyen los siguientes:

(1) diferentes aspectos de la etapa evaluativa; (2) guías y factores importantes en la fase del diseño; y (3) aplicaciones y limitaciones tecnológicas del principio; y (4) algunos aspectos económicos.

La discusión de los tópicos se hará para aplicaciones en sistemas de producción ya establecidos y que recobren energía mediante el proceso biológico de digestión anaeróbica.

ETAPA EVALUATIVA DE LAS GRANJAS

La fase evaluativa es el primer paso a realizar para ayudar a definir los sistemas energéticos a ser integrados y tener una idea clara de las ventajas, dificultades y restricciones que técnica y

económicamente se pudiera confrontar en la adaptación de las fuentes energéticas y elementos al sistema de producción existentes. Esta actividad se realiza en gran medida al analizar los factores internos y externos que van a afectar la planificación, diseño y desarrollo del principio.

FACTORES INTERNOS

- (1) Ventajas naturales del área
- (2) Grado de mecanización de la operación
- (3) Distribución de las facilidades existentes y características de la operación y organización

FACTORES EXTERNOS

- (1) Tipo de actividad fabril y agrícola en las vecindades
- (2) Suministro de alimento animal combustibles y servicios básicos
- (3) Condición de vida y mano de obra
- (4) Servicios públicos disponibles
- (5) Actitud de la gente del poblado en las vecindades
- (6) Incentivos gubernamentales
- (7) Evaluación del potencial legal y problemas ambientales

Las ventajas naturales del área están relacionadas con su localización, orientación y topografía--terreno montañoso, inclinado, plano, etc.--la disponibilidad de tierras, régimen de lluvias, evaporación, quebradas en las cercanías, depósitos de agua subterráneos, corrientes naturales, caídas de agua, manantiales, nivel friático, lagos, irradiación solar, condiciones del suelo para cultivos, régimen de vientos, condición climatológica, temperaturas máximas, mínimas y humedad. La información estadística y el análisis van a ser importantes para trazar la estrategia a seguir en el

diseño y estimar el nivel de aprovechamiento de las fuentes energéticas disponibles.

Un alto grado de mecanización es una situación muy favorable ya que le provee un uso a la energía recuperada. Esta no solo se emplearía en el área de procesos (sistemas de secado y equipos para conservar las características físicas, biológicas y químicas del producto) sino también en la maquinaria adicional para aumentar la producción y minimizar las pérdidas para comercializar.

La disponibilidad de suministros básicos como los combustibles (líquido o gaseoso) y servicios de agua y luz son de primerísima importancia. Esto facilita un rendimiento adecuado en un sistema en que la sustitución de fuentes energéticas pudiera ser el patrón que ofrezca un mejor aprovechamiento de los recursos de producción. Por otra parte, los suministros de alimento animal son otro parámetro de mucha importancia. En base a él y a la disponibilidad de residuos sólidos estabilizados se consideran; la adición de las operaciones de cultivo de heno y otros géneros, sistemas acuíferos para algas y peces. Su consideración es una necesidad por el crédito que en el renglón alimenticio pudieran aportar al esquema económico total de la operación. Debe entenderse que la calidad del alimento es algo que tiene que acordarse en base a un punto óptimo que permita obtener las mayores ventajas tanto por los ingresos por producción y como por los créditos por recobro de energía, ventas de sub-productos y deposición de desperdicios.

La distribución de las facilidades para la producción de la granja a revitalizar es de singular importancia para la aplicación efectiva del concepto. Esta distribución será más conveniente entre más se acerque la organización existente a uno de los prototipos de los sistemas característicos de producción como por ejemplo; producción en línea, áreas de producción en paralelo, etc. Desafortunadamente las experiencias tenidas en algunos países en vía de

desarrollo, las de granjas en la mayoría de los casos no siguen un patrón que ofrezca la posibilidad de planificar una acción específica y uniforme. Hay que estudiar cada caso y definir una estrategia acorde. Por consiguiente, en base a que las actividades que se realizan en las granjas están identificadas con la distribución de áreas de proceso, se necesitará un cuadro sintetizado que caracterice las distintas funciones en cada área, tanto de máquinas como de hombres, para que las estructuras y máquinas que se adicionen sean más efectivas al acoplarlas con el formato de organización existente.

La existencia de la agro industria que brega con el procesamiento de productos provenientes del campo, u otro tipo de industria localizadas en las vecindades o en el área rural, van a significar unas ventajas para el concepto de integración. Esto podría de forma inmediata, favorecer suministros de combustibles a precios razonables lo cual permitiría el uso del biogas en otro factor importante de la economía de la planta. También favorecen el desarrollo del principio, mejoras de las infraestructuras de vías de comunicación y la existencia de servicio público disponibles. En adición, la industria en el área proveerá experiencia que puede asistir en la solución de problemas.

Para promover una actitud positiva de las gentes hacia esta tecnología debe de iniciarse un programa de educación, especialmente cuando las granjas están cerca al poblado. La misma debe continuar durante el tiempo en que se realiza el proyecto. Esto tiene como propósito promover una atmósfera de confianza y credibilidad entre ambas partes con respecto a lo que se quiere hacer. La acción es necesaria en cualquier situación sea iniciativa privada o gubernamental.

La participación del gobierno y el potencial legal existente en materia de regulaciones son muy importantes para el desarrollo de

esta tecnología. Esta puede hacerse a través de actividades que auspicien estos desarrollos sean de tipo económicos o mediante la facilitación del trámite que pudieran interferir su iniciación y finalización. Para que el potencial legal sea efectivo, el gobierno a través de las agencias responsables, deben promover la investigación continuamente para obtener el dato empírico necesario con el fin de promulgar el tipo de regulaciones que dé guías significativas y adecuadas para el control de la tecnología implementada por el principio de integración. No se anticipan problemas ambientales.

El sistema de transporte, la mano de obra y las condiciones de vida son factores que podrían afectar en algún grado la fase de diseño y desarrollo. Todo va a depender de la localización de la granja. Si la granja está en zona rural no se espera cambien drásticamente ya que los desarrollos se diseñan dentro de un consenso de criterios simples de tal forma que destrezas especiales no se requieren por parte del personal que trabaje en las distintas labores que se realicen. El transporte será según las infraestructuras existentes. Si en cambio la zona rural con industrias a sus alrededores, el sistema de transporte es de esperarse sea mejor que el caso anterior. La mano de obra sin destreza pudiera escasear y es posible que sea baja por razón de la competencia, significando esto un efecto económico de consideración en la operación. Es de esperarse que las condiciones de vida se encarezcan por la existencia de la industria y que el obrero sin mucha destreza emigre adicionando ésta un elemento más para acelerar la escasez que esto traería. Como las granjas, las fuentes de energía y los procesos que se integran son bien específicos en naturaleza y los mismos requieren de áreas amplias y relativamente distantes de zonas urbanas no se contemplan desarrollos en el perímetro de zonas urbanas.

GUIAS Y FACTORES IMPORTANTES EN LA FASE DE DISEÑO

Es importante resaltar que el desarrollo de un trabajo de inge-

nería exige identificar parámetros que respalden el diseño y la ejecución de los proyectos, parámetros que muchas veces como es el caso de la aplicación del principio de integración energética, pertenecen al dominio de disciplinas o de situaciones aparentemente ajenas al ámbito de la ingeniería. Por tal razón los proyectos de esta naturaleza requieren la formación de un grupo de trabajo de tipo interdisciplinario que estudie, diseñe, especifique y desarrolle, estructuras maquinarias y elementos a integrar.

Teniendo definido los propósitos del diseño y los parámetros primarios es importante y antes de establecer los objetivos y las guías se debe tener claro cual es la capacidad y limitaciones del sistema de producción existente. Además, un conocimiento de las propiedades físicas, mecánicas y calidad del producto o productos y de los desperdicios sólidos resultantes del proceso de producción, para identificar y considerar la magnitud y posibles soluciones de los problemas de flujo, recolección, manejo, almacenamiento, corrosión, seguridad y los relacionados con el diseño de estructuras y selección de equipos.

El diseño debe proveer como objetivo inmediato las necesidades energéticas en un porcentaje alto empleando criterio de recobro y conservación con un costo total relativamente bajo. El diseño debe girar en torno a realizar unos sistemas simples que al acoplarlos a los existentes revitalicen y no interfieran la operación de producción. Esto requerirá observar los siguientes puntos: (1) poner en práctica ideas que sean de sentido común; (2) emplear el efecto de gravedad existente en el área al máximo para que la cuota de energía que se use para operar el sistema acoplado sea mínima; (3) hacer un inventario del gasto de energía de la operación existente y clarificar aquellos casos de consumo crítico, estos consumos deben tratarse de disminuir con sistemas que utilicen directamente el biogas; (4) obtener el espacio de tiempo de contribución efectiva de las fuentes energéticas renovables--sol, viento, caídas de agua y

desperdicios--para buscar la mejor armonización de equipos y todas las actividades de la futura operación, esto ayudará a dar una idea más amplia sobre las limitaciones y capacidades de los sistemas acoplados; (5) evitar automatizar la operación de los sistemas recordando que la misma debe ser en su mayor parte manual para armonizar una operación simple con el nivel de preparación del elemento humano que atenderá la administración y funcionamiento de todo el sistema de producción; (6) establecer un término aceptable entre flexibilidad deseada en el sistema como un todo y la economía de la construcción y producción; el grado de flexibilidad va a ser un factor de mucho impacto en el esquema económico de la operación; (7) tener siempre presente que por la naturaleza de la operación, nivel de destreza humana y combustible resultante del proceso anaeróbico la seguridad es un factor a considerar en el diseño de las estructuras y en la selección de equipo y maquinaria; (8) considerar el problema de corrosión inminente, por razón del material orgánico y los productos resultantes del proceso de digestión anaeróbica; estos materiales deber ser de características tales que prevengan o inhiban la corrosión; (9) mantener los problemas de contaminación al ambiente a un nivel bajo; deben anticiparse soluciones sencillas en caso de manejos erráticos, fallas humanas o casos fortuitos; (10) todas las ideas, cambios y adiciones deben de orientarse hacia un objetivo: mantener un alto grado de eficiencia y efectividad del sistema para evitar situaciones continuas de fuera de servicio o interrupciones en la operación por tiempos largos; y (11) uso al máximo fuentes residuales de energía como una buena política de conservación.

APLICACIONES Y LIMITACIONES

El desarrollo y prueba de distintos prototipos es la fase que permite evaluar la efectividad del principio y las limitaciones de tipo tecnológica. Estas dos cosas incidirán a su vez en el grado de

efectividad funcional y en el tipo de beneficio económico a conseguir.

Resultados de estudios de naturaleza empírica sobre el uso del sol, agua y viento para producir energía han dado resultados favorables. El recobro de energía del desperdicio animal mediante la digestión anaeróbica ha sido demostrado en estudios a nivel de escala pequeña y grande. Proyectos realizados en Brockman y Green Bay, Wisconsin, Energy Harvest, Illinois, a pequeña escala lo corroboran. Otras actividades de recobro de energía térmica residual han sido estudiadas y sus aplicaciones en modelos de plantas industriales y en actividades comerciales han sido debidamente probados. Por lo tanto es cuestión de integrar todos estos subsistemas, evaluarlos y establecer qué logros económicos son factibles y qué prototipo es más ventajoso desarrollar.

La sección que impulsa los programas industriales del Departamento de Energía de los Estados Unidos tiene bajo supervisión varios proyectos de sistemas energéticos integrados para tamaños moderados. Estos proyectos servirán para conocer de las limitaciones de tipo técnico dentro de la base conceptual simplista requerida. Los mismos están distribuidos en actividades que comprenden granjas para cría de cerdos, otras que combinan la actividad de producción de grano, alcohol y producción de leche. La actualmente en proceso de diseño en Puerto Rico comprende una ganadería de 500 cabezas Holstein que opera con una producción de leche de 1400 litros por día. El desarrollo propuesto incluye las siguientes actividades: (1) recolección y preparación de los desperdicios sólidos; (2) producción y preparación de gas rico en metano vía proceso anaeróbico de desperdicios sólidos, limpieza y almacenamiento; (3) uso del combustible biogas para: producción de fuerza eléctrica, como fuente calorífica para regenerar la sustancia refrigerante usada en el sistema de refrigeración por absorción; (4) uso de la energía del viento para producir energía eléctrica que

alimente las bombas de agua de suministro que succiona de los depósitos subterráneos para atender el consumo de agua en la operación principal de ordeño y el suministro de agua para los bebederos de animales; (5) uso de colectores solares para recolectar la energía calorífica necesaria para mantener las temperaturas mesofílicas de operación de los digestores; (6) actividades de recobro de energía residual para proceso de secado y también para asistir el mantener las temperaturas de operación mesofílica (98°F) en ambos digestores; este recobro también se realizará mediante el uso de intercambiadores de calor compactos para calentar agua los cuales se acoplarán a las unidades de refrigeración de expansión directa existentes usadas para preservar la calidad de la leche; (7) actividades de conservación mediante la inclusión de un sistema de refrigeración por absorción el cual reducirá el consumo de Kw-Hr actualmente crítico por el uso del sistema de refrigeración directa; también se reciclará agua acumulada en las charcas para el proceso de dilución del sólido animal, el agua se bombeará periódicamente de las charcas previniendo ésto el consumo de agua excesivo y agotamiento de reservas, este reuso se sincronizará con la actividad de evaporación característica existente en el área; (8) se integran también actividades relacionadas con recolección de agua lluvia, cría de peces y algas en charcas, preparación de hatos para cultivos de heno. El material fertilizante y nutriente se obtendrá de los desperdicios sólidos estabilizados mediante el proceso anaeróbico.

Aunque existe la tecnología para darle el uso adecuado a las fuentes de energía reusables y para realizar todas las actividades descritas, debe indicarse que las eficiencias obtenidas con los moto-generadores que han usado el biogas han alcanzado cifras del 14 al 15 por ciento. Sin embargo, el empleo de mezclas de biogas en determinadas proporciones con el diesel o gas natural parece ser la alternativa para aumentar los niveles bajos de eficiencia antes mencionado.

ASPECTOS ECONOMICOS

La comparación económica de sistema a sistema es difícil hacerlo ya que la tecnología que se desarrolla en uno y otro caso van a ser diferentes. Parámetros como ingresos totales, costos de operación y conservación serán, como es tradicional, las referencias fundamentales para enjuiciar el éxito económico de la aplicación del principio. Sin embargo los créditos económicos por recobro de energía, medidas de conservación, mejoramiento de la calidad del producto o productos, costos de alimentos y métodos de contabilidad serán objeto de riguroso escrutinio para aceptar su validez o rechazarlos. Un formato guía para normalizar la contabilidad y realizar la evaluación de proyectos de esta naturaleza ha sido publicado por el Departamento de Energía de Estados Unidos.

Para un análisis económico fundamentado en proyecciones de tipo teórico se recomienda considerar entre otras cosas: valor total de la inversión, costos de operación, ingresos, características de los créditos y financiamiento. Los resultados van a depender de la realidad de los números conseguidos.

Independientemente del esquema y guía y los valores que resulten no se debe presumir que estos costos y créditos son automáticamente aplicables. Antes debe realizarse un estudio de factores tales como: costos locales de mano de obra y costos de los materiales, condiciones del mercado del producto o productos, tamaño de la planta, métodos eléctricos y agua; tiempo de disponibilidad de la planta adaptada; tiempo de retención de los sólidos en la digestión anaeróbica, etc.

Como se dijo antes los créditos van a variar en una y otra aplicación. Por ejemplo en el desarrollo propuesto para la ganadería Ubarri los posibles beneficios económicos se describen según la Tabla I.

TABLA 1

POSIBLES CREDITOS PARA SISTEMA INTEGRADO EN GANADERIA UBARRI

ACTIVIDAD / MEJORA	DESCRIPCION DEL CREDITO
Molinos de Viento	1. Reducción consumo Kw-hr por empleo de bombas de trasiego de agua depósitos subterráneo y agua de las charcas.
Reuso del agua de actividades limpieza de salas de ordeño y agua de dilución	2. Reduce costos por uso de agua en el proceso anaeróbico.
Producción alimentos - Aprovechamiento residuos sólidos estabilizados como complemento fertilizante.	3. Reducción de los costos de alimentación de animales.
Adición sistema absorción	4. Reducción consumo Kw-Hr actualmente crítico con el sistema refrigeración DX para mantener calidad de la leche.
Tratamiento biológicos anaeróbico y deposición de desperdicio	5. El beneficio se concibe en base a y los ahorros que en costos se obtendría por empleo de materiales químicos y por consumo de energía que el tratamiento y manejo de desperdicio no estabilizados requerirían
Mejora Calidad producto	6. Aumento de ingresos por mejores mercados.
Uso biogas en maquinaria y sistemas transportación	7. Ahorros por consumo de combustible líquido.
Ventas de subproductos	8. Material fertilizante, heno, etc.

Los resultados finales del estudio servirán para corroborar estos créditos y el tipo y magnitud de gastos e ingresos.

BIOENERGY FROM ANAEROBICALLY TREATED WASTE WATER

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ENERGY ALTERNATIVE FOR THE CARIBBEAN

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INTRODUCTION

The present economic situation is based on an almost unlimited supply of fossil fuels and minerals. This system has forced the consumption of raw materials to such high levels that the finite natural resources threaten to give out. The consequent threat of a world energy crisis has stimulated the search for ways to produce energy from new and renewable resources. The modern economic system has also caused the production of large amounts of domestic, industrial and agricultural wastes.

Although wastes may contain useful and valuable components, including potential energy sources, recovery is often not considered competitive because of the low prices of these products on the world market. Consequently, the disposal of large amounts of waste materials has resulted in pollution of the natural environment on a global scale.

It is apparent that if wastes could be considered as a source of raw materials rather than as unwanted materials of negative value, then many problems that face our society would be minimized. In this respect waste water can be considered as a potential source of energy. But it is well to point out that the discharge and treatment of waste waters, using present technology, consume significant amounts of energy, as can be seen in Table 1.

