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Preliminary Energy Sector Assessments of Jamaica

Volume III
Renewable Energy:

Solar Energy — Commercial & Industrial
Solar Energy — Agricultural
Biogas Applications
Energy Conversion From Waste

Prepared For

Department of State
U.S. Agency for International Development

Under Contract No. AID-532-79-11

JANUARY 1980

PRELIMINARY
ENERGY SECTOR ASSESSMENTS OF JAMAICA

CHAPTER 5

BIOGAS APPLICATIONS

for

UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT

CONTRACT NUMBER AID 532-79-11

TASK 4

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FOREWARD

The eight reports of the Preliminary Energy Sector Assessments of Jamaica conducted by the United States Agency for International Development Energy Team are contained in the following five volumes:

Volume	I	Executive Summary
	II	Economic Assessment
	III	Renewable Energy:
		(a) Solar Energy - Commercial & Industrial
		(b) Solar Energy - Agricultural
		(c) Biogas Applications
		(d) Energy Conversion from Waste
	IV	Coal Prefeasibility Study
	V	Electric Utility Rate Analysis

These studies were initiated by the USAID in conjunction with the Government of Jamaica to further the objectives of Jamaica's Five Year Development Plan and its Energy Sector Plan. The studies also represent USAID's first energy assessment of a developing country.

Due to the diverse technology requirements and the high degree of specialization required by each of the studies, a United States Energy Team of experts was assembled. The individual team members were selected based upon a demonstrated balance between academic and "hands-on" experience in the specific study area.

Energy Systems International (ESI), had overall responsibility for systems planning, project management and integration of all elements of the Preliminary Energy Sector Assessments.

These reports should not be considered as the final product of any study area, but as baseline documents to be used for identifying specific energy programs and projects for implementation in the near-term to assist Jamaica in alleviating its critical energy problem.

Any comments or questions concerning this study should be directed to:

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ACKNOWLEDGMENTS

The success of the Preliminary Energy Sector Assessments of Jamaica was assured through the joint cooperation, professionalism, competence and diligence of the entire U.S. Energy Team and their key Jamaican counterparts. The assessment was a concentrated effort over a fifteen week period in Kingston, Jamaica, during which many government agencies, institutions, private sector organizations and individuals became involved and generously supported study development. The many excellent people involved are too numerous to mention herein, but a few have been singled out for recognition because their outstanding effort and support helped to provide study continuity and progress.

Special thanks go to Dr. Henry G. Lowe, Director, Energy Division of the Ministry of Mining and Natural Resources and to the MMNR staff for providing the inspiration and leadership from the Jamaican side to ensure that there was enthusiastic support and contributions to this study from all Jamaican counterparts. A special note of appreciation goes to Dr. K.C. Lee, Senior Principal Scientific Officer, Scientific Research Council and to the members of the Biogas Working Group for their unselfish dedication and collaboration with the energy team during the Biogas Applications Study.

Special thanks must also be given to the United States Agency for International Development, in particular, Mr. Jerome Hulehan, General Development Office, USAID Kingston, Jamaica Mission, and Dr. Jerome Bosken, Deputy Director, Energy Office, USAID Headquarters, Washington, D.C., for their encouragement and support of the project and for their assistance throughout the study.

Most importantly, special acknowledgment is given to those who took the time to make important contributions to the study through their interviews and discussions with the U.S. Energy Team members. Some of these people and organizations are identified in Appendices C, E, and F of this Chapter.

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This specific Study, Chapter 5, Biogas Applications was prepared by Dr. Rolf Skrinde, Olympic Engineering, in conjunction with Energy Systems International.

CREDITS

Dr. Rolf Skrinde of Olympic Associates, Inc. was the principal contributor and principal investigator for this study. He spent a total of eight weeks in Jamaica on an intensive effort to prepare this report. Energy Systems International integrated the report with the other study efforts, typed, edited and prepared the final report.