TABLE 1
GROSS ENERGY CONSUMPTION OF SOME
ANAEROBIC SEWAGE TREATMENT PLANTS

System	Annual Consumption per p.e. (a)		
	in M.J.	in Therms(b)	in kWh
Low-rate	35	0,33	10
Low-rated activated sludge type	55	0,52	15
Oxydation ditch(Pasveer) type	90	0,85	25

a) A population equivalent (p.e.) is defined as the biochemical oxygen demand (BOD) by micro-organism to digest the daily amount of organic waste, discharged on the average by one inhabitant. In this case 1 p.e. equals a BOD of 54 g O₂/day. Another approach is to define p.e. in relationship with the chemical oxygen demand, whereas the organic waste is chemically oxidized to conform with the K₂Cr₂O₇ method and with the amount of Kjeldahl-nitrogen (TKN) present in the discharged waste.

Assuming the relationship $\frac{\text{COD}}{\text{BOD}} = 2.5$ for untreated domestic

sewage and a discharge of 10 g TKN/p.e day, 1 p.e. equals then $2.5 \times 54 = 135$ g O₂/day (without nitrification) resp. $135 + 4.57 \times 10 = 180$ g O₂/day (with nitrification)

b) Conversion factors
 1 Btu = 1.06x10³J
 1 therm = 10⁵ Btu

It is assumed that the total energy consumed in the U.S. for domestic municipal waste water processing costs more than \$130 million annually. The secondary and tertiary treatment may increase this amount by nearly ten times. This is equivalent to an energy volume of 100 million barrels/yr of oil, which is approximately one percent of the total energy consumption in the U.S.(2).

The situation in the Netherlands Antilles is as follows: the annual energy costs for conventional aerobic treatment of the domestic water of the capital Willemstad (100,000 p.e. excluding industries) would probably range between \$145,000 - and \$365,000 - depending on the type of system. This is about 16 percent of the total annual cost for waste water treatment.

One should understand that another 60 percent of the total costs are caused by capital liabilities. Therefore, it seems that there are more important budget items than "energy" to save on. Furthermore, it should be noted that in the Caribbean huge amounts of energy are consumed for purposes other than waste water treatment. In the Netherlands Antilles, for instance, annual energy costs of air conditioning are estimated at \$23 million. A dramatic decrease will be achieved by a more climate-adapted design and construction for tropical housing.(3)

However, because of the large capital investment needed for waste handling and the increasing energy costs and consumption, alternative processing methods should be sought and tested. Priority should be placed on those processes with which not only energy conservation but also energy production and a reduction of capital costs may be obtained. The University of the Netherlands Antilles (UNA) started research into anaerobic waste water treatment by means of an upflow anaerobic sludge bed system (UASB) at the end of February 1982. If the investigations prove successful, the UASB

system will become a substantial part of an integrated waste processing scheme.

The high costs of waste handling pose a problem to Curacao because of the small scale of the different facilities for waste disposal. Under the proposed scheme, waste water treatment and solid waste handling facilities are joined to one processing plant in which waste recovery might become feasible. Valuable materials like glass, plastics and scrap should be separated from the (municipal) solid waste for local manufacturing or export. The organic fraction will be converted into compost together with the surplus sludge derived from the waste-water treatment unit. Only a small fraction of the original volume has to be discharged as sanitary landfill. This compost and treated effluent will be used in agriculture. Consequently, local employment will be stimulated and Curacao will become less dependent on imported food and other necessities. In an arid climate like there is on Curacao, water is scarce and expensive. The value of a "second quality" water like treated effluent will amount to \$0.60/m³.(4) The UASB reactor will be an internal energy source of the integrated plant since it is likely that methane will be produced. See Figure 1.

THE UASB-SYSTEM

New methods have been developed in energy saving waste water treatment techniques. This has led to the development of the Upflow Anaerobic Sludge Blanket Reactor (UASB). It was during experimental work on a continuous anaerobic process at the Wageningen Agricultural University in the Netherlands that the degree of sophistication required for practical commercial use was achieved.(5) The main part of the UASB system consists of a reactor tank in which a mixed bed of bacteria is located. This microbial population is composed of facultative and strict anaerobic bacteria which utilize chemically bound oxygen. In the UASB sys-

tem the raw waste water passes through the reactor in an upward direction and pollutants are absorbed by the microorganism.

The digestion is, in essence, a sequential process. Complex organic matter is hydrolyzed and, subsequently, acid forming bacteria converts the hydrolyzed compounds into simple molecules, viz. volatile fatty acids (VFA), CO_2 , NH_3 , and H_2 . The VFA and other intermediates in turn serve as substrate for methane bacteria and are mainly converted into CH_4 and CO_2 . In a balanced digestion process, however, the separate steps take place simultaneously at an optimal temperature of 33°C (90°F). The gas produced rises to the surface at the top of the reactor where it is carried off via a gas globe and a water seal. Also at the upper area of the reactor the separation of sludge and effluent takes place.

A disadvantage of the UASB process is its sensitivity to disturbances if certain limits in the fluctuations of pH, loading rate and temperature are exceeded. Another possible disadvantage may be that anaerobic treatment must be considered as a primary biological treatment facility. Residual pollution, the presence of ammonium and anaerobic conditions, compel subsequent aerobic biological treatment of discharge to sewage. In moderate climates the process temperature is sometimes a problem too, and the system is self supporting only if strongly-polluted waste waters are processed. In the Caribbean, however, there is no need for an external heat supply since temperatures are almost at a constant and optimal level of 27°C (81°F). This implies that the system may also be energy self-supporting even in case of processing weakly-polluted waste water.

Some advantages of the anaerobic upflow process are:

Substrate loading reactor: the anaerobic biomass can take care of heavy loads ($10 \text{ kg COD/m}^3 \text{ day}$) because of the high

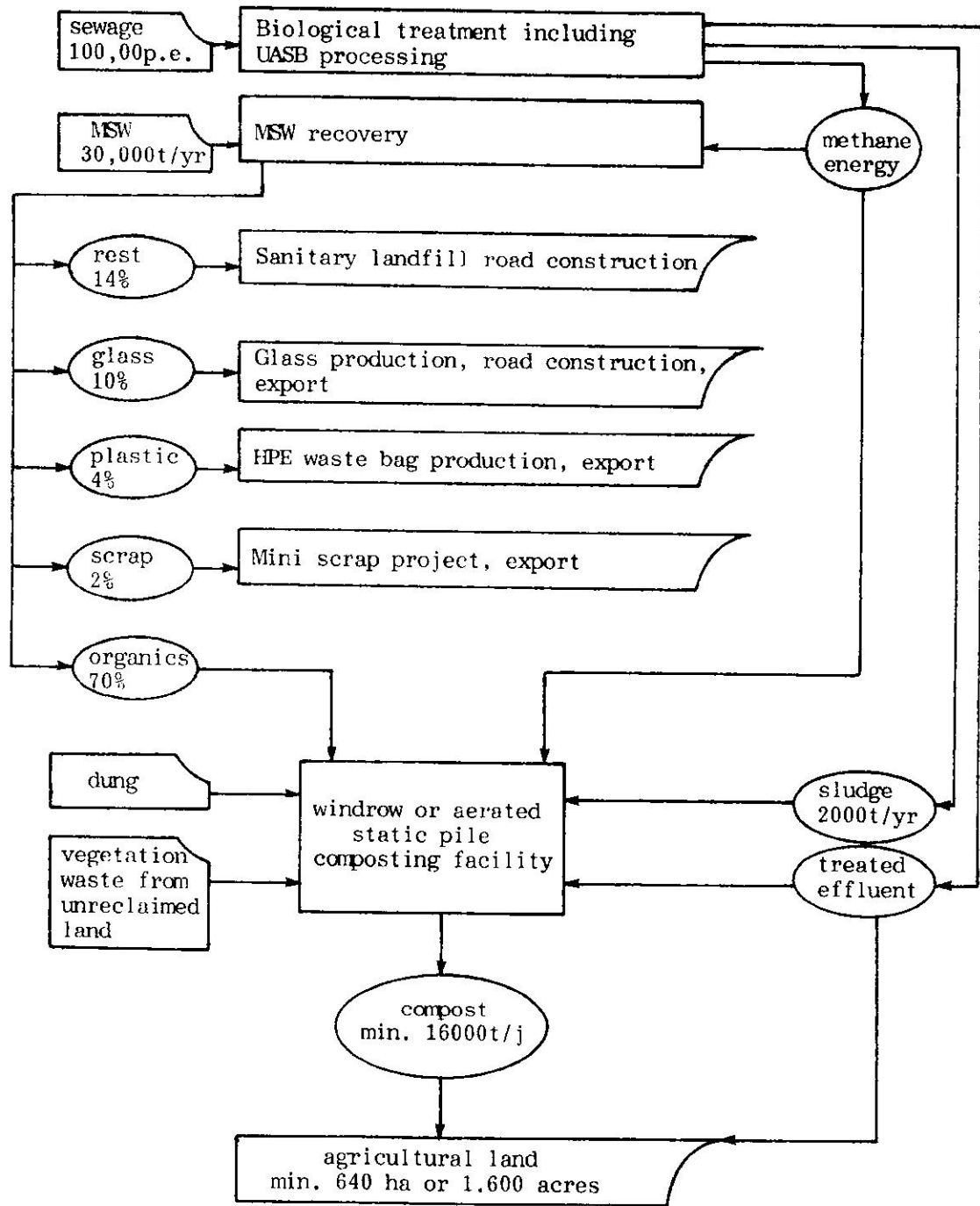


FIGURE 1
 CONCEPT OF AN INTEGRATED WASTE PROCESSING SCHEME
 FOR CURACAO

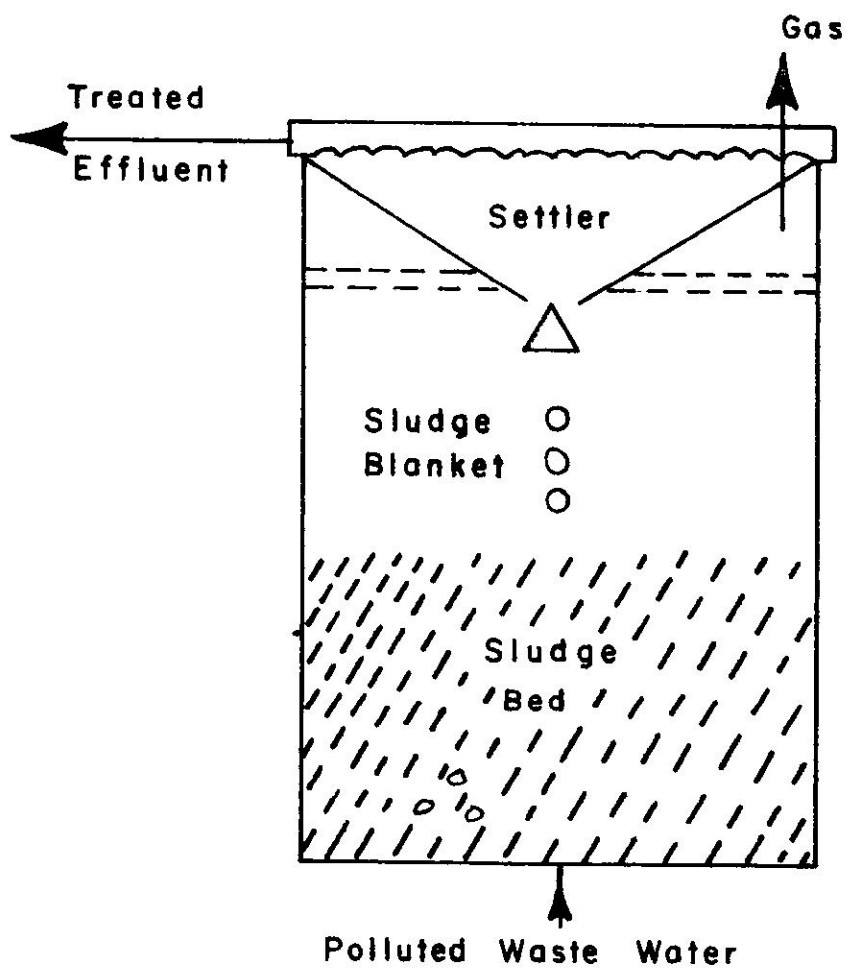
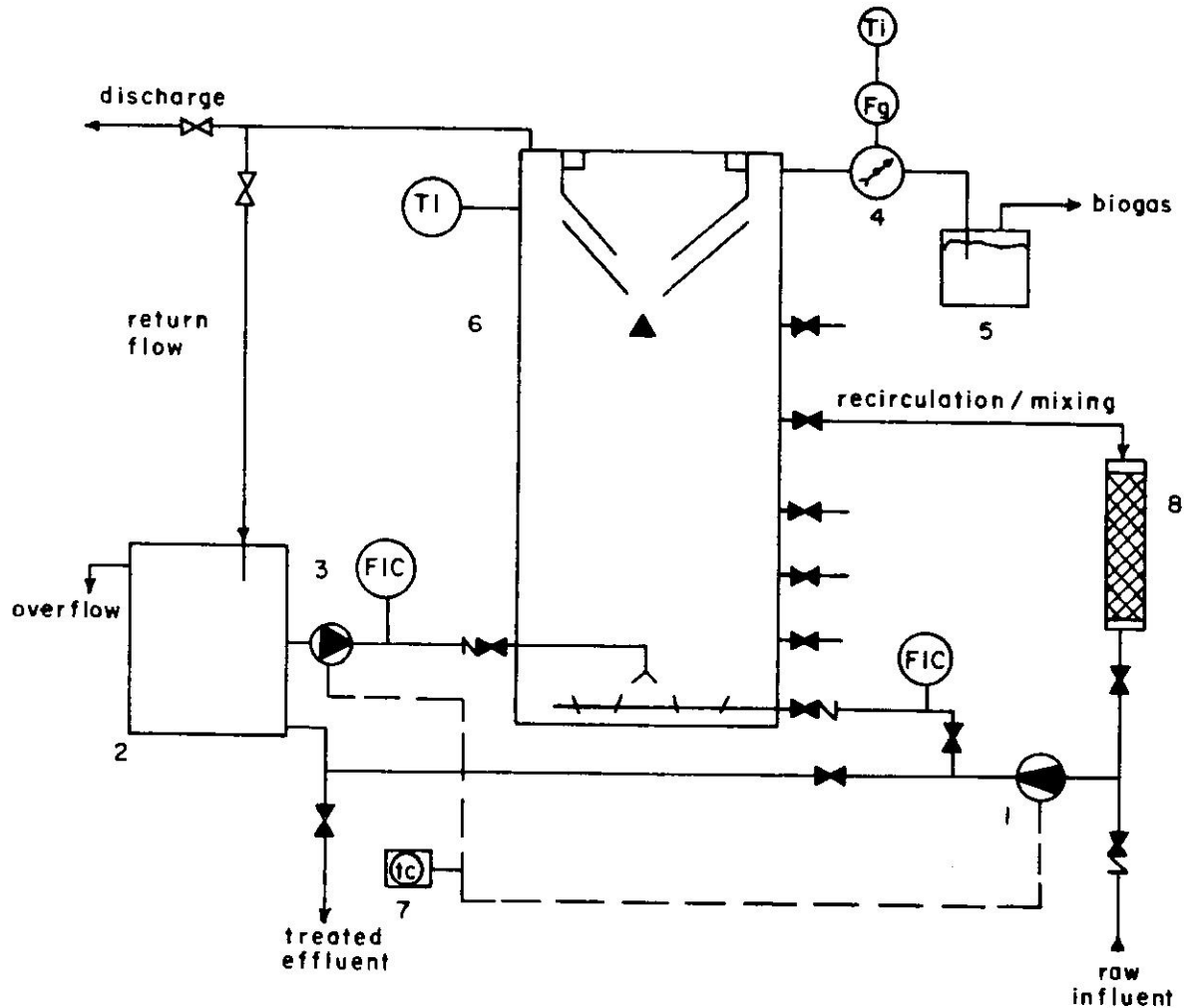


FIGURE 2
UASB SYSTEM

Fig. 2: Process flow diagram UASB pilot plant.



1. Centrifugal pump, in line capacity $\leq 800 \text{ m}^3/\text{h}$
2. Storage vessels, 400 L
3. Pulse pump, in line capacity $\leq 800 \text{ m}^3/\text{h}$
4. Gasmeter
5. Waterseal (waterpressure ca. 2")
6. UASB-reactor, 500 L
7. Timer controller for optional alternating pumping
8. Filter

sludge retention of the reactor, viz. 25-30 kg VSS/m³, and the fairly high specific bio-activity of the sludge, viz. 0.7-1.1 kg COD/kg VSS/day at 30°C.

As a result of the high loading rate, short hydraulic retention times, (e.g. six hours) are possible.

Small-sized facilities and area are required. Therefore, in many cases anaerobic (pre) treatment has proven to be financially competitive with aerobic treatment and other anaerobic treatment facilities. (Table 2, Table 3).

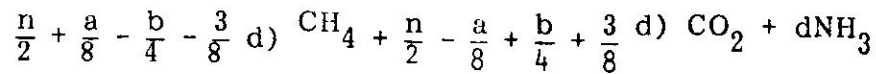
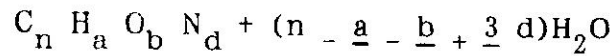
Sludge quality and quantity: the sludge is well-stabilized, settles easily, and has a high dry matter content (Sludge Volume Index 10-30 ml/g). Compared to aerobic treatment systems, surplus sludge production is relatively small (4-10 times lower) and amounts to 5-15 percent of the removed COD.

Nutrients: as a consequence of the low sludge production in the anaerobic process, less nutrients (nitrogen and phosphorus) are required compared to aerobic processes.

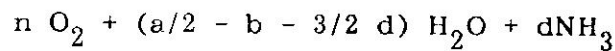
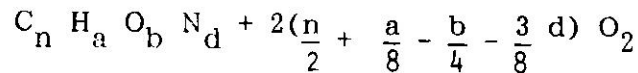
Energy: since ambient temperature in the Caribbean is almost optimal for the process and since energy is only required for pumping, an energy surplus should be expected.

ENERGY PRODUCTION

From a given amount of average type waste having a general composition of $C_n H_a O_b N_d$ a rough estimate of the producible methane can be obtained from the formula:

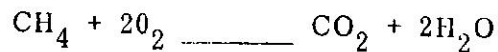


The COD of the same waste can be calculated with the formula



From both formulas one can deduce that the stabilization attained in anaerobic treatment is directly related to the methane production, since the ultimate oxygen demand is two mols O_2 / mol CH_4 .

This is in accordance with the equation:



From this one can calculate that oxidation of 1 grammol CH_4 (22.4 l at $0^\circ C$ / 760 mm Hg) demands 64 g Oxygen, or 1 kg COD equals 0,35 m^3 ($0^\circ C$, 760 mm Hg).

The relationship between CH_4 and COD is given by the formula:

$$V_{\text{CH}_4} = (1-Y) 0,35 L_{\text{COD}} N_{\text{COD}} \quad (\text{Nm}^3)$$

with

V_{CH_4} is methane production (m^3 , 0°C , 760 mm Hg)

Y is yieldfactor: fraction of removed COD used for development of new bacteria (sludge growth), in general 5-15%

L_{COD} is waste load expressed as kg COD

N_{COD} is processing (removal) efficiency of COD

TABLE 2
INDICATIVE COST COMPARISON OF AEROBIC AND ANAEROBIC WASTEWATER TREATMENT FACILITIES
MODERATE CLIMATE (2)

Type of Facility	AEROBIC			ANAEROBIC		
	Trickling Filter	Activated Sludge	Upflow Anaerobic	Sludge Blanket		
Load kg COD/m ³	3.3	0.33	5	10	15	
Type of Industrial Sewage	flex (b) retting sugar	flex (e) retting sugar	flex retting sugar	flex retting sugar	flex retting sugar	flex retting sugar
Size of Plant P.E.	14,000	50,000	14,000	50,000	14,000	50,000
Capital costs \$/P.E.	26.20	15.79	21.71	13.40	17.37	13.92
Net Annual Costs \$/P.E.	6.10	2.96	7.29	2.99	2.19	2.03
Annual Energy Consumption \$	7,600	5,600	28,800	23,600	1,200	700
Annual Energy Production \$	-	-	-	-	16,600	21,200
Net Annual Costs \$/P.E.	3.16	-	3.98	-	1.42	-
Net Annual Costs \$/P.E.	-	4.68	-	5.50	-	1.62

Notes: a) Table is in an adaptation of Dutch figures (ca. 1976). Assumed is an exchange rate 1 US\$ = Hfl. 2,50

b) Flex retting industry: Q = 500 m³/d, temperature 30-35°C (86-95°F), COD 5000 g O₂/m³, BOB 3000 gO₂/m³ processing includes secondary treatment and sludge-handling.

c) Seasonal beetsugar industry (130 d/yr); Q = 2600 m³/d, temperature 30-40°C, COD 750-3000 gO₂/d load max. 8000 kg/d; processing with sludge handling.

d) Continuous beetsugar processing; characteristics conform (c); processing without sludge-handling.

e) Conform (d) but processing with sludge handling.

f) Electricity costs based on US c 4,4/kWh (flex retting) resp. US c 2,6 kWh. Prices of electricity have sharply increased in the Netherlands since 1977. Probably US 12 at the moment.

g) Methane energy value based on US c 4,25/Nm³ CH₄. Price of natural gas (9000 kcal/Nm³) has sharply increased in the Netherlands since 1977. Probably US c 22 at present.

TABLE 3
 COSTS OF ANAEROBIC UASB-PROCESS AND AEROBIC ACTIVATED SLUDGE TREATMENT (REF. 5A)

Assumption made in the calculations		Estimate of running costs of anaerobic treatment at different COD-influent values	Estimate of running costs of an activated sludge plant (exclusive sludge treatment and disposal).
1.	Amount of waste to be treated (Q): 8000 kg COD/day continuously (=45,000 i.e.)	6. Investment costs: anaerobic reactor volume price in f/m ³	Assumptions made in the calculation
2.	Maximum permissible loading rate at 30°C : 12 kg COD/m ³ /day hydr. loading rate: 4m ³ /m ³ /day	500 f 750 1000 f 500 1500 f 390 2500 f 300 5000 f 250	1. Amount of waste to be treated (Q): 8000 kg COD/day continuously (=45000 i.e.) COD of the waste: 2000 mg/l(COD/BOD = 1.6)
3.	Treatment efficiency (E): 90%	7. The waste is treated at the temperature it is supplied (30°C)	2. Treatment process: activated sludge process consisting of a plastic covered aeration pond combined with a settler
4.	Minimum HRT: 4 hours	8. All prices in Dutch Guilders (US\$ 0,40)	Sludge concentration : 3 kg SS/m ³ Sludge load : 0.4 kg BOD/kg SS OC/load : 1.7
5.	Sludge growth (Y): 0.1 kg sludge-COD/kg removed Methane production: (1-Y)E Q 0.35 = 0.9 · 90/100 800 · 0.35 = 2270 Nm ³ CH ₄ /day		Treatment efficiency : 90% Aeration energy : 0.67 kWh/kg O ₂ Volume aeration pond : 4200 m ³ Volume settler : 350 m ³ Energy requirement : 5700 kWh/day Prices in Dutch Guilders

TABLE 3
COSTS OF ANAEROBIC UASB-PROCESS AND AEROBIC ACTIVATED SLUDGE TREATMENT (CONTINUED)

Cost Estimates						Cost Estimate
COD of Waste (g/m ³)	1600	2000	3000			Capital Costs (x f 1000)
reactor volume required (m ³)	1330	665	665			Aeration ponds (f 40/m)
						Aerators 240 kW
Capital Costs (x1000)	749	665	665			Settler
(reactor + gasholder)						
Yearly Running Costs (x 1000)						Total
I. without gas utilization						Yearly Running Costs (x f 1000)
interest + redemption	112.3	99.8	99.8			Interest + Redemption (15% of Capital Costs)
(15% of capital costs)						Maintenance + Renewals (2% of Capital Costs)
Maintenance + renewals	15	13.3	13.3			Labour
(2% of capital costs)	60	60	60			Energy 2.08x10 ⁶ kWh (a f 0.12)
Labour + supervision	187.3	173.1	173.1			
Total costs/year (x f 1000)	4.16	3.84	3.84			Total (x f 1000)
Costs per i.c. (f/i.e.)						457.3
						10.20
2. With gas utilization						
(assumed gas prices (0.17/N ³))						
Total costs/year (xf 1000)	36.3	32.1	32.1			
Costs per i.c. (f/i.e.)	0.81	0.71	0.71			

Remarks: 1. Energy process higher now
2. Capital costs activated sludge plant too low in our opinion.

Since the generated methane is a fraction of the total production of biogas, there is a slight variation in energy-content.

Depending on its "purity" biogas has a heating value of 7000-9500 kcal/Nm³ methane CH₄ or 29-40 MJ/Nm³CH₄ (780-1060 BTU/ft³) which means that an equivalent of about 3 kWh/Nm³CH₄ (n_{el} 30-40%) can be obtained). At Curacao presently 1 kWh costs \$0.145 (April 1982).

APPLICATIONS AND IMPORTANCE OF ANAEROBIC WASTE WATER TREATMENT

Because the development of modern anaerobic systems, especially the UASB-type, is rather new, only a relatively small number of industrial-scale plants are in operation. Most of these plants operate in moderate climate countries (like the Netherlands, West Germany, Sweden, and the U.S.A.) Since high biogas production allows internal energy supply for heating, there are substantial savings on running costs.

UASB processing has general applications to a wide variety of agricultural and related industries. Also the treatment of other waste waters from industrial and non-industrial sources have proven to be feasible.

Some examples of waste-waters tested on pilot-plant-scale and/or tested on industrial-scale are outlined in Table 4.

TABLE 4
OUTLINE OF SOME INDUSTRIAL - SCALE OPERATING OR PILOT PLANT
SCALE TESTED UASB APPLICATIONS FOR WASTE WATER-TREATMENT

Treatment of leachate from sanitary landfills (6)
Heavily polluted leachate (COD 25000 ppm) contains high amounts of heavy metals, hence there is a risk of contamination of ground-water. Laboratory research and pilot-test at 20°C and 33°C have shown that COD-removal efficiencies of more than 70% respectively 90% are possible with a biogas production of 0,52 Nm³/kg removed COD (57% CH₄). An extra advantage is a removal of metals from the effluent up to 98% efficiency.

TREATMENT OF WASTE WATER FROM SLAUGHTERHOUSES AND MEAT PROCESSING INDUSTRIES

This application is tested now with a 30 m³ reactor in the Netherlands. Subsidiary aims are energy generation and protein-recovery.

TREATMENT OF WASTE WATER FROM STARCH-INDUSTRIES

Several starch industries in the Netherlands are equipped now with UASB-systems, e.g. a maize starch-industry (60,000 p.e.; capital costs US\$ 16,70/p.e.). At potato starch-industries, waste water (COD 18 kg/m³) is treated at loading rates up to 15 kg COD/m³.d. At loading rate of 8 kg COD/m³.d. (40 p.e./m³) a biogas-production of 6,5 - 7,5Nm³ (71-77% CH₄) per m³ treated effluent is obtainable, as well as a pollution removal efficiency of 95% as COD respectively 98% as BOD. The net surplus is used for starch processing.

BEETSUGAR-INDUSTRIES

Many beetsugar factories in the Netherlands are equipped now with USAB-systems. Loading rates 20 kg COD/m³.d. (100 p.e./m³) at high purification, efficiencies are possible. The net energy surplus is used as boiler fuel in the factory.

BREWERIES

In 1981/1982 the construction of the world's largest industrial anaerobic waste water-treatment complex at G. Heileman Brewing Company at La Crosse, Wisconsin was completed. This brewery produces over 1 million bbl (1,59 million hl) per year. The plant is designed to process over 19000 m³/d (5 MGD) of brewery waste water with a pollution rate of 1800 g BOD/m³ or 2880 g COD/m³. Total load amounts 34,000 kg BOD/d (75,000 lbs BOD/day) equal to 54,500 kg COD/d (120,000 lbs COD/d) or more than 400,000 p.e. A load reduction of 85% BOD is expected. Methane production is

(Continuation Table 4)

calculated at 17,600 m³/d (621,600 ft³/day) with a heating value of 7130 kcal/m³ (900 BTU/ft³). Options for using the bio-energy are either electricity generation or boilerfuel. The gross value of the biogas is estimated at (1981) \$816,870 per annum (\$40/therm). The operating costs (personnel, utilities, chemicals, maintenance and sludge removal) are estimated at (1981) \$240,000/year or \$492,288/year including process heating. Net operating benefits amount therefore \$324,582/year. Capital costs (exclusive of sewer or street work, or outside utilities) would be \$6.5 million as of the 4th quarter of 1981. Based on the projected return on bio-energy this would imply a 20 year pay back; however it is expected that, as energy prices inevitably rise, the rate of return will increase and the payback interval will decrease.

DOMESTIC WASTE WATER

At the University of Wageningen, the birthplace of the UASB-system, remarkable results have been achieved with domestic sewage. Under dry weather flow conditions 65 - 85% COD reduction was obtained at temperatures higher than 6°C (43°F). The biogas production amounted 220 l/kg COD (at 20°C or 68°F). Expected is a net CH₄ - production of 7,6 - 9,1 Nm³ CH₄/p.e./year (1 p.e. equals 54⁴ g BZV/m³d). During rainfall in a combined sewerage system however, COD reduction is expected to diminish to 50-75%.

The climate in the Caribbean offers an ideal condition in which to use the UASB process as an energy producing utility. Since temperatures are in general higher than 24°C (75°F) and since there are only small fluctuations on the average annual temperature, no heating of the reactor will be required. Produced biogas can therefore be used for other purposes. In this respect waste waters from local food processing industries (cane sugar, distilleries, meat processing, etc.) are undoubtedly promising energy sources.

In the Netherlands Antilles there are only a few food processing industries. No pollution loads are known for these industries since an overall study of environmental pollution has not yet been completed and the following pollution figures are only rough estimates.

A rum distillery is located on St. Maarten, but no production figures are available yet. Because of results at other fermenting and distillery industries a high pollution rate and therefore a high gas-production may be expected. (E.g. with molasses industries, expected figures are: pollution ratio ca. 10 kg BOD/m³, BOD/COD = 0,8, expected gas-production 4Nm³CH₄/m³ treated waste water.

The Amstel brewery on Curacao produces 132,000 hl beer/year. Breweries, like most food industries, do not operate in an identical manner. Some use Lauter turns, others mash filters; some recover liquor, others do not; some use corn grits, others rice; and so on. Consequently, the amount of waste and the pollution load of the sewage may differ considerably. Waste water volume varies 20-40 hl./hl. beer produced. Pollution rates range 500-1800 g BOD/m³ or 900-2900 g COD/m³.

Assuming the same sewage characteristics as for the Heileman-brewery (see Table 4) the pollution loading rate is estimated at

33,500 p.e. with a gas-production estimated at of 1460Nm^3 (51600ft^3) CH_4 /day will be obtained. This volume equals a heating value of 49×10^6 MJ (46×10^6 BTU or 464 therms) /day. This energy may be used as a fossil fuel substitute for steam generation. If electricity were generated from this biogas, an annual production of 1,600,000 kWh with a local substitute value of \$232,200 (or \$6.93/p.e.) can be estimated.

In this situation not only an energy credit is obtainable, but also reusable water is a possibility. Because of the arid climate in the Netherlands Antilles, the main fresh water source is distilled sea water; price range of this water is \$2 - \$4.50/ m^3 . In the beetsugar industry a significant reduction of the use of process water can be realized by recirculating treated effluent.

The slaughterhouse on the island of Curacao slaughtered in 1980: 195 cows, 42 calves, 5,995 pigs, 3901 sheep, 1512 goats, 14 turtles and 18 other animals. The pollution loading rate is estimated at ca. 8000 p.e. or $1400\text{ kg COD}/\text{m}^3\cdot\text{d}$. This equals a methane production of $400\text{ Nm}^3/\text{day}$ or $75,000\text{ Nm}^3\text{CH}_4/\text{year}$, meaning a substitute value of electricity for the amount of ca. \$32,700 or \$4.10 per p.e. per year.

Presently industries in the Netherlands Antilles are forced by law to purify waste water or they are taxed for discharging waste water. Consequently, up to now industries have been interested in waste water treatment only if a positive income is obtained from the process. Even then, however, waste water treatment probably will be considered "branch-foreign" unless high energy credits are obtained.

With respect to domestic waste water, the Curacao government plans to construct several waste water treatment plants for the town of Willemstad within a few years. One aerobic activated sludge

plant (4000 p.e.) is under construction now. Because almost all construction materials are imported, capital costs of a plant of this size are very high (up to \$140/p.e.).

A waste water treatment facility composed of a UASB reactor as a primary biological stage and a trickling filter as a secondary biological stage is expected to be financially competitive with the one stage activated sludge systems being planned.

For the town of Willemstad (100,000 p.e.) a gross energy production of 800,000 Nm³CH₄/year with a heating value of 2.39 x 10¹⁰ kJ/year (2.26 X 10⁵ therms/year) may be feasible and would provide an electricity generation of 2.4 X 10⁶ kWh with a local value of (1982) \$348,600 or \$3.49/p.e. Estimates of investment costs and running costs of a one-stage aerobic waste water treatment plant and a two stage UASB facility are made in table 5.

TABLE 5
COST ESTIMATE OF 100,000 P.E TREATMENT FACILITIES

	1 Stage aerobic activated sludge treatment	or	2 Stage treatment UASB + aerobic activated sludge
Load	100,000 p.e.		13500 kg COD/day
Q(m ³ /day)	10,000		10,000
Loading rate, 1° stage:	10 p.e./m ³		40 p.e./m ³ or 5.4 kg COD/m ³ .d.
			10 p.e./m ³
Efficiency			
1° stage:	95%		70%
2° stage:	-		85%
overall	95%		95%
Volume			
1° stage:	10,000 m ³		2,500 m ³
2° stage:	-		3,000 m ³
Methane production			800.000 Nm ³ /year
<u>Capital costs (x1000\$)</u>			
aerobic treatment + sedi- mentation + sludge drying	8000		3350 (I ₁)
UASB + gasholder			1400 (I ₂)
dual-fuel generator	-		100
Total	8000		4850 (I _t)
per p.e.\$	80		48.50
<u>Annual costs (x1000\$)</u>			
investment costs	920		557.8 (11,5% of I _t)
maintenance	80		33.5 (1% of I _t)
	-		19.6 (1,30% of I _t)
I ₂) labor	200		200
contingencies	160		97 (2% of I _t)
Energy consumption	240		100.5 (3% of I ₁)
Energy production (electricity)	-	minus	348.6
Total	1600		667.3
costs ₃ per p.e. ()	16		7
per m ³ treated effluent ()	44		18

N.B. Estimate does not include net revenues from effluent sales: \$0,56/m³ or \$1,63 million/year (water losses assumed 20%). In that case 1-stage aerobic activated sludge plant is financially self-supporting and 2-stage waste water treatment plant has a net revenue of \$964.000/year, which can be used for operating the integrated waste processing scheme (fig. 1).

From these calculations one can see that:

1. Investment costs of the two stage (UASB + activated sludge) facility are 39 percent lower than for the one-stage activated sludge facility.
2. Annual costs of the two-stage facility are 50 percent lower than for the one-stage facility.
3. In case effluent sales for irrigation purposes are realized, the one-stage facility will be self supporting, while the two-stage facility has a net revenue of \$964.000/year, which can be used for operating the integrated waste processing scheme as indicated in fig. 1.

ARRANGEMENT OF TEST EQUIPMENT UASB REACTOR PROCESSING DOMESTIC WASTE WATER

Before and during the tests several logistic and technical problems had to be solved. Two factors made this difficult. There is only limited analyzing capability at the UNA and no equipment for field investigations. There was no budget in 1982 for this purpose, and the budget for 1983 has been cut drastically because of the economy. The initial investigations were made possible with the help of some local institutions which made some equipment and materials available.

The designed pilot-plant has a capacity tuned to the capacities of local available pumps and measuring-instruments.