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5.1 EXECUTIVE SUMMARY

5.1.1 Introduction

Biogas, a high grade fuel similar to butane, is a mixture of methane and carbon dioxide which burns with an invisible to blue flame and is useful for cooking and other purposes. It is produced simply by anaerobic digestion of organic matter. Agricultural crops can be used as feedstock, but a common practice is to digest manure from animals such as cattle, pigs and chickens. In producing biogas, the slurry retains its original fertilizer components and therefore, biogas is an energy dividend which can be obtained merely by operating the digesters.

5.1.2 Terms of Reference

The objectives of the biogas study were to assess the feasibility of biogas generation and prepare recommendations for projects that might be undertaken. Included were energy and economic evaluations, as well as a review of low cost facility designs which would be most suitable for conditions in Jamaica.

This biogas study was initiated in August 1979. After a planning period and development of a questionnaire, site visits were made to selected farms and institutions in all parishes of the country where biogas could be generated. Based upon these studies and discussions with representatives of institutions and agencies which would be involved, a recommended program in biogas was prepared for presentation to the government of Jamaica and to the Final Report Conference held on November 13-14, 1979 in Kingston, Jamaica.

5.1.3 Background Information

Jamaica has many characteristics which could lead to successful development of biogas as an alternate energy source. Much of the economy is agricultural in nature and therefore large amounts of biomass materials are available. In rural areas where biogas plants could be built there are often shortages of butane and kerosene, so the plants would be located in areas of greatest need. The ambient temperature is sufficiently high throughout the year in Jamaica that auxiliary heating of digesters is not necessary. This obviates the need for costly equipment which is required in colder climates, where biogas is economically justified even when such heating adds significantly to construction and operating costs. Finally, biogas plants are cost effective in Jamaica, where all oil and gas must be imported.

Cooking is often done with butane or kerosene in Jamaica. Generally, 100 cu ft of gas per day is sufficient to supply the cooking needs of a family of six. Approximately 2.7 lbs of butane or 1/3 gallon of kerosene can be replaced by 100 cu ft of biogas.

A brief review of biogas progress in countries which have major programs, such as India, Korea, the Philippines, Taiwan, China and the United States, indicates that Jamaica should be able to institute a successful biogas program with little initial research and development effort.

5.1.4 Study Method

In order to obtain input from those already involved in developing this energy source, a Biogas Working Group was formed with representation from appropriate agencies and institutions. Meetings were held with this group and with private individuals. Visits were made to sites where biogas plants are now operating, and surveys were made of 75 farms, communities and schools throughout Jamaica to evaluate the potential for a program of biogas works (see Appendix E for survey results). Certain farms were selected based on livestock figures provided by the regional offices of the Ministry of Agriculture. Though this survey should not be considered a full market analysis, the preliminary results indicate that the potential for a viable biogas program exists. Upon completion of the surveys, the data were evaluated, economic and energy analyses were made, and a recommended five year biogas program was developed.

5.1.5 Findings

The surveys showed that farmers and managers of institutions were quite receptive to the concept of biogas. In some cases their knowledge of the subject was fairly good, and many expressed an interest in installing their own biogas plants.

The Scientific Research Council (SRC) has been conducting research and development on design of family size biogas plants for the past five years. They are presently concentrating on developing lower cost designs. A basic design has now been developed and perfected through the testing and demonstration program and will enhance the potential for success.

The economic potential for biogas use is excellent in Jamaica. Because of the high price of imported fuel, the cost of butane or kerosene for cooking purposes averages from J. $100 to J. $250 per year per family. The present biogas plant design would have a construction cost of about J. $1,000 per family size unit, and a Chinese design being studied by the SRC may reduce this to as low as J. $300. Using the two designs for a national program of implementation could result in an estimated average cost of J. $500 per family size unit. The pay back period could be as low as one and one half years but would probably average in the range of two to four years on the basis of energy alone. This does not include the fertilizer and other values of the digested residue.