The installation as a whole includes after some modifications (see Fig. 2):

1. Centrifugal pump for optional influent supply to storage vessels and optional discontinuous, automatically time controlled, sludge water recirculation in the UASB reactor (cap. 800 l/h).
2. Storage vessels (400 l).
3. Pulse pump for feeding UASB reactor from storage vessels.
4. Gasmeter
5. Waterseal
6. UASB-reactor (500 l) composed of two oil drums and a tilted plate interceptor with gas globe, welded together. Waste water treatment and methane generation proceeds as follows: substrate containing influent is made to flow upwards through the reactor by means of the pulse pump. The gas produced in the process carried off via the gas globe the top of the reactor, the gasvolumemeter and the water seal. In the upper part of the reactor, the sludge/ water mixture is separated by the tilted plate interceptor, the sludge flows back into the reactor vessel and the treated effluent overflows into the storage vessels or is directly discharged.
7. Time controller for alternating operation of centrifugal pump and pulse pump.
8. Filter as a prevention against clogging in recirculation system.
9. Devices for waterflow indication and manual control and temperature measurement.

The installed flow scheme has the following processing options:

1. Raw influent is periodically pumped to the storage vessels and after that the UASB reactor is fed during a predetermined time interval. The overflow of the UASB reactor returns to the vessels. Sludge water mixing is optional. Before the vessels are refilled with raw influent, treated effluent is discharged to the sewers (batch type system).
2. Raw influent is continuously pumped to the storage vessels and the UASB-reactor is fed simultaneously. Return flow of the

treated effluent to the storage vessels and/or sludge water mixing are optional.

The installation was assembled at the site of municipal waste water treatment plant "Klein Hofje". This plant consists only of a facility for primary sedimentation (Dortmund-type) and anaerobic digestion of primary sludge. Partly stabilized sludge from this digester was used to start the UASB-reactor on February 28, 1982. Average composition of the initial sludge in the reactor was ca. 12 kg TSS/m³; 80% VSS.

RESULTS

A sludge adaptation period of six weeks was projected. However, the pilot-test experienced several technical break downs and, consequently, low efficiency resulted. The effective operation of the pilot plant is only 60 percent until now, and, therefore, the start-up period has not yet been completed .

At the Klein Hofje site, municipal waste water from a separated sewer is discharged. Based on a daily discharge of 50-80 l/cap. day and a load of 54 g BOD or 125 g COD/cap. day, a pollution-rate of more than 1500 g COD/m³ was expected. The pollution rate, however, was never more than a disappointing 486 g COD/m³.

This low value cannot only be explained by assuming biological oxidation during long hydraulic retention time in the sewerages. Probably large amounts of infiltration water are entering the sewerages as well. It was noticed that especially after rainfall the COD sharply decreased. A consequence of this phenomena is that even after start-up and sludge adaptation, the UASB reactor will not operate at a maximum loading rate because hydraulic retention time will become the limiting factor.

Shortly after the first start-up, it turned out that a raw waste water supply directly to the UASB reactor was not immediately possible because of clogging effects in the influent system and centrifugal-type pump. For that reason waste water was periodically pumped into the storage vessels. The UASB-reactor was fed from there. Since the biomass in the reactor was not completely adapted, the organic loading rate was kept low by returning the overflow to the storage vessels. Under these circumstances the produced biogas was not released very well from the sludge particles unless the reactor can be brought into vibrations. Forced recirculation of the sludge-water has given some improvement. The results of this period are given in Table 6. From these results it is apparent that the average COD-removal efficiency is still low; however, on some days a COD-removal of 60 percent and more was obtained.

On March 15 the pulse pump was damaged and had to be replaced. The subsequent test period was characterized by a biogas production which decreased from 22 l/day to less than 6 l/day. Finally gas production stopped. Sludge content proved to be very low, and the reactor was refilled with new sludge.

On April 8, however, the packing of the centrifugal type pump started a leak so that providing a supply of raw influent was no longer possible. This pump still has not been replaced and tests are temporary stopped.

TABLE 6
TEST RESULTS

Period	March 2-7	March 8-14	March 16-23	April 1-7(3)
<u>Pollution ratio</u>				
Influent gCOD /m ³	325	327	300	486
Effluent gCOD /m ³	173	170	212	248
efficiency %	47	48	29	49
Load gCOD/d m ³	0.455	0.916	0.600	0.389
<u>Gas production</u>				
theoretical Nm ³ CH ₄ /period	67.5	138.5	55	60 (1)
measured m ³ biogas/period	132.4	232.2	76	98.4 (5)
CH ₄ ratio %	56	66	(4)	67 (6)
Hydraulic ret. time average	1 day	1 day	1 day	1 day
Recirculation rate d ⁻¹	4	4	4	4

- (1) Assumption CH₄ production is 0,35 (1-Y) (CZV) L(CZV) with y=0,10
- (2) Sludge content during test periods March 2-14:
12 kg TSS/m³; 81% VSS
- (3) Initial sludge content of test period April 1-7:
14,6 kg TSS/m³; 89% VSS
- (4) Probably inaccurate
- (5) Average temperature 30°C
- (6) Correction for temperature; no corrections for solubility of gas in waste water.

CONCLUSIONS

1. UASB processing of industrial waste water represents a cheap and promising method of waste removal and energy recovery.
2. Climatic conditions in the Caribbean are pre-eminently appropriate to obtain an optimal net energy production.
3. It is expected that domestic waste water can be treated with a net energy yield. Further feasibility studies, however, are necessary.
4. A higher benefit from waste water treatment can be obtained if energy production is desired and if the treated effluent is re-used as process-water for industries or for irrigation.

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EL I.N.R.A DENTRO DEL DOMINIO
DE LA ENERGIA BIOMASICA

Presentado en

UNICA WORKSHOP ON BIOMASS AS AN
ENERGY ALTERNATIVE FOR THE CARIBBEAN

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Por

Aubert Parfait

Es preciso que desde el comienzo señalemos las preocupaciones del Instituto Nacional de Investigación Agronómica en el campo de la biomasa. Según Chartier la valorización energética de la biomasa, más que cualquier otro medio energético, se encuentra en interacción permanente con otros sectores de actividad (producción de alimentos, producción de madera), es decir que los problemas macroeconómicos deben considerarse detenidamente.

Por consiguiente se ha procurado organizar las investigaciones dirigidas por el I.N.R.A. en una Comisión de Energía Biomásica para asegurar especialmente la definición y la evaluación de los programas. A la misma vez, se han designado delegados regionales para la energía. Una de sus responsabilidades es dar a conocer mejor las actividades de I.N.R.A.

En el último informe de actividades de la Comisión de Energía Biomásica se presentaron los programas en proceso bajo tres áreas:

Los Recursos. Bases de la producción, potencialidad de producción del territorio, mantenimiento de la naturaleza renovable de la producción, impacto ecológico, y características de las diferentes biomásas y de su movilización.

Las Transformaciones. Celulosa, fermentación alcohólica y fermentación metánica.

Análisis del Sistema de Producción y de los Medios de Transformación. Balance energético, penetración de medios energéticos en los sistemas de producción agrícola y forestal, y estudios económicos.

El I.N.R.A. mantiene un centro de investigación en la región Antillas-Guayana. Naturalmente este centro es parte del esfuerzo general de las investigaciones. Pero también ha habido dentro del cuadro una reflexión especial del Comité Regional de Economía Energética y del Comité de Técnica Solar de Guadalupe. Además esa política regional se define de común acuerdo con los otros territorios

franceses de ultramar. Se ha llegado a tomar en cuenta, de manera relativa, los recursos y las necesidades energéticas, el nivel de sensibilización y las realizaciones previas.

Una de las primeras etapas fue el examen de la situación local. Guadalupe consumió en 1980 cerca de 300,000 toneladas de productos petroleros desglosadas en las siguientes proporciones:

- transporte por carretera 39.2%, de los cuales aproximadamente la mitad fue gasol
- producción de electricidad 27.1%
- industria 1.8%
- aviación 22.6%
- otros 9.3%

Se ha hecho también un inventario preliminar de potencialidades de energía renovable. Se ha encontrado que el problema mayor consiste en la necesidad de reconsiderar en parte el modo actual de producción de energía. Es necesario pasar de una política de concentración a un sistema diversificado de producción de energía y al más bajo costo.

La agricultura es un sector favorable para aplicar tal política. Notemos desde el comienzo que los insumos de energía fósil tienen escasa importancia en la agricultura local. La mecanización, la irrigación, el uso masivo de abono nitrogenado, son prácticas todavía poco desarrolladas. Es por esto que se ha estimado que las necesidades de los cultivos se suplen solo en alrededor de un 50% mediante la aplicación de diferentes abonos.

El objetivo principal es, pues, aumentar la productividad de la agricultura y de la cría en Guadalupe. Es necesario, sin embargo, procurar desde ahora racionalizar el uso de los abonos, del agua y de los productos fitosanitarios.

Esta política también se ubica en el marco del mejoramiento de los recursos locales de biomasa. En efecto, con una irradiación solar incidental del orden de $1,800 \text{ KWh/m}^2$ y suponiendo una eficiencia de la fotosíntesis de alrededor de 0.4%, el equivalente energético de la biomasa producida junto a la Guadalupe es de más de 950,000 TEP, es decir más de tres veces el consumo actual de productos petroleros.

Los programas de investigaciones del I.N.R.A. en esta zona geográfica se derivan de observaciones anteriores. Para comenzar hay un proyecto para la medición de la irradiación solar en Guadalupe con miras a construir un mapa de yacimiento solar y un banco de datos. Estos trabajos se llevan a cabo en colaboración con diversos centros de investigación locales.

No se contempla por lo pronto involucrarse directamente en cultivos energéticos, aún cuando se están llevando a cabo ciertas investigaciones agronómicas con la caña de azúcar, una planta que genera un excelente rendimiento fotosintético. Pero en otros centros del I.N.R.A. se han estado acumulando datos sobre el jacinto de agua, las biomásas de hidrocarburos (euforbiáceas) y las oleaginosas.

Muchos de los proyectos tienen que ver con el uso racional del agua. Citamos en particular la tolerancia de plantas hortenses seleccionadas por la sequedad y la valorización óptima de las precipitaciones del agua y la irrigación. En este último caso, la estación de bioclimatología ha llevado a cabo por muchos años una intensa actividad. Se han venido realizando en forma continua estudios interdisciplinarios sobre: el comportamiento de los suelos hacia la irrigación, la selección de cultivos capaces de asegurar la mejor valorización del agua, la determinación de las necesidades específicas de las plantas, y la influencia de la irrigación sobre la fertilización.

Continúa la preocupación en torno al aumento de la productividad agrícola. Actualmente se estima que uno de los factores de progreso sería, sin duda, enfocar el cultivo de leguminosos. A la misma vez, también conviene valorizar al máximo la biomasa residual de origen agrícola o de otra procedencia. En el primer caso, el bagazo representa el volumen, el substrato más interesante: los residuos reservados son considerados en segundo plano.

Las destilerías y las centrales azucareras tienen su autonomía energética gracias al bagazo. Los equipos de investigación de Guadalupe quieren mejorar la transformación energética. Ellos pronostican utilizar la gasificación y la pirolisis en vez de la combustión. En este caso habrá un excedente muy importante de bagazo que podrá utilizarse para el mejoramiento orgánico de los suelos. I.N.R.A. persigue conjuntamente con varias otras organizaciones un programa de este tipo para el cultivo de productos comestibles. En esto la estación agronómica juega el papel principal. Esta última recalca que el contenido de materias orgánicas es particularmente importante para el terreno. En nuestro caso donde los suelos a veces son pobres debido a la actividad de los microorganismos, la no-restitución de las materias orgánicas del terreno ocasionará una baja en la fertilidad. Tales consideraciones han servido de base para emprender los trabajos para la fabricación de compuestos derivados de desperdicios y el uso del lodo de las estaciones urbanas de purificación de aguas.

La industrialización en Guadalupe es escasa pero la contaminación causada por las vinazas de las destilerías conlleva malas consecuencias para el plan ambiental. El tratamiento de estas vinazas por vía aerobia consume mucha energía. La fermentación metánica es, pues, una mejor solución para reducir la contaminación. Esta es la alternativa por la cual se ha optado recientemente en los programas de investigación de I.N.R.A.

Antes de terminar, es necesario decir algunas palabras sobre el programa de cooperación de I.N.R.A. en la región del Caribe. Existe una preocupación constante por dedicar mayores recursos financieros a estas gestiones que nos permita cultivar relaciones con el mayor número de países. En estos momentos, sin embargo, el ámbito de la energía biomásica ha sido poco explorado.

El programa de investigaciones de I.N.R.A. sobre los usos energéticos de la biomasa se sustenta sobre la necesidad de satisfacer las necesidades de productos y sobre el cuidado de una producción menos centralizada de la energía. La protección de ambiente y el mantenimiento de la naturaleza renovable de la producción son también una de nuestras mayores preocupaciones.

BIOCONVERSION OF STRONG ORGANIC WASTE STREAMS
TO METHANE GAS:
THE BARCARDI CORPORATION'S ANAEROBIC TREATMENT PROCESS

Presented at

UNICA WORKSHOP ON BIOMASS AS AN
ENERGY ALTERNATIVE FOR THE CARIBBEAN

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By

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The Bacardi Corporation has investigated numerous disposal and treatment alternatives to find the most acceptable method for disposing of the "mosto" or still bottoms produced during the distillation of rum. For example, the concentration of mosto for use as a cattle feed extender, the wet oxidation of mosto, the use of concentrated mosto or "CMS" as a boiler fuel and the anaerobic digestion of mosto were all investigated. As a result of an agreement entered into between the Bacardi Corporation and the U.S. Environmental Protection Agency in late 1979 which required a 75 percent BOD removal from its mosto waste stream, the company decided, because of its previous studies, to utilize an anaerobic biological treatment process.

The Bacardi rum distillery, the largest in the world, has, like other distilleries, a waste stream that is high in organics. Based on the information developed during the evaluation of various treatment technologies, Bacardi decided that anaerobic biological treatment was the most beneficial all around method for the mosto stream. The average characteristics of the mosto stream are seen in table 1.

TABLE 1
AVERAGE MOSTO STREAM CHARACTERISTICS

Parameter	Concentration ppm
BOD ₅	36,000- 42,000
COD	85,000-105,000
TSS	4,000- 8,000
Nitrogen (Kjehldahl)	790- 1,450
Phosphorous (Orthosphate)	59-98

The reasons for choosing the anaerobic process can be summarized as follows.

1. The process is suitable for high strength organic waste. The waste is hundreds of times stronger than domestic wastes and stronger than many industrial wastes.
2. O & M costs are low. Aerobic treatment would require as much as 8,000 horse power for aeration alone.
3. The process generates energy in the form of methane gas. Aerobic treatment does not produce recoverable energy.
4. There is a minimal sludge production. Aerobic treatment would produce a large amount of sludge requiring handling and disposal.
5. Depending on the cost of energy, the energy produced has the potential of paying for the treatment plant.
6. Several variations can be adapted to specific needs. Depending on the strength and characteristics of the waste and the level of treatment required, the retention time and the design of the process can be custom tailored.

Another reason for choosing an anaerobic process is that Puerto Rico is an oil importing country; therefore, any process that replaces imported oil is beneficial to the economy. The practicality of anaerobic treatment diminishes as the organic content of the stream to be treated decreases. This is a general rule; however, recent developments in this field have demonstrated that weak but highly biodegradable wastes can be treated cost effectively with energy recovery. This new technology makes use of highly efficient anaerobic filters allowing hydraulic retention times on the order of from a few hours up to a day.

The advantages of an anaerobic process over an aerobic one are as follows:

1. Loadings are not restricted by oxygen transfer. The loa-

dings achievable in anaerobic systems are much higher than in aerobic systems. In anaerobic systems the loadings are determined by the viability of the bacteria to the loading and by possible material handling limitations such as pumpability. Given enough time, anaerobic bacteria capable of performing efficiently under extremes of organic concentration can be developed.

2. The anaerobic process is not restricted by the high cost of oxygen transfer. It takes a significant amount horsepower for aerators or an expensive oxygenic plant to treat waste aerobically.
3. There is a usable end product in the form of gas. Aerobic treatment only produces CO₂, water and large volumes of sludge to be disposed of.
4. Less biological solid is removed per pound of BOD. In the anaerobic treatment approximately 90 percent of the degraded organics are converted to gas and only approximately 10 percent go to solids.

Most of this is possible because the anaerobic biological filter, invented by Dr. P. McCarty, is a great improvement over the conventional anaerobic contact digester.

Until the development of the anaerobic filter, it was difficult at best to develop and maintain a high Volatile Suspended Solids (VSS) level in the digester due to the difficulty of settling the solids in the effluent for recycle to the digester. The advantages of the anaerobic filter over other conventional processes are as follows:

1. Unlike the contact process which requires both recirculation and mixers, it only requires very low horsepower to divide recirculation. A total of only 12 horsepower is required in our 3.25 million gallon anaerobic filter.

2. There is a smaller tankage needed due to the higher loadings. Although anaerobic plants may be more capital intensive because of the methane handling equipment required for energy recovery, the high loading rates and smaller tanks require less space.
3. There is a more stable, larger inventory of attached organisms. This is one of the most important advantages of the anaerobic filter. Not only is the anaerobic filter system more stable, but this large inventory of attached organisms allows higher loading rates to be achieved than are possible in the contact process. Also, no clarification is required; thus capital costs are increased and operation is made simpler.
4. Not only is a higher loading rate possible in the anaerobic filter, but higher BOD and COD removals are achieved, leading to a more highly stabilized effluent.
5. The fact that only about 10 percent of the organics removed from the waste go to solids is a very important advantage. Also, the solids appear to be more settleable than those produced by the contact process since the solids produced in the anaerobic process appear to slough off the filter media in larger pieces. The importance of low solids production can be appreciated by those responsible for aerobic treatment plants because solids disposal is one of the most difficult problems to solve. Cities like Philadelphia and New York "ocean dump" via barges as there is no other viable disposal method available.
6. Fast "restart" after prolonged "resting" periods. Based on observation made by Dr. McCarty and others and confirmed in our studies, it is possible to stop "feeding" an anaerobic system completely for months and to restart it in a matter of a few hours or days by initiating feed and by bringing the temperature to the normal operating range of the system. A laboratory anaerobic unit was

held dormant at an ambient temperature for six months and was restarted within a matter of a few hours by initiating feed and raising the temperature to ca. 37°C. The ability to maintain an anaerobic system dormant for long periods is very important for maintenance and other types of plant shutdown. Aerobic systems cannot be allowed to become dormant for long periods of time because they will lose their activity and must be restarted as aerobic bacteria will auto-oxidize if aeration is continued or die from lack of oxygen if aeration is halted.

The methane fermentation of complex waste is a complicated biochemical process. A complex organic waste mixture is acted on by various micro-organisms which begin to break down this waste. Part of the waste is converted to less complex intermediates which in turn are broken down to acetic acid, methane and possibly to other less complex intermediates; part of the waste is converted to acetic and to lesser amounts of propionic acid which in turn are degraded to methane. The propionic acid may also be converted to methane and acetic acid before the methanogenesis is complete. Carbon dioxide is also formed and part of it is also reduced to methane as the oxygen molecules in the carbon dioxide are used by certain bacteria to oxidize the complex waste. A number of different micro-organisms must be present for efficient waste stabilization and methanogenesis to occur.

One disadvantage of anaerobic versus aerobic treatment can be suggested indirectly. An aerobic system can generally be developed rapidly by seeding with aerobic plant clarifier bottom effluent; an anaerobic system requires months to acclimate and is very slow to develop and stabilize. Seed for anaerobic plant startups must be carefully selected and often must be developed in laboratory or pilot plant cultures. The fact that methanococcus bacteria divide once every three to five days while aerobic bacteria do so every few

hours also contributes to the very slow development and stabilization of anaerobic systems. The anaerobic culture used at the Bacardi plant was developed from fresh cow manure and has acclimated to the point that it can withstand large variations in waste characteristics and concentrations and is not affected by hydrogen sulfide concentrations twice as high as those reported to be fatal.

Until now we have concentrated on the BOD removal or waste stabilization aspects of anaerobic treatment. As we have noted earlier, the anaerobic process also produces a methane rich gas which can make a significant contribution to the energy requirements of the plant using it. In fact, there are a number of studies which use anaerobic digestion solely for the production of energy from a variety of organic feedstocks. The bioconversion of vegetable and plant material to an easily handled, transportable end fuel may very well become a significant energy source of the future. Anaerobic processes have not been studied carefully and significant technical advances will be made in the next decade to direct more and more attention to it as a potential energy source.

The patented Bacardi Corporation's anaerobic process was first tested in three pilot scale units. Some of the pilot plant findings have been incorporated into the full scale plant while others are expected to be incorporated the second phase of the anaerobic plant. The seed used to startup the full scale plant was developed in the units which are used to test modifications and improvements.

The potential to produce significant amounts of energy was one of the key factors that led Bacardi to select the anaerobic option for treating the mosto stream. Thus, one million gallons of waste having roughly a 20,000 ppm concentration of BOD is expected to produce well over one million cubic feet of methane at 80 percent BOD removal. It is obvious that the potential for replacing fuel oil

with methane will represent a significant savings. Unfortunately, the micro organism population in the first phase of the anaerobic plant is still being built up; therefore, estimates of how much methane will be produced are incomplete. At the moment the process is producing the equivalent of 75 barrels/day of oil from the Phase I anaerobic filter.

The process schematic of the anaerobic plant can be summarized quickly. Mosto enters the holding tank and is fed at a controlled rate to the unique anaerobic filter nutrients. Then pH control chemicals are added and the mosto is cooled during the transfer to the anaerobic filter. The treated anaerobic filter effluent will be pumped into a deep ocean outfall for final disposal. The methane rich gas produced is either fed to the boilers, stored in a pressure sphere, or flared off if it cannot be used or stored.

BIOMASS - A POTENTIAL ENERGY SOURCE FOR JAMAICA

Presented at

UNICA WORKSHOP ON BIOMASS AS AN
ENERGY ALTERNATIVE FOR THE CARIBBEAN

San Juan, Puerto Rico

April 26 - 29, 1982

by

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JAMAICA AND THE WORLD ENERGY SCENE

Since 1973 Jamaica has been spending increasingly larger percentages of export earnings on oil bills. Jamaica paid 18 percent export earnings for oil in 1973 and 48.1 percent in 1979. This has contributed to Jamaica's balance of payments problems. In 1978 while oil contributed approximately 50 percent of the total world energy consumption, Jamaica depended on imported petroleum for approximately 90 percent of its total energy supply. The other 10 percent was from bagasse used in the sugar industry (9 percent), and a small amount of hydro power (1 percent). Currently, the sugar industry, which was previously self-sufficient in terms of energy, because it used bagasse for process steam and electricity generation, is depending on petroleum for nearly 45 percent of its energy supply.

Jamaica has experienced a very high level of per capita energy consumption. Even when the consumption by bauxite/aluminum sector is excluded, Jamaica per capita consumption levels are higher than those of other oil-importing developing countries. While the world average Bbl/capita is 9.5 fuel oil equivalent (f.o.e.), that for developed countries is 28.9 f.o.e. and for developing countries is 1.8 f.o.e. Only some oil-exporting developing countries have lower per capita consumption than Jamaica, which enjoys about 8 Bbl f.o.e. per capita.

Because of the Venezuela/Mexico Accord of 1981, Jamaica is importing crude oil from Mexico and Venezuela and continues to import from Curacao, Trinidad and Aruba. While volumes of imported oil have not varied much, there has been a steady

The Caribbean Development Bank sponsored the author's participation at the Biomass Workshop.

and overwhelming increase in costs. Thus 16.1×10^6 Bbls oil imported into Jamaica cost J\$44 $\times 10^6$ in 1972, J\$331 $\times 10^6$ in 1978 and J\$1028 $\times 10^6$ in 1981. Petroleum consumption by sector in 1980 is reflected in the following table.

TABLE 1
PETROLEUM CONSUMPTION BY SECTOR

SECTOR	VOLUME ($\times 10^3$ Bbls)	Percent
Aviation	765	4.92
Bunkers	236	1.52
Bauxite/Aluminum	8234	52.93
Sugar	145	0.93
J.P.S*	2681	17.24
Cement	195	1.25
J.O.S*	55	0.35
Railways	23	0.15
Others	3221	20.71
TOTAL	15,555	100.00

*J.P.S. - Jamaica Public Service Company (Electricity)

J.O.S. - Jamaica Omnibus Service Company

In 1980 the Jamaica Public Service Company used 2.47×10^6 Bbls fuel oil and 0.21×10^6 Bbls automotive diesel oil to produce a net electricity generation of 1.27×10^9 kwh. In the same year the sugar factories used 145×10^3 Bbls fuel oil to produce 242×10^3 tons of sugar.

The above facts indicate that the present situation must be changed if Jamaica is to proceed with its development. This is so as there is a close relationship between energy consumption and economic growth. Jamaica, like many other countries, can no longer base patterns of scientific, technological, industrial and economic expansion on the availability of abundant, cheap petroleum. The question is, where does Jamaica turn for its energy source?

BIOMASS - A POTENTIAL SOURCE?

The first attempt which parallels the search for oil and gas is the quantification of all resources which can provide an alternative to imported petroleum. Of great importance also is Jamaica's focus on conservation, which can result in a saving of 10 to 15 percent of fuel costs.

Highest priority should be given to the exploration of such quantified resources which reflect:

- a) availability of cheap technology, especially where the use of local material is possible;
- b) possibilities for low operational and maintenance costs;
- c) abundance and "renewability" of the resource;
- d) minimum scarce skills requirement and maximum use of technological know-how which already exists on the island or which can form the base for rapid modernization or transference of more efficient techniques;
- e) optimization of foreign to local expenditure ratio, so that the former is kept as low as possible;
- f) non-competition for food, especially protein;
- g) optimal protection or preservation of terrestrial, aquatic and atmospheric environment (in a benefit ratio).

Based on the above criteria, the high priority and short term options for Jamaica lie in exploitation of its small-scale hydro, bio- and low-cost solar, wind, urban and industrial waste potential.

In the medium term Jamaica can plan for the best use of its proven peat resources, while in the medium to long term the development of such potentials as OTEC, large-scale hydro, solar and geothermal resources can be pursued. This, of course, assumes that the country persists with its avid search for oil and gas. However, it must be realized that even if the finding of commercially viable quantities of oil becomes a reality, the use of this potential will still decrease in the medium to long term.

A projection of possible diversification of the energy supply mix by 1990 is shown below:

TABLE 2
PERCENTAGE NATIONAL ENERGY SUPPLY MIX

SOURCE	1975	1980(%)	PROJECTED 1990 (%)
Oil	90	91.1	71.0
Coal	-	-	8.0 (if feasible)
Peat	-	-	8.0
Bioenergy	9.0	7.5	9.5 (Conservative)
Bagasse	8.7	6.8	2.0
Other*	0.3	0.7	2.0
Hydro	1	1.4	2.0
Solar**	Minimal	Minimal	1.0
OTEC	-	-	0.5

* Estimates - Includes wood and charcoal currently used, and fuel alcohol, urban wastes, biogas, etc. projected.

** Includes low and high temperature solar for crop drying, water heating, electricity generation and cooling.

The evidence is that at least another 2 percent of the energy bill could be reduced if focus within the next five years is placed on development of Jamaica's bio-resource potential for energy. Even if the oil bill were to level off over this period, a somewhat optimistic assumption, there would be a few million dollars available for diversion to other needs. It is also important to note that conversion of bio-resources to energy, even though of limited impact, is of value to improve the life styles of the population and the expansion of industry in the rural areas.

There is growing attention to bio-energy usage in developed countries which have implemented programs a) to improve productivity of plants that could be used for fuel, b) to increase efficiency with which plant matter can be converted to liquid and gaseous fuels, and c) to develop improve methods of converting solid bio-fuels.

The Ministry of Mining and Energy in Jamaica embarked on a program in March, 1981, to quantify all the biomass resources on the island. The project summary, an outline of the framework within which the survey was conducted, and an abstract of the first report are attached to this paper. (See Appendix)

In August 1981, the status of biomass utilization and bio-conversion technologies existing in Jamaica was assessed. The most significant users of biomass were the rural and low-income urban household sector (firewood and charcoal) and the sugar industry (bagasse). At the end of the first phase of the survey, there were indications for research and developmental work aimed at harnessing other biomass resources such as crop and forestry residues, urban wastes, agro-industrial wastes and animal manures for energy.

TABLE 3
CURRENT BIOMASS UTILIZATION IN JAMAICA

<u>LOCATION</u>	<u>FEEDSTOCK</u>	<u>TECHNOLOGY</u>	<u>CAPACITY/ QUANTITY</u>	<u>STATUS*</u>
14 Units throughout the island	Animal Manure	Anaerobic Digestion	6 - 67m ³ more potential quantified	13 - 0 1 - I
Rural and Urban Factory	Crop Residues and Surpluses	Fermentation Digestion	Not available	P
Field and Factory Sites Islandwide	Woody Residues	Direct Combustion Gasification	Over 24x10 ³ yearly potential	P&D
Agro-Industries Urban and Rural: 12 Sugar Factories Island- wide	Bagasse	Direct Combustion	Approx. 1.3x10 ³ Tons/year	0
Other-Urban and Rural	Food Processing By-Products	Fermentation Anaerobic Digestion	Over 8x10 ³ T/Yr. Potential	P
Urban areas	Municipal Solid Waste (Carbon- based)	Direct Combustion	Approx. 3x10 ⁵ Tons yearly potential	P
Islandwide	Sewage Sludge	Anaerobic Digestion	3x10 ³ T/Yr. potential	P
Mostly Coastal	Aquatic Plants	Digestion	N/A	P

* STATUS - P = Planning; D = Design; C = Combustion; O = Operation; I = Inactive.

The move to realize the maximum potential from biomass in Jamaica should be accelerated subsequent to the articulation of certain policy decisions concerning exploration of bio-resources in Jamaica, reliable technical economic feasibility studies, and valid research and development in converting the wide variety of feedstocks available or the extraction of fuels from energy crops.

Finally, it must be realized that the value of biomass conversion lies not only in the energy end product, but also in a wide range of by-products usable for feeds/foods, fertilizers and fibres.

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APPENDIX I-A

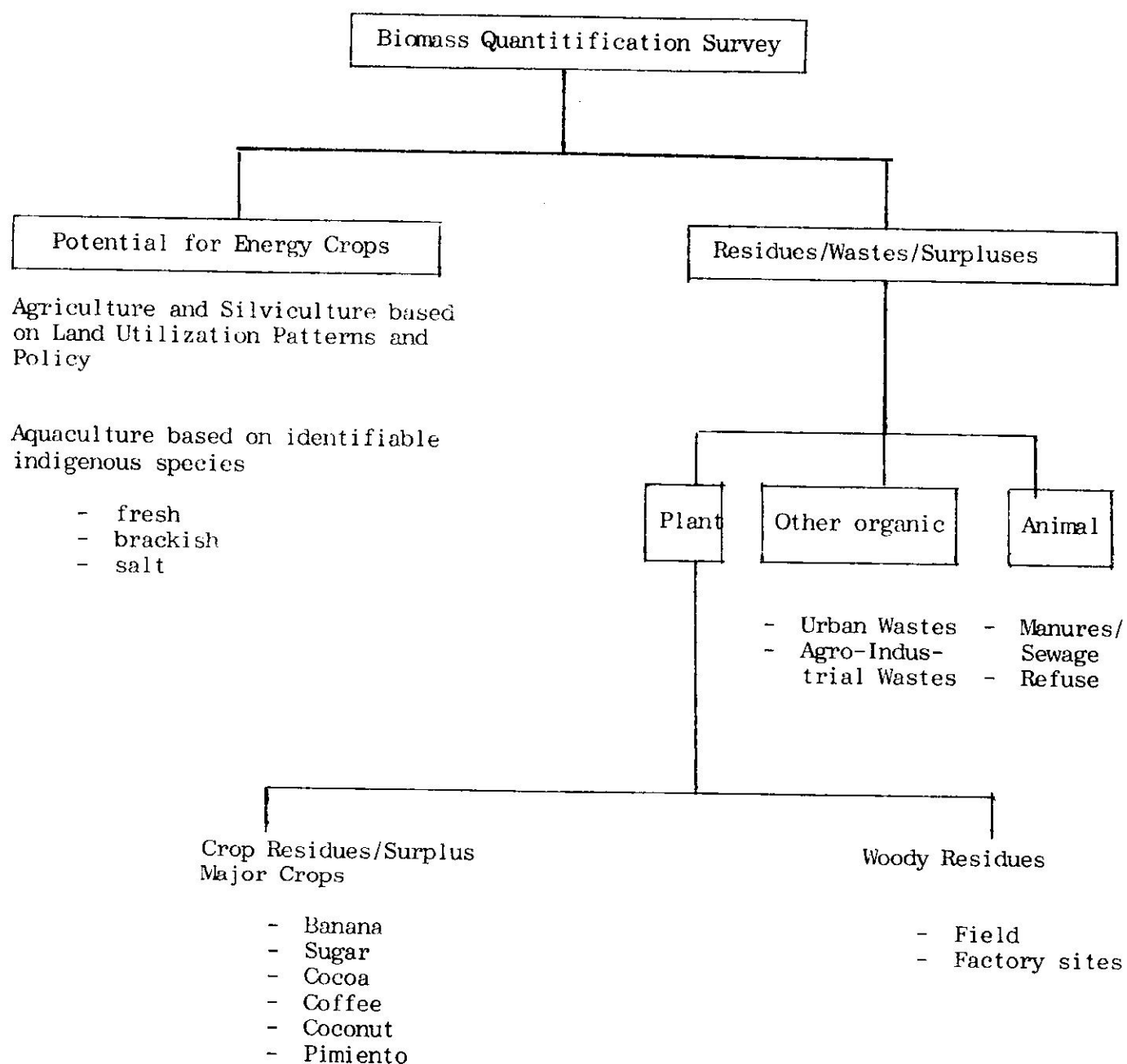
OUTLINE OF BIO-RESOURCE ACTIVITY

- PROJECT: Biomass Survey - Islandwide.
- EXECUTING AGENCY: Ministry of Mining and Energy, Energy Division
- AIM:
1. Collection, Collation and Analysis of data required for the quantification of Biomass Resources in Jamaica which have potential for conversion to utility (Residential and Industrial) and transportation fuels.
 2. Development of a Scenario of Options for Biomass Utilization for energy in Jamaica.
- DESCRIPTION:
- Phase I (a) Identification of Types of Biomass resources in the Island, Location and Quantity of each type which is available for energy.
- Phase I (b) Optimization of Biomass Conversion Technology for particular resources identified, taking into account nature, quantity, location and demands of particular sector. Estimation of present, future demands for By-products of Biomass Conversion Technology eg. Feeds, Fertilizers, Fibres and other chemicals.
- Phase II Planning and execution of experimental and developmental (pilot) projects on a small scale to demonstrate effectiveness of the processes and validate them to private and public sector institutions in the society.
- JUSTIFICATION: No previous overall assessment of Biomass sources of energy has been done in Jamaica. This is a necessary prerequisite for the formulation of a range of policy options for harnessing and converting particular biomass resources for specific fuel end uses. Such policies would set the framework within which business ventures proposing to use these resources would be assessed, as well as guide government investment or encourage-

ment support to local private sector in
projects which will use these resources.

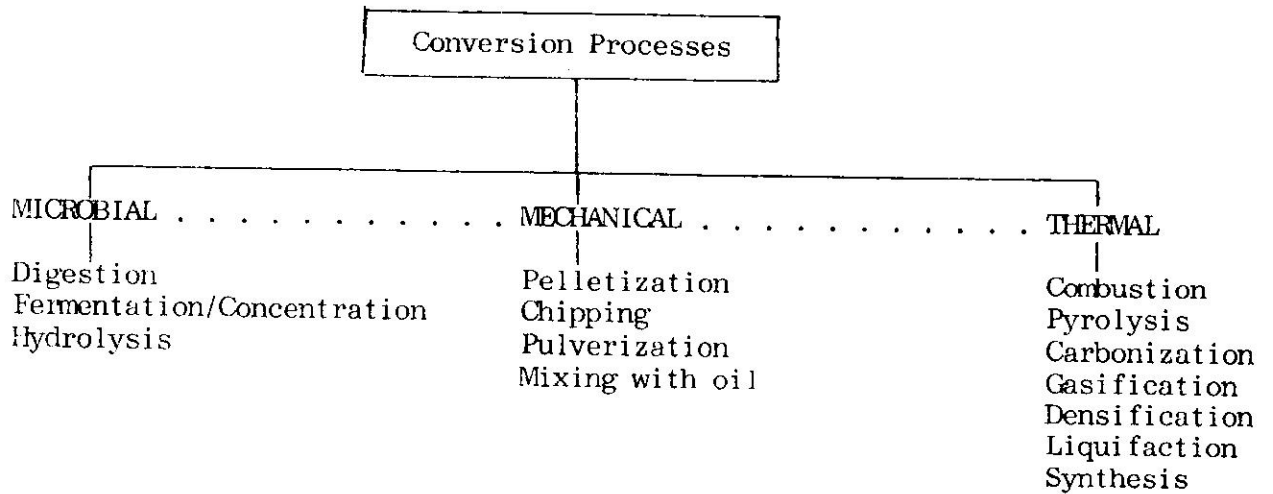
TOTAL ESTIMATED
COST:

Phase I - Year I - J\$20,000.00
Phase II- Year II- J\$60,000.00



An additional survey was conducted on a small sample, in order to verify certain patterns of charcoal and fuel wood consumption implied in the results of the Household Sector Survey in 1979, and to indicate current and future trends in Biomass fuel (Charcoal and fuelwood) supply/demand patterns.