The Ministry of Agriculture is interested in assisting in a national program of biogas energy throughout the rural areas of Jamaica. Personnel from this Ministry could play an important role in the program because of their knowledge of the agricultural sector and their normal day-to-day contacts at the local level.

A biogas program would be compatible with the objectives of the <u>Energy Sector Plan</u>, Section 4.3-B.v. The suggested biogas program would help divert the present energy supply mix away from imported petroleum, develop an economically feasible non-conventional energy form adapted to local needs, accelerate the development of an indigenous biomass energy source, and contribute to Jamaica's energy self-sufficiency through the development of a non-conventional energy source. Moreover, it would reduce the cost of energy to low income groups by replacing purchased butane, kerosene and other fuel with essentially free energy from renewable feedstock.

5.1.6 Conclusions and Recommendations

Based on climate, rural population, animal numbers, Jamaica's dependence on expensive foreign oil and the enthusiasm shown in many sectors, it is concluded that a national biogas program would be successful. To ensure this success the experts on the study team formulated a group of recommendations:

(1) Select for large scale implementation one of the SRC family and medium size biogas plant designs.

(2) Postpone program to install a biogas plant at UWI-Mona Campus.

(3) Implement the Option A (Section 5.7.3.1 and Table 5-7) five year biogas program immediately.

(4) Begin a detailed marketing study to assess the commercialization potential.

(5) Conduct feasibility study for a large scale biogas unit for electricity generation.

(6) Re-assess the feasibility of Obtion B, the accelerated program (Section 5.7.3.2 and Table 5-9) after the detailed marketing study.

(7) Explore the interest of government and private institution in funding Option C (Section 5.7.3.3 and Table 5-11).

(8) Establish a Jamaican Government biogas program organization.

(9) Begin a comprehensive training and public awareness program.

5.1.6.1 Recommended Biogas Applications Program

Based on the recommendations cited above, a Biogas applications program has been defined that could be implemented over a five year time frame (Section 5.8.3).

5.2 INTRODUCTION

Programs to satisfy energy needs with biogas which can be produced continuously from renewable biomass sources have recently captured the interests of scientists and government leaders in many developing countries. Application of the technology was slow until 1950, but has increased at an accelerated pace over the past three decades because of increasing energy costs and the rapid rate of depletion of fossil fuel reserves. The oil embargo of 1973-74 was especially important in focusing attention on those energy sources such as biogas which are indigenous, renewable and environmentally clean.

It is only logical that the developing countries have taken a great interest in biogas technology. The economic base and population of these countries are mainly rural and it is in the rural areas where agricultural and animal wastes, which are the major raw materials for biogas production, abound. It is also the rural populace who are usually more vulnerable to the price and supply fluctuation of conventional fuels, and could benefit immediately and directly from family and community size biogas systems. Surveys have revealed that in rural areas approximately 50% of the energy requirements of a typical household are used for cooking.

In addition to cooking, biogas can be used in internal combustion engines. It also can be used for lighting and as fuel for appliances such as absorption-type refrigerators. In some cases environmental pollution control and re-feed of digested sludge to animals are important economic considerations. It is clear that biogas production has important implications in the areas of energy, agriculture and environment, and merits vigorous institutionalized efforts at encouraging its use where appropriate.

Jamaica has many conditions which could lead to successful application of biogas as an alternate energy source. Much of the economy is agricultural in nature, and ambient temperatures are high enough throughout the year so that auxiliary heating of biogas digesters is not necessary. This obviates the need for costly equipment which is required in colder climates.

It is significant that biogas energy can be provided directly to the rural areas of Jamaica, where butane and kerosene are becoming increasingly unavailable and require a substantial portion of the family's budget. A biogas energy program can therefore play a significant role in contributing to Jamaica's effort to achieve greater energy independence.

5.3 TERMS OF REFERENCE

5.3.1 Objectives

The Terms of Reference for the biogas study, Task 4 of the overall energy study, are given in Appendix A. The objectives were to assess the feasibility of biogas generation in Jamaica and prepare recommendations for projects that might be undertaken. Included were energy and economic evaluations, as well as review of low cost facility designs which would be most suitable for the conditions which prevail in the country.