Phase 1(b) - Assessment of Conversion Technology available for converting biomass to energy was carried out under the following headings:



Based on -

- a) i) assessments of the State of the art with respect to the above processess
- b) ii) location and quantities of specific bio-resources identified
- c) iii) assessment of demand of products and co-products in each sector
- d) iv) implications for collection, transport and storage of raw materials and co-products
- e) v) availability of skills, equipment and materials to effect or adapt the technology.

A scenario of options for Bio-resource utilization in Jamaica was constructed.

BIOMASS SURVEY
MINISTRY OF MINING AND ENERGY, JAMAICA

SUMMARY

Phase 1 of the Ministry of Mining and Energy's Biomass quantification survey, which began in March 1981, has now been completed.

The islandwide survey was carried out with a view to determining the types, location and quantities of biomass resources with potential for conversion to utility and transportation fuels. The first phase was divided into two parts, the identification and quantification of Biomass resources and the optimization of biomass conversion technology. The survey results show that plant and animal residues and surpluses as well as other organic wastes constitute the largest percentage of fermentable and combustible sources of energy in Jamaica.

It is estimated that manure from cattle, pigs and poultry has the potential to supply over 800 million Kwh per year. Another interesting estimate is that local sewage can supply some 40 million Kwh per year.

In addition, large quantities of crops residues and surpluses exist in Jamaica. Banana prepared for export for example, has a rejection rate of 70 percent and of that 20 percent is completely wasted. Cocoa pods, pimento residue and coffee husks all amount to quite substantial wastes that could be productively used for fuel. The survey also showed that thousands of existing coconut trees, unsuitable for lumber because of their decayed condition, could be used for fuel.

Although there are relatively small quantities of residues from vegetable, root and fruit crops, these could be used in bio-gas digesters as it has been found that the combustion of vegetable and animal feedstock enhances yields of biogas (in conjunction with other factors such as optimal temperature and pressure).

Large quantities of woody residues with considerable fuel potential are also wasted both in the field and at the factory sites. Estimates show that upward of 1,000 tons of woody residues from factories and workshops are wasted every year.

The survey also indicated that, as far as charcoal and fuel-wood consumption is concerned, unless serious attention is paid to a re-forestation program, the situation will become critical in a few years time, especially if the nation takes the call to use more bio-fuels seriously and increases the demand.

Phase I of the survey also involved an assessment of conversion technology available for obtaining energy from biomass. The processes fall under three main headings

- a) Microbial Conversion; eg. Fermentation and digestion,
- b) Thermal Conversion; eg. pyrolysis and gasification and
- c) Mechanical Conversion; eg. densification

Phase II of the survey will begin in April of this year and will involve the planning and execution of small scale experimental and developmental projects to demonstrate the effectiveness of the various processes and validate them to private and public sector institutions in the society.

ALCOHOL FUELS FROM AN INTEGRATED BIOMASS
SYSTEM: TECHNOLOGY AND ECONOMICS

Presented at

UNICA WORKSHOP ON BIOMASS AS AN
ENERGY ALTERNATIVE FOR THE CARIBBEAN

San Juan, Puerto Rico
April 28-29, 1982

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United States, Virgin Islands

INTRODUCTION

In 1980 the Caribbean Research Institute began a project to determine the feasibility of using food and agricultural waste provided by farmers or cooperatives to produce alcohol fuels. A special small scale fermenter and still was developed for this purpose. To make the system more energy effective, a condensing solar panel was added for preheating the beer and the steam feed water. This project worked to the extent that fuel could be produced for \$.86 a gallon and could be used by farmers or cooperatives. It was evident that a larger cooperative could make use of a continuous fermenter, a stock-pile and materials, and could add both flexibility and efficiency in using or marketing many of the side products.

To develop this idea further, the Institute postulated a hypothetical farm cooperative with about \$38 million in assets and a desire to get into the biomass fuel/by-products field. The hypothetical cooperative was located on an imaginary Caribbean island that, frankly, was modeled after St. Croix, U.S. Virgin Islands. It had suitable land and shipping, tax incentives, and some industrial structure.

The feedstocks considered were molasses, grain (corn or sorghum), and a combination. Ethanol versus butanol production and the use and price of by-products such as carbon dioxide gas (CO_2), hydrogen (H_2), distillers dry solids (DDS), and chemicals such as acetone, acetic acid and formaldehyde were also evaluated.

Since this was designed to operate in a smaller, less developed area, high production levels for a single product were sacrificed for the stability of several products with interlocking feed-back loops. This formed the basis for the model.

DATA AND RESULTS

A 25 gallon a day alcohol system costing \$3,000 and using "free" agricultural wastes (spoiled cattle feed, yams, and cassava) can produce ethanol for \$.86 per gallon using solar pre-heating. The limiting factors were feedstock availability and the lack of continuous fermenting equipment. It would take one or two weeks for a small farmer to get enough waste for 25 gallons of fuel. More than economics and technology are required to make the proposition work; stability and diversity must also be present.

ALCOHOL PROPERTIES

The basic properties of the most important alcohols are summarized here. The following classes of properties are presented:

- . Physiochemical properties
- . Fuel properties
- . Economics of production

The physiochemical properties are basic information available in all chemistry handbooks. The tabular form of presentation allows rapid comparison among the alcohols of different chain lengths. The fuel properties are a mixture of information on heat content, ignition temperature, and the like. For comparison purposes, note that available information has been presented for isooctane (gasoline). The rationale for isooctane (gasoline) is obvious since it is a fuel replaceable partially or totally by alcohols.

Ethyl alcohol (Ethanol)

Ethanol is the second smallest of the alcohols in molecular weight. It is almost explosively volatile and flammable. Because of its thousands of years record in drug abuse, it is one of the most rigidly controlled substances, largely because of the revenues generated by its users. For these reasons and because of the early advent of cheap and abundant hydrocarbon fuels, ethanol fuel production was shelved for many years.

Ethanol vaporizes at 78.4°C and is infinitely soluble in water. The difference between the boiling points of water and ethanol are so great that this has been a traditional method for separating mixtures of the two. Because of its "waterlike" polarized chemical character, it has a limited solubility in oil or gasoline if any water is present.

The energy value of ethanol is about 73.4 to 84.0 Btu per gallon compared 115 to 124 KBtu per gallon for gasoline. However, the octane ratings are about 99 for ethanol and 90 for gasoline and 9 for ethanol. This means that a well-tuned engine can get within acceptable limits of efficiency using ethanol.

There is no lubrication capacity in ethanol, and so oil must freely reach all parts. The octane and Btu rating is too low for efficient diesel operation. In addition, two cycle motors cannot use ethanol without complex schemes to add oil. These and other factors make it advisable to look at other alcohols and processes.

Coproducts. Stillage, the residue of fermentation and distillation in the production of ethanol, contains many nutritive elements. This is particularly true of grain stillage which has been used as an animal feed or feed supplement for years. Marketing these coproducts is essential to the economics of ethanol production.

Fresh stillage is a mixture of various nutrients dissolved or suspended in water. It can be fed directly to animals but is not tolerated in large quantities because of the limited capacity for water intake by cattle and other animals. Fresh stillage also degrades rapidly, particularly in warm climates, and disposing of the stillage output of a commercial plant will result in a complex distribution problem. Fresh stillage can be concentrated or dried. In this way, the product can be stored and shipped, making marketing easier and more predictable.

Market for Coproducts. The total market includes oilseed, animal protein, and other mill products. As a point of reference, a 50-million gallon ethanol plant will produce about 177,000 tons of DDG per year, i.e., about 45 percent of the 1976 market for that commodity. A 600-million-gallon ethanol program, a near-term objective in the United States, will produce almost two million tons of DDG, or about seven percent of the total 1976 feedmarket and about five times the amount of DDG sold in the United States in 1976. In the 1963 to 1976 period, the domestic market for all animal feeds increased at an average rate of about 1.2 percent annually. The market for soybean meal (with which DDG is more directly competing) expanded at a rate of about 3.5 percent over that period. This expansion was not quite sufficient to absorb the expanded fuel production. Some substitution between DDG and soybean may take place and, as a result, some readjustment of agricultural production patterns will probably take place as the demand for corn feedstock increases.

Ethanol as a Fuel and as a Chemical. Ethanol may be used in various forms for fuel:

- . As a blend with gasoline in various proportions.
- . As hydrated lower-proof ethanol.
- . As neat anhydrous ethanol.
- . As fuel supplement in dual-carbureted diesel engines.

TABLE 1

PHYSICOCHEMICAL PROPERTIES

Name	Formula	Molecular Weight	Specific Gravity	Boiling Point	Vapor Density (Air=1)	Vapor Pressure (mm Hg)	Solubility in water	Flash point
*Methyl Alcohol (Methanol)	CH_3OH	32.042	0.792 (20°/4°C)	64.5°C	1.11	160 (30°C) 125 (25 C)		54°F
*Ethyl Alcohol (Ethanol)	$\text{C}_2\text{H}_5\text{OH}$	46.070	0.7904 (20/20°C)	78.4°C	1.59	50 (252°C)		57°F
n-Propyl Alcohol (Propane-1)	$\begin{array}{l} \text{CH}_3 \\ \\ \text{CH}_2 \\ \\ \text{OH} \end{array}$	60.097	0.804 (20/4 °C)	97.3°C	20.8	20.8 (25°C)		59°F
Isopropyl Alcohol (Propano1-2)	$\begin{array}{l} \text{CH}_3 \\ \\ \text{CH} \\ \\ \text{CH}_2 \\ \\ \text{OH} \end{array}$	60.097	0.7874 (20/4°C)	82.4°C	2.08	44 (25°C)		53°F
Iso-Butyl Alcohol	$\begin{array}{l} (\text{CH}_3)_2\text{CH} \\ \\ \text{CH}_2 \\ \\ \text{OH} \end{array}$	74.124	0.8032 (20/20°C)	108°C	2.56	12.2 (25°C)	102 (20°C)	82°F
Tert-Butyl Alcohol	$(\text{CH}_3)_3\text{COH}$	74.124	0.783 (25/25°C)	82.4°C	2.56	42.0 (25°C)		52°F

TABLE 1 (Cont.)

Name	Formula	Molecular Weight	Specific Gravity	Boiling Water	Vapor Density (Air-L)	Vapor Pressure (mm Hg)	Solubility in water	Flash Point
Ammonia	NH ₃	17.03		33 35°C	0.59		901 0°C	
** Hydrogen	H ₂	1.007 97	0.070 (-252°C)	-252 5°C				
* Iso-Octane	C ₈ H ₁₈	114.224	0.696.3 (110/10°C)	N 99°C	3.94	388.31 (100°C)		
Reference	1	1	1	1	1	1	1	1

* Most likely combustion fuels.

** "Fuel cell" fuel-
by product of n-
butanol production

x gasoline

Ethanol also is used as a chemical in the perfume and pharmaceutical industries. Each of these potential markets for ethanol has some constraints which bear on the decision making process of producing ethanol. Some of these constraints result from the differences in the properties of fuel ethanol compared to petroleum based fuels now used.

TABLE 2
COMPARISON OF PROPERTIES

PROPERTY	GASOLINE	ETHANOL	NO. 1 DIESEL
Molecular Weight	126	46	170
Heating Value			
Higher (Btu/lb)	20,260	12,800	19,240
Lower (Btu/lb)	18,900	11,500	18,250
Lower (Btu/gal)	116,485	76,152	133,332
Latent Heat of Vaporization			
(Btu. lb)	142	361	115
Research Octane	85.94	106	
Motor Octane	77.86	89	10.30
Stoichiometric Air/Fuel			
Ratio	14.7	9.0	
Flammability Limits			
(Volumen Percent)	1.4 to 7.6	3.3 to 19	

Butyl Alcohols

The four monohydric butyl alcohols are: n-butyl alcohol, isobutyl alcohol, sec-butyl alcohol, and tert-butyl alcohol.

Five methods for the production of n-butyl alcohol are:

(1) fermentation, (2) a process based on aldol, (3) the oxo process, (4) as a by-product in the high pressure oxidation of propane and butane, and (5) the Ziegler process.

The fermentation process operates on a carbohydrate mash with the action of the bacteria Clostridium saccharobutyl acetonicum liquefaciens or C. aceto-butylarium. After 36 to 48 hours of fermentation and subsequent distillation, this process yields a 30 percent by weight return of 60 percent n-butyl alcohol, 30 percent acetone, and 10 percent ethanol. Vacuum removal of the acetone during fermentation may increase the butanol yield, as acetone is the main toxin for the bacteria.

The aldol process utilizes either ethyl alcohol or acetylene as a raw material with crotonaldehyde appearing as a chemical intermediate. The yield in this process is about 85 percent of the theoretical.

The butane-propane oxidation process is a Fischer-Tropsch process.

The Ziegler process was commercially developed by the Continental Oil Company in 1962 for the production of even-numbered carbon alcohol. N-butyl alcohol as a C₄ alcohol is at the lower end of this production and could be considered a by-product.

Isobutyl alcohol is derived primarily as a by-product in high pressure methanol synthesis. However, some isobutyl alcohol can be recovered in the Fischer-Tropsch oxidation process for the

production of acetaldehyde using butane or propane as a feedstock. Isobutyl alcohol also is a major component; 74 percent in molasses and 12 to 24 percent in corn, of the alcohols present in fusel oil resulting from the fermentation process. Its major use is as isobutyl acetate in the lacquer industry.

To form sec-butyl alcohol, butylene is absorbed by sulfuric acid, forming butyl hydrogen sulfate which is reacted with steam. Its principal use is as chemical intermediate to the production of methyl ethyl ketone, a solvent. Secbutyl alcohol is also used as a solvent and a coupling agent in hydraulic brake fluids, paint removers and industrial cleaning compounds.

The majority of tert-butyl alcohol is produced in a fashion similar to that of sec-butyl alcohol, but isobutylene is used as a feedstock instead of butylene. Isobutylene is absorbed by sulfuric acid forming isobutyl sulfate which is steamed to form tert-butyl alcohol.

Tert-butyl alcohol is very miscible with many organic compounds and becomes useful as a blending agent. Some of the uses of this alcohol are as follows: as a selective solvent and extraction agent in the drug industry; for the removal of water from compounds and substances; in the manufacture of perfumes (artificial musk); in the purification of chemicals by recrystallization; and as a chemical intermediate. Tert-butyl alcohol is an authorized denaturant for proprietary ethyl alcohol and for specially denatured alcohols.

Whereas all the alcohols mentioned to this point have the same physical appearance, tert-butyl alcohol has a freezing point close to room temperature and in a pure state often appears in crystalline form.

The basic problem with the butanol fermentation is the production of mixed solvents (butanol, ethanol, and acetone), the low solvent concentration (around 2.2 percent) requiring considerable energy for separation and purification of the products, and the low yield (around 34 gm solvent/100 gm fermentable sugar). The problem of mixed solvents can be partially solved by selecting mutants with little or no acetone producing activity. The concentration problem might be overcome by simultaneously performing an extractive separation while fermenting, thus removing the toxic end product. However, economics will control this possible production from sugar. Therefore, only a 28 percent improvement is theoretically possible. To achieve this the H_2 produced must be recycled to insure the full efficiency. It seems obvious that improving product concentration, possibly through extractive fermentation, may be the most promising development to pursue in the butanol area.

The fusel oil fraction represents only about 1.5 percent of the alcohol production. Therefore, it is not a significant factor in cost reduction. In fact it is not an oil but a mixture of propyl, amyl, and butyl alcohols. Most investigators suggest that it not be recovered; rather, savings could be taken by utilizing a two-column distillation system and letting the fusel oils go over in the alcohol product. This may be all right for fuel grade alcohol; however, this point needs to be tested. It should be noted that additives such as tert-butyl alcohol have been used because of their energy content. "Fusel oils" make a good diesel fuel and were approved recently by the EPA. However, for industrial or spirits grade alcohol, the fusel oil must be recovered.

Acetic Acid

Acetic acid as such cannot be considered as a liquid fuel but is an important chemical building block in organic synthesis. The two major uses for it are as vinyl acetate (latex paints, plastics and

adhesives), and acetic anhydride (cellulose acetate, esters, solvents).

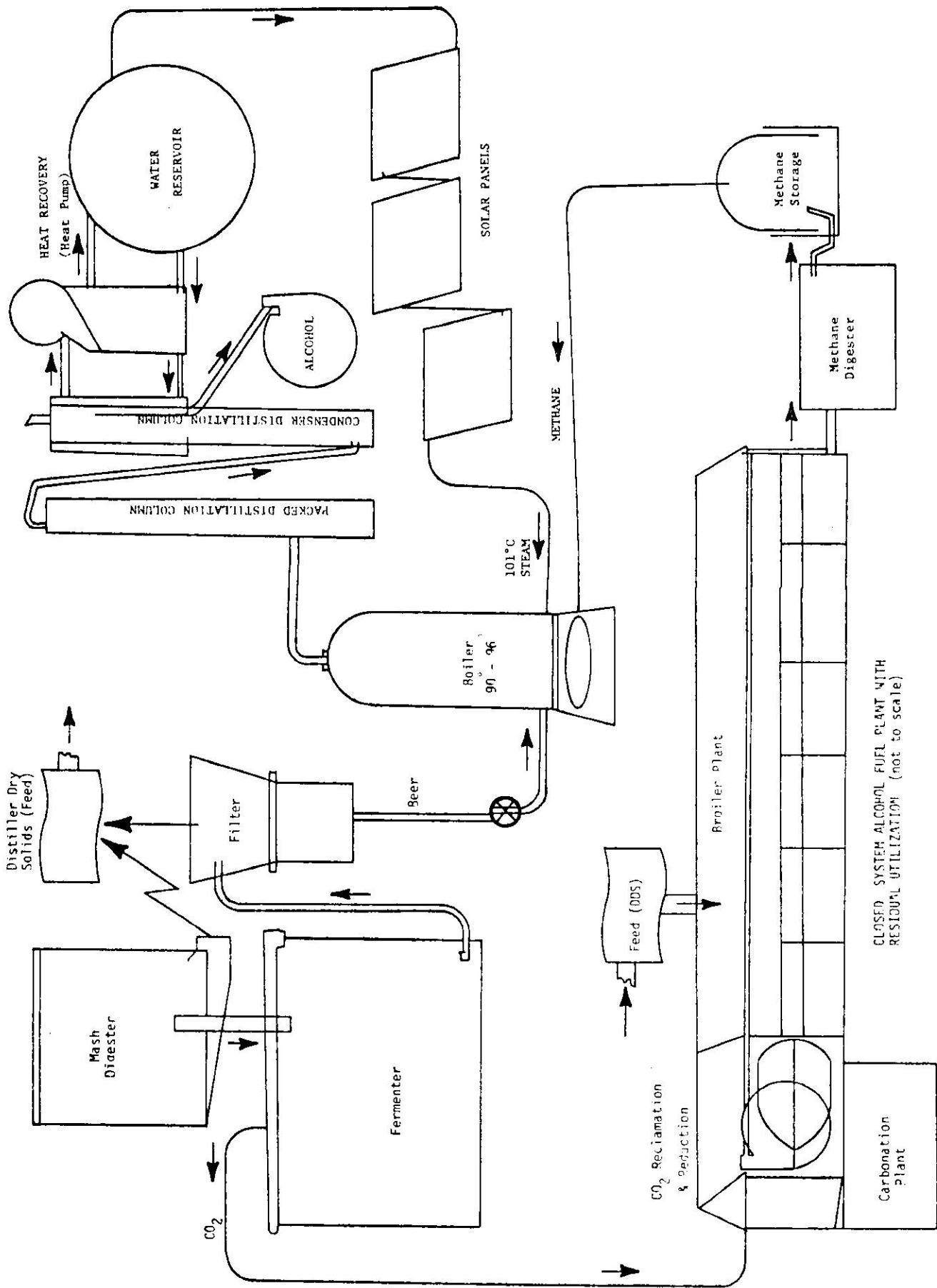
Total acetic acid production in the USA was around 3.0 billion pounds in 1974, representing about 50 percent of total world production.

Table 3 summarizes and Figure 1 pictures the different processes presently used for its production. Note the following points:

- (1) Practically all acetic acid is produced from petroleum.
- (2) Oxidation of gases, ethylene and butane, have been the major routes used.
- (3) Methanol carbonylation is based on natural gas chemistry; hence, future coal gasification processes may be applied profitably. Besides, this process has a relatively lower unit investment, is independent from slower-growing co-products markets and is based on the lowest cost fuel sources. For these reasons, this process accounts for most major new capacity.

In Figure 2 the various alternatives for acetic acid production from biomass are illustrated. There are two distinct possibilities:

- (1) Biological process (fermentation)
- (2) Thermochemical conversions (pyrolysis)



CLOSED SYSTEM ALCOHOL FUEL PLANT WITH RESOURCE UTILIZATION (not to scale)

TABLE 3
COMMERCIAL ACETIC ACID PROCESS IN THE USA

Process	Company	Annual Name Plate Capacity M pounds	Catalyst	Temperature (°C)	Pressure (Psih)	Process yields to acetic 1%	Recovered by product
a) n-butane liquid phase	Celanese	550	Cobalt acetate	150-225	800	57	Acetaldehyde
Oxidation (LPO)	Union Carbide	680					
b) ethylend liquid phase Celanese		510					
oxidation LPO via acetaldehyde	Eastman	400					
Wacher/Farbwerke Hoechst							
2.1) ethylene to acetaldehyde			Palladium/copper chlorides	125-130	150	95	None
2.2) acetaldehyde to acetid acid			Manganese acetate	66	0	95	None
c) methanol carbonylation	Borden	115	Cobaltous iodide	210-250	7,000	59-87	None
BASF/Monsanto	Monsanto	315	Rhodium Iodide	175-245	220	90-99	None
d) ethanol fermentation	Publicker	80					
e) byproducts in glycerine production	FMC	40					

ECONOMY OF ALCOHOL PRODUCTION

Table 4 shows current market prices of the various alcohols (along with calculated equivalent costs/ 10^6 BTU) as obtained from the November 17, 1978 issue of Chemical Marketing Reporter.

TABLE 4
CURRENT MARKET PRICES FOR ALCOHOLS

ALCOHOL	CURRENT MARKET PRICE	CURRENT PRICE/ 10^6 BTU
Methanol	38 - 49 / gallon	\$ 5.99 - 7.72
Ethanol	\$1.04 - 1.14 gallon	\$12.29 - 13.47
n-Propyl Alcohol	\$1.87/gallon	\$16.98
Isopropyl Alcohol	63 - 70 /gallon	\$ 6.93 - 7.70
n-Butyl Alcohol	\$1.25 - 1.69/gallon	\$11.95 - 15.18
Isobutyl Alcohol	\$1.27 - 1.67/gallon	\$10/42 - 14.39
Sec-Butyl Alcohol	\$1.43/gallon	\$13.72
Tert-butyl Alcohol	\$1.75/gallon	\$17.34

TABLE 5
 BASE RAW MATERIAL AND BY-PRODUCT PRICES IN 1980 DOLLARS

<u>Item</u>	<u>Prices</u>
<u>Raw Material</u>	
Corn	\$3.50/bu
Grain Sorghum	\$2.80/bu
Wheat	\$3.85/bu
Potatoes	\$20/T
Sugar beets	\$30/T
Beet molasses	\$.36/gal
Starch	\$.08/lb
<u>By-products</u>	
Corn distillers dried grain	\$120/T
Sorghum distillers dried grain	\$120/T
Wheat distillers dried grain	\$120/T
Potato distillers by-product	\$6/T
Sugar beet distillers by-product	\$98/T
Molasses stillage	\$18/T
Starch stillage	0
CO ₂ (atm)	\$3./100#
H ₂	\$5./100#

TABLE 6
NET RAW MATERIAL COST IN 1980 DOLLARS

Item	Units	Corn	Grain Sorghum	Wheat	Cull Potatoes	Sugar beets	Starch	Molasses
Raw Material price	dollars	3.50/bu	2.80/bu	3.85/bu	20/T	30/T	.80/l	.36/gal
<u>Conversion</u>	gal/ethanol	2.8/bu	2.80/bu	2.8/T	28.8/T	25.3/T	.66	.4/gal
Unit raw material cost	\$/gal ethanol	1.06	.98	1.39	.79	1.38	1.20	1.00
By-product price	dollars	120/T	120/T	120/T	8/T ^{1/}	95/T	0	\$15/T
<u>Conversion</u>	lbs by-product	16.8/bu	16.8/bu	20.7/bu	296#/T	264#/T		15.6/gal ^{1/}
Unit by product credit	\$/gal ethanol	.36	.36	.44	.03	.60	0	0.12
Net raw material cost	\$/gal ethanol	.80	.62	.95	.66	.78	1.20	1.12

^{1/} Potato and potato distillers by-product 75 percent moisture.

Source: DPRR estimate

By-Product Credits

The possible by-products from these processes are numerous. Possibilities include CO_2 or H_2 , animal feed, lignin, fuel credit solids, pentoses (xylose), furfural, and fusel oil.

The CO_2 is produced in quantities of roughly one pound per pound of ethanol in a relatively pure by-product stream. At the present time, there is no industrial use for this CO_2 in the volume it would be manufactured. Possible future uses include industrial gases, dry ice, carbonation of beer or drinks, and as a supplement to increase green house production.

Of all the by-products, the animal feed derived from the dried distillers solids has the greatest potential. DDS is comparable to, and is a market substitute for, soybean or fish protein. In large volumes this product could shift the protein concentrate market from elastic to nonelastic. There is also a possibility of extracting the solids in order to recover a high quality of human protein. In the short term the use of the solids for animal feed is the most realistic as this is current practice and needs no testing. If alcohol fuel were to become a serious proposition, over 100 plants of greater than 25,000,000 gallon capacity each would be required. Such a capacity could yield 2 - 5 million tons of high protein animal feed per year. This would be a significant by-product, and research is needed to establish its economic feasibility.

The unfermented solids consist largely of lignin materials. Lignin has nearly twice the energy content of cellulose and hemicellulose. Present technology envisions burning the solids for fuel value in the process. Research is warranted on ways to convert the lignin to liquid fuels or chemical feedstock; alcohol solubilized lignin, fractionation of lignin to yield a polymer grade material, and conversion of lignin to phenolics are a possibilities.

By-Product Prices

A distillers dried grain base price of \$110 per ton for corn, sorghum, and wheat distillers dried grain was used for the estimate. This price was based on the average prices for corn distillers dried grains at Cincinnati which ranged from \$89.56 to \$139.22 per ton and averaged \$110 per ton in terms of 1977 dollars over the period. Typically, distillers dried grain at Cincinnati trades in the range of 60-85 percent of soybean meal (44 percent protein) at Decatur. Distillers dried grains have a total protein content of about 27 percent which makes them a substitute high protein feed for certain livestock, principally beef and dairy cattle.

The following distillers dried grain price forecasting equation has been estimated by Wisner and Gider (1977) 1/:DDG =

$$3,3325 - 0.022227 (DDG_s) + 0.265566 (SBM_p) + 0.148753 (C_p) + 0.518949 (EC_n)$$

(-3.21) (12.81) (2.92) (1.98)

where:

DDG_p = Distillers dried grain price in dollars per ton at Cincinnati

DDG_s = U.S. distillers dried grains supply in thousands of tons.

SBM_p = Price of 44% protein soybean meal in dollars per ton at Decatur

C_p = Corn price in cents per bushel

EC_n = Cattle numbers in five major European protein feed importing countries

1/ Wisner, R.N. and J.O. Gidel, "Economic Aspects of Using Grain Alcohol as a Motor Fuel, With, With Emphasis on By-product Feed Markets." Iowa State University, Economic Report Series No. 9, Appendix IV, June 1977.

This equation indicated an elastic demand for distillers dried grains; a given percentage increase in supply could be sold with a lesser percent decrease in price. The equation also shows a direct price relationship between distillers dried grain and 1) soybean meal, 2) corn prices, and 3) cattle numbers in five major Euro-

pean protein feed importing countries. It is important to note that this statistically estimated price forecasting equation is based on historic data with distillers dried protein feed sources available in the U.S. If distillers dried production increased so that it represented a significant proportion of total high protein feeds available, then the demand price relationship would become price inelastic: a large percentage price decrease would be required to clear the market. Under such conditions by-product credits to net ethanol production costs would decrease and the price and production of substitute feeds such as soybean meal would also decrease. The price impact of increased distillers dried grain production would depend largely on the extent and timing of an ethanol industry growth. The larger the industry, the greater the related price impacts. Price data were not found specifically for wheat and grain sorghum distillers dried grains. It may be possible that slight price differences can result when nutrient contents vary among the by-products of different raw material grains.

TABLE 7

ANHYDROUS ETHANOL PRODUCTION FROM SWEET SORGHUM (20,000,000 GPY) 330 DAYS/YEAR

<u>Capital Required</u>	\$37,000,000		
Borrowed Capital (25% assumed)	\$9,300,000		
Investment Capital	\$28,700,000		
<u>Production Cost</u>		<u>\$/yr</u>	<u>\$/gal</u>
Sweet sorghum at \$210/acre (1.813 MM tons/yr) 26.94 tons/acre		\$14,141,221	\$0.60
Labor (Including benefits at 20% (12 men/shift + 9mgmt Services)		1,200,500	0.05
Chemicals		253,000	0.01
Process Water at \$1.50/Mgal		330,000	0.03
Cooling Water at \$1.50/Mgal		182,000	0.03
Power (plant generated)		--	--
Fuel		1,425,000	.06
Insurance (2% TFC)		749,200	.03
Maintenance (4% TFC)		1,498,000	.06
Depreciation (20 yrs.)		2,181,111	.10
Interest (10% - 10 yrs.)		550,000	.03
Interest on Start up and Work. Capital (12% - 10 yrs)		576,734	.02
		<u>Total Production Cost</u>	<u>1.01</u>
Income at \$1.50/gal (include product credits)		30,000,000	1.50
Gross Profit (before tax at 48%)			0.27
Net Profit after tax			0.14
Reserve for Payment on loan Principal		950,000	0.04
Available after loan payment			0.10
Return on Investment			(+8.5%)

TABLE 8
 BEST CASE ECONOMICS FOR PRODUCING ETHANOL FROM GRAIN
 OR SUGAR

	<u>Grain Based Material</u>		<u>Sugar Based Material</u>	
	<u>Corn</u>	<u>Sorghum</u>	<u>Juice</u>	<u>Molasses</u>
Production Cost, \$/gal	0.51	0.51	0.25	0.25
Feedstock Cost, \$/gal	0.73	0.79	0.79	0.79
Intermediate Cost, \$/gal	1.40	1.24	1.04	1.04
Potential Byproduct Credit, \$/gal	0.34	0.34	(fuel)0.06	-
Final Manufacturing Cost, \$/gal	1.06	0.90	0.98	1.04
Added Capital-Related Costs, \$/gal	--	--	0.17	0.04
Final Manufacturing Cost, \$/gal	--	--	\$1.15	\$1.08

*No Return on Investment

TECHNOLOGIES OF ALCOHOL PRODUCTION AND BY-PRODUCTS

Sweet Sorghum or Sugar Cane Juice

The alcoholic fermented products from cane juices are immediately associated with rum. In tropical countries rum has either blackstrap molasses (left over from sucrose crystallization) or virgin syrup (concentrated sugar cane clarified juice) as its raw material.

More recently, and mainly due to the depressed sugar market and the possibility of using ethanol as fuel, some large and integrated cane factories in Brazil, Louisiana, and Missouri have used cane juices as the fermentation raw material.

In these factories part of the sugar mills have been converted into rum production facilities. From the practical point of view this situation has worked well under very specific market conditions; however, it has a drawback because what is optimum for sugar crystallization or for rum manufacture is not necessary optimum for ethanol fuel.

Here is the method used to process cane. Clean sugar cane stalks from the field are cut and the juice extracted in a standard roller milling unit. The juice is treated with chemicals, solids precipitate, and the supernatant is filtered in rotary vacuum filters. The clarified juice is sent to the evaporators where it is concentrated for optimum sucrose crystallization. However, the juice could be taken from a "weak" first effect evaporator to a sucrose concentration that could produce around 10 percent (w/v) ethanol after fermentation. Note that this operation, which joins both processes, still is not well defined. The concentrated juice, with nutrients added, is inoculated with yeast and batch fermented until sucrose is exhausted (fermentation times vary widely in practice). The fermented mash is centrifuged. After an acid

wash, separated yeast can be recycled to the fermentor in order to increase ethanol productivity. A 95 percent (w/v) ethanol product is produced by straight rectification/distillation and absolute ethanol by areotropic distillation.

Stillage, filter muds, and wash waters and fuel oil are wastes. Yeast is a byproduct. The bagasse from the milling operations is burned to provide the total power requirements for the operation. Hence, the facility is energy selfsufficient. Moreover, spent electricity is usually available.

Sweet Sorghum

For a long time it has been known that some varieties of sorghum store sucrose, invert sugar in their stalks, and store some starch in the grain.

The systems study of sugar crops made by Lipinsky et al (1978) made clear that without sweet sorghum the prospects for fuels from biomass from sugar crops would be relatively dim, except in critical circumstances. However, with sweet sorghum as the central sugar crop for biomass fuels purposes, sugar crops may have a three way potential.

Although sweet sorghum has an enormous potential, this crop has not been studied either in terms of agricultural practice or processing into liquid fuels.

Because sucrose and invert sugar are stored in the stalk; the stalks might be processed by following the sugar cane technology. Small amounts of starch in the grain eventually could be added to corn to be converted into soluble sugars by enzymatic or acid hydrolysis and then to ethanol by anaerobic yeast fermentation. Alternatively, the stalk could be processed by employing new technologies like the Tilby separator or the Ex-Ferm process.

In any event, sweet sorghum needs to be processed in conjunction with another crop, either sugar cane or corn. In this capacity crop harvesting and availability could be extended, storage problems minimized and operation days of the alcohol plant increased.

Alcohol from Molasses

The process using molasses is typical of those materials in which the carbohydrate is initially in the form of sugar. The molasses used is generally blackstrap molasses, a byproduct of sugar manufacture. In making sugar, the juice squeezed from the sugar cane is concentrated and sugar is crystallized. After two or three batches of sugar crystals are obtained, the impurities in the mother liquor are so concentrated that further sugar crystallization is impractical. This remaining mother liquor is blackstrap molasses. Another important material is invert or high test molasses. This is produced by adding dilute acid to sugar cane juice, inverting the sucrose, then neutralizing and finally evaporating some of the water from the solution. Beet molasses from sugar beets are seldom used for making industrial alcohol in the U.S. Saccharine materials used in minor amounts include pineapple waste, sorghum cane, citrus waste concentrate, waste from fruit canneries, pineapple juice and corn sugar syrup. The molasses process is essentially a section of the corn process. The molasses from storage tanks is pumped directly into the fermenters where water, acid, yeast nutrients and yeast are added as in the corn alcohol process. The fermentation is carried out in 36 to 48 hours with agitation and cooling. Newer processes are run continuously with cell recycle. The beer produced contains 6 to 10 percent alcohol.

Butanol-Acetone

This is an anaerobic fermentation process which had been operated in large volume (more than 100,000 tons per year during World War II) in the United States until the early 1960's when the

Preliminary calculations suggest that a plant designed to consume approximately as much stock as would produce 25×10^5 gallons per year (82,500 tons per year) of ethanol would require 1.1×10^6 bushels of grain per year, and would produce 6750 tons of mixed solvents per year. Of this, butanol would be 4930 tons, acetone would be 1550 tons, and ethanol would be 270 tons. The plant would require a total investment of approximately $\$20 \times 10^6$, and the cost of production would be about $\$0.65 \times \0.70 per kilogram mixed solvents. When a reasonable return on investment is added to the production cost, a selling price of the solvent produced by fermentation is double that produced by conventional petrochemical means. For example, present production in the U.S. of these solvents is given in the following table along with 1978 prices.

TABLE 9
PRICES OF SOLVENTS

	Price		
	<u>\$/kg</u>	<u>\$/lb</u>	<u>\$/gal</u>
n-butanol	0.46	0.21	0.95
acetone	0.37	0.17	0.90
ethanol (95%)	0.37	0.17	0.86

Based upon current prices, the price of the mixed solvent produced by fermentation should be $\$0.43$ per kilogram, which compared to the estimated costs by fermentation greater than $\$0.60 - 0.70$. The following tables give additional information:

TABLE 10

ESTIMATED INDUSTRIAL ENERGY BALANCE FOR THE PRODUCTION OF ETHANOL FROM GRAIN

	25 x 10 ⁶ Gallons (95 volume %) Ethanol Per Year	
	330 Operating Days Per Year	
	2.82 Gallons (95 volume %) Ethanol Per Bushel of Grain	
		75,741
		<u>Energy Production</u>
		1. Ethanol
		47,200
		<u>BIU PER GALLON OF 95 VOLUME % ETHANOL</u>
		<u>Energy Production</u>
		1. Ethanol
		47,200
		2. Fusel Oil
		(5 gallons per 1000
		gallons ethanol)
		548
		3. By-product Grains
		(5.7 lbs per gallon
		ethanol)
		42,912
		4. Farming By-Products
		124,500
		<u>245,701</u>
		<u>245,701</u>

Energy Consumptions

1. Farming

2. Grain Processing

Milling & Solids Handling

Cooking & Fermentation

3. Distillation

Beer Still: Aldehyde, Rectifying
& Fusel Oil Columns

4. Stillage Handling

Evaporation
Drying

47,200

8,660

12,440

57,700

36,600

9,240

171,840

TABLE 11

ENERGY BALANCE FOR THE PRODUCTION OF ETHANOL FROM CORN - SCHELLER ESTIMATE

20 x 10⁶ Gallons (96 volume %) Ethanol Per Year
 330 Operating Days Per Year
 3.0 Gallons Anhydrous Ethanol Per Bushel of Corn

<u>Energy Consumption</u>		<u>BTU PER GALLON of 96% ETHANOL Energy Production</u>
1. Farming	47,200	1. Ethanol 72,600
2. Grains Processing Grinding, Cooking, Preparations Fementation	24,800	2. Fusel Oil & Aldehydes (12 gallons per 1000 gallons ethanol) 1,000
3. Distillation Beer Still & Centrifuge Distillation	40,400 25,000	3. By-Product Grains (7.2 lbs per gallon ethanol) 45,000
4. Stillage Handling Liquid Concentration By-Product Grain Drying	63,200	4. Farming By-Products (stalks, cobs, and husks, assumes 25% of material is returned to land for ferti- lization.) 124,000
	<u>201,800</u>	<u>243,200</u>

1. In a single step a vacuum would enrich the alcohol coming overhead from the fermenter. At 3-5 percent alcohol concentrations the volatility of the alcohol (ratio of alcohol in the vapor to that in the liquid) is the order of 8-10 percent. Hence, a 3 percent alcohol solution, when boiling, will produce around 20-24 percent alcohol solution when the vapor is condensed.
2. Removal of alcohol from the fermentation broth at a lower concentration (most alcohol fermentations achieve 8-10 percent alcohol concentrations) would speed up the fermentation since high alcohol concentrations tend to be inhibitory to the fermentation. Thus, smaller equipment could be used for the same productivity.

Two problems have been encountered with this process. First, large amounts of CO_2 are evolved with the ethanol (a weight approximately equal to the alcohol) so that the vacuum system has to handle large amounts of non-condensable gas. Some way needs to be found to take the CO_2 off separately from the ethanol. Second, the yeast alcohol fermentation operates best at 3037°C . At this temperature a vacuum of one lb./sq. in. would be required to boil the alcohol, which is difficult to achieve without expensive vacuum equipment.

One way around this latter problem has been suggested. This is to utilize a thermo-tolerant organism (45°C) for producing alcohol. To date searches for a thermo-tolerant alcohol producing yeast have not been successful although a thermo-tolerant bacterium, Clostridium thermocellum, is being studied that will produce alcohol at 65°C . The problem with this organism is its sensitivity to alcohol since it stops growing above one percent concentrations in the fermentation broth. Genetic experiments are underway to develop alcohol tolerant strains. If this succeeds, then vacuum fermentation may be an important technology.

REVIEW OF SOLAR DISTILLATION (9)

In order to save energy as fuel in distillation of ethanol-water mixtures, solar energy could be considered applicable.

Solar distillation has been used mainly to obtain potable water from sea water, the process being actually an evaporation unit operation. The solar energy collectors employed have been of many varied but simple designs without costly energy concentrating devices.

The average values of water evaporated have been in the order of 0.10 gal/sq ft/day. With this figure and assuming heat effects of the same order of magnitude, the distillation columns of ethanol 50,000 gallons per day factory would need reboilers of around five million square feet of surface. This type of application is not then recommended for what has been commonly known as solar distillation or sea water evaporation. If solar energy is to be used in distillation columns, new collecting designs are needed.

Seven contracts from DOE are developing systems that are varied on the theme of producing steam at 300-550F. Two basic schemes are being used. One uses a central receiver, the other a distributed system. Both collect and concentrate direct sunlight to heat a working fluid, which could be water, steam or oil. The feeling at this point is that solar heating for industry unit operations like distillation is viable yet not economical. Current costs are two and one-half times that of the systems they would replace. However, collectors costs can not come down until they are mass produced.

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Report on
Biomass as an Energy Alternative for the Caribbean
Workshop

San Juan, Puerto Rico

April 28-29, 1982

UNICA Commission on Science and Technology

BIOMASS AS AN ENERGY ALTERNATIVE
FOR THE CARIBBEAN WORKSHOP

SUMMARY REPORT

It is the opinion of the UNICA Science and Technology Commission that the April 28-29, 1982 San Juan Workshop on Biomass as an Energy Alternative for the Caribbean was a greater success than the first Workshop on Wind because of many circumstances. Some of the most favorable conditions were the familiarity of the UNICA contact persons among themselves and with the project, which stimulated a direct interest in their involvement and commitment to its success. Also the workshop followed the Fuels and Feedstocks for Tropical Biomass II Seminar which provided the UNICA contact persons unique opportunity to become acquainted with the subject.

Again, following the format of the Wind Workshop, the group was separated in three working sessions: Education and Training Needs, Research and Development Needs, and Demonstration Needs.

It may be gathered from the recommendations that biomass is perceived as one of the energy alternatives for the Caribbean which could be utilized faster based on the agricultural experience and knowhow of the region. Consequently, a generalization of the recommendations can be formulated as follows:

- (1) Securing funding to establish research, development and demonstration projects of specific nature in the region on biomass as an energy source should have the highest priority.
- (2) In order to implement the above recommendation, education and training programs to prepare the human resources needed in tropical biomass for the region are a must.

(3) UNICA should play a vital role in technology information, disseminating, R&D projects evaluation and technology transfer between their member institutions.

(4) The UNICA Foundation role of securing funds for implementation the above is essential and indispensable to carry out such programs.

If the above recommendations are implemented the science and engineering capabilities of UNICA member institutions in biomass matters would be greatly enhanced. Also, the role of the universities and research institutes as providers of solutions to society problems would be strengthened.

The UNICA Science and Technology Commission wishes to thank all the UNICA contact persons for their participation in their workshops and in particular the moderators of the session who drafted the workshop reports. Also, we are deeply grateful for the funding support from the National Science Foundation, Exxon Education Foundation and the UNICA Foundation.

BIOMASS AS AN ENERGY ALTERNATIVE
FOR THE CARIBBEAN WORKSHOP

San Juan, P.R., April 28-29, 1982

WORKSHOP SESSION, GROUP NO. 1

EDUCATION AND TRAINING NEEDS

Report by

Dr. R.L. Sullivan, Moderator

General

Participants in the Education and Training Workshop session included:

Dr. Jairo Lascarro (University of Puerto Rico)
Eng. Gerardo Manan Paniagua (INTEC, Dominican Republic)
Mrs. Lourdes Iturralde (Universidad Simón Bolívar, Venezuela)
Mr. William Chalmers (Caribbean Development Bank, Barbados)
Dr. Glenda S. O'Brien (University of the West Indies, Jamaica)
Mr. Gerald Lalor (University of the West Indies, Jamaica)
Dr. R.L. Sullivan (University of Florida, USA)

Recommendations

- (1) UNICA should decentralize the work of the Commissions into technology working groups and increase the number of contact people.
- (2) To fund the increased activity stemming from the new structure UNICA should actively seek new additional funding for a three year budget.
- (3) Each working group should be encouraged to submit budgeted

proposals to the appropriate Commission to fund specific activities e.g., workshops, continuing education programs, etc.

- (4) Each working group should establish communications and data collection procedures.
- (5) UNICA should fund exchange programs among Caribbean universities as a means for improving the transfer of new technology knowledge in the region.
- (6) UNICA should sponsor a special workshop on education with emphasis on university curriculum development and communication techniques aimed at improving the region's awareness of the various new technology options.
- (7) Each working group should publish an edited volume describing the state of the art of its specific technology for each country in the region.
- (8) Each working group should be responsible for promoting its specific area of concern within the Commission.
- (9) Video cassettes should be made for each technology to promote its development and use among teachers and public officials.

BIOMASS AS AN ENERGY ALTERNATIVE
FOR THE CARIBBEAN WORKSHOP

San Juan, P.R., April 28-29, 1982

WORKSHOP SESSION, GROUP NO. 2

RESEARCH AND DEVELOPMENT NEEDS

Report by

Dr. Al Binger, Moderator

General

It is the general view of the working group that there is a great need for collaboration and exchange of technological know-how between member institutions. It is felt that UNICA must address itself to the development of a mechanism to allow for such transfer. It is also commonly felt that there exists in the region various technologies which are needed in other countries.

The efficiency of UNICA members is being affected by:

- (1) Inadequacies in the procurement and dissemination of information
- (2) Obstacles preventing collaboration between regional institutions.

UNICA could be an efficient organization in the development and propagation of science and technology in the region if it could overcome some of these problems.

Research and Development

These are short term recommendations aimed at stimulating developmental work for various UNICA members and at addressing certain problems which some members are presently having.

We interrelate our project goals in energy with those for the protection of the environment and construct our project proposal in order to take advantage of all funding which exists in other areas such as environment protection, agriculture, etc. Attempts should be made to have joint projects developed whenever possible, realizing that projects must be specific nature for the sites involved. One of the main potentials seems to be for the utilization of cocoa and coffee waste in generating biomass. We should recognize that duplication can be both good and bad. However, duplication should result in more efficient use of funds.

Wherever possible UNICA should speed up the distribution of funds coming into the region for R&D and whenever time allows before importing foreign technology we ask UNICA personnel if such technology had been previously tested in the region and with what result. Projects aimed at utilizing biomass as chemical feedstocks should be given priority. The orientation of such projects is more technologically and financially demanding but they are potentially more feasible. It is therefore recommended that all such projects be undertaken in collaboration.

The UNICA representative in each country, after consulting with his colleagues, should identify the areas of research and development with specific input and submit these to UNICA for processing. Hopefully this will provide a current assessment of energy R&D in the region.

A techno-economic evaluation unit should be established to provide this service for cost-benefit analysis so as to deduce the benefit of project. In developmental work, all pertinent data from the region should be supplied so as to allow analysis for site and regional applicability and potential. That U.S. AID policies in the region should be evaluated to see how they promote:

- (a) regional collaboration
- (b) developing expertise within the region

As there is a present funding shortage, it is suggested that UNICA solicit funds in an effort to act as a source of interim financing for collaboration projects with regional application.

Closer working contacts should be maintained with research and development institutions in the region as these institutions usually have more funds, personnel and equipment to assist the developmental phase of projects. UNICA would therefore seek funding for the actual development of collaboration of regional projects.

We accept the offer of collaboration from French Overseas University Programs offered by Professor J. Renoux of AUPELF. UNICA should make representation to funding agencies for funds to aid in organizing this information service and to provide the required training to allow the transfer of technology from this source to the countries where it can be utilized.

Until an information machinery is in place for the dissemination of information, person-to-person communication should be undertaken. Since the existing questionnaire is viewed as being difficult to comply with, it is suggested that each person supply his present project with his immediate needs for information and funding in order that UNICA Secretariat can provide whatever short term assistance it can.

UNICA should include in its current publications a section on research projects stating: institution, persons, projects in progress and current status, projects in planning, projects in which institutions are seeking collaboration, funding availability and requests for assistance from members. This will allow UNICA contact persons to be aware of funding availability for research and distribute this information to people whom they think can benefit from this.

UNICA should consider providing the following:

- (a) information update

- (1) the ongoing R&D projects in energy within the region
- (2) the requirements of our individual institutions from UNICA
- (3) proposed methods which UNICA will employ to meet these needs.

In addressing the first question we realized that such information was extremely limited and the steps instituted by UNICA in the past by means of survey had not had the anticipated results. As a short term solution it was proposed that some time before the conclusion of this session all persons actively involved give a brief report on what they are pursuing and state whether they are interested in any form of collaboration.

The second requirement was for education. In institutions where technology is developed for the masses (e.g., charcoal project) in association with R&D we recommend that UNICA's know-how be provided to inform bureaucrats and potential users as to the need, as well as the operational techniques, for that technology. The social factors involved in giving new technology to our people cannot be overlooked.

In order to meet these needs we proposed that UNICA consider the establishment of a program for educating bureaucrats, and then an associated demonstration programme for the populous in the need and utilization of such technology.

Our second recommendation for UNICA, which is in the unique situation to identify and assess regional needs with regards to socio-economic parameters and then solicit the funds and award these on the basis of competitive grants for institutions or a combination of institutions to achieve these needs, is that such activities be done in collaboration with other bodies in the region which share UNICA's concern for technological development in the region.

It is recommended that regional institutions submit collaboration projects through UNICA for funding. These two recommendations will allow UNICA to act as a stimulating and evaluating body to promote technological development within the region.

We all agree that the establishment of the Information Dissemination System, is critical to the success of UNICA. This Information System is to be developed in collaboration with OLADE, TEU of CDB, CARIRI, SRC and other regional institutions. The prime purpose of this unit will be to acquire and disseminate information to UNICA contact persons in each country.

BIOMASS AS AN ENERGY ALTERNATIVE
FOR THE CARIBBEAN WORKSHOP

San Juan, P.R., April 28-29, 1982

WORKSHOP SESSION, GROUP NO. 3

DEMONSTRATION NEEDS

Report by

Dr. Modesto Iriarte and Mr. Salvador Lugo
Moderators

General

This workshop was attended by a small group (six persons) representing Guyana, St. Lucia, Jamaica, Netherlands Antilles and Puerto Rico.

At the outset the group decided to establish the following criteria for the selection of demonstration projects: (1) availability of biomass on a commercial scale; (2) this biomass would be in an existing commercial activity; (3) the projects would be of such nature that they could be done elsewhere in the Caribbean (technology transfer); (4) projects should be culturally acceptable to the region and the countries involved.

With this criteria in mind, a discussion was held of the various biomass related activities being carried out in each of the regional areas mentioned. Various projects with a potential for developing into "demonstration" stage were discussed. Several were identified as needing further R&D, others were ruled out because enough commercialization has already been developed or because they were not within the general interest of the majority.

While sifting the options, the countries borne in mind in terms of biomass potential were Guyana, Jamaica, St. Vincent, Haiti,

Dominican Republic, Venezuela and Colombia. There could be others.

Only one demonstration project was identified and discussed at length for implementation. Discussions and reasons for discarding other projects are presented.

Demonstration Project for Implementation

It was the general consensus that a demonstration project to produce gas by pyrolysis of biomass would be very convenient for the Caribbean.

Gas is probably the best type of fuel for direct combustion; its transportation and handling and use offers advantages even over liquid fuels. The suggested project could start with a conference workshop sponsored by the University of Guyana and producing pyrolytic gas from the management of the forest industry. The gasifier has been developed by a German firm.

The conference at Guyana would include a series of lectures on the operational experience, and design details of the Guyana facility ecosystem impacts of the region as well as a visit to the plant. After the conference a task force would be identified to work in the development of this project. The task force could proceed as follows: (a) make an initial assessment of the process, the logistics and management, and outline a plan based on a selected site; (b) prepare a proposal for securing funding from private and government agencies; (c) implement the proposal when funding is secured.

Other Projects Discussed

(1) Direct burning of biomass was discussed. It was concluded that for small capacity boilers there is a long history of commercial

projects in operation. Demonstration needs are required for large utility boilers but the interest would be centered on a small number of the most developed countries such as Puerto Rico, using large blocks of electrical energy.

(2) Water hyacinths used for tertiary treatment as a source of biogas. This project was discussed and it was concluded that it is feasible but that there is not now too strong an incentive in developing a demonstration project.

(3) Sea weeds as a source of biomass. This was discarded because it requires R&D before a demonstration unit can be attempted.

(4) Need of data bank in biomass for the Caribbean. This was discussed and it was concluded that UNICA has a separate project on this.

(5) The need to determine:

- (a) Bio-fuel consumption in the Caribbean
- (b) Charcoal uses
- (c) Fire wood uses

This can help in identifying further demonstration projects.

Other Recommendations

For consideration at some future effort for demonstration projects we wish to put forth the following possibilities: biogas or proteins from the banana operation at St. Lucia; explore in Antigua the possibility of biogas from the expansion of pork and poultry production. In Dominica explore possible use of wastes from coconut users and from food processing.

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