The study also addressed the feasibility of generating biogas as an integral part of the sewage treatment facilities on the Jamaican campus of the University of the West Indies.

In addition to the tasks contained in the specific study Terms of Reference, the Energy Team members were also responsible for completion of the requirements outlined in the Project Management and Detailed Study Plan discussed in Chapter 1. During the course of the study, the team members were to conduct three assessment reviews to ensure that timely progress checks and necessary study plan alterations were made. The team members were also requested to make two presentations. The first was a seminar planned midway through the assessment; the second at study completion in which the results, conclusions and recommendations were highlighted at the Final Report Conference. As a result of the project summary given during the first day of the conference, a number of questions were asked to clarify study procedures, options, constraints, and considerations made when formulating specific recommendations. The questions were fielded by the team experts and Jamaican counterparts during splinter group discussions held the second day. The tapes of the biogas splinter group question and answer session were transcribed and are contained in Appendix G.

5.3.2 Schedule

The biogas study was initiated in August 1979. After a brief planning period and development of a questionnaire, site visits were made to farms in all parishes of the country. The field work, which was completed in early November, served a three-fold purpose of assessing the biomass availability for biogas generation in rural areas, assessing the interest of farmers, and providing biogas information to potential users of this alternate form of energy. Based upon these studies and discussions with representatives of institutions and agencies which would be involved, a recommended program in biogas was prepared in November 1979, for presentation to the Government of Jamaica and to the Final Report Conference.

5.4 BACKGROUND INFORMATION

5.4.1 Nature and Biochemistry of Biogas

The biogas produced by anaerobic digestion consists of between 50 and 70 percent methane and 25 to 45 percent carbon dioxide, with small amounts of hydrogen sulfide and other contaminants. It is a high grade fuel which burns with an invisible to blue flame, and has a heat value which ranges from 500 to 650 Btu/cu ft, depending on the methane concentration.

The anaerobic digestion reaction may be considered to be a three-stage process. In the first stage, biomass consisting of complex organic coumpounds are broken down into simple organic compounds amenable to fermentation. The second stage consists of anaerobic fermentation of these simple substrates into organic acids. The organic acids become substrates for the third stage of decomposition, accomplished by methanogenic bacteria, which produce the methane in biogas.

Methanogenic bacteria are sensitive to certain environmental factors, such as changes in pH. Gas production is optimum between pH 6.6 and 7.6, and when the pH drops below 6.6 there is a significant inhibition of bacterial activity.

Although the organic acids produced during the second stage of the anaerobic digestion process tend to depress the pH, this is counteracted by the destruction of volatile acids and reformation of a bicarbonate buffer by methane-forming bacteria during the third stage. Under equilibrium digestion conditions the combined biochemical reactions tend to maintain the pH in the proper range, but unbalanced conditions often occur in starting up a new digester. From the above it may be seen that reactions which occur in biogas plants are indeed complex and require carefully designed facilities in order to provide optimum operating conditions.

Feedstock materials for biogas plants may be generally classified as originating from animal sources and plant sources. Of animal origin are human wastes or night soil; manure from cattle, hogs, poultry, goats and sheep; and slaughterhouse and fishery wastes. Harvested plants and agricultural residues, both terrestrial and aquatic, constitute the plant origin category of raw materials. These include rice straw, leaves, bagasse, forest litter, marine algae, seaweeds and water hyacinths.

Most biogas digesters in operation today utilize animal manure as primary feedstock material. It generally is readily available and contains carbon, nitrogen and trace elements in approximately the correct ratio for optimum metabolism by anaerobic organisms.

5.4.2 Types of Biogas Plants

Figure 5-1 is a flow diagram of a standard biogas system, which consists of a feedstock holding basin, digester, a gasholder, and a basin to hold and dewater digested residue. Biogas plants may be broadly classified as batch and continuous systems. In the batch system, the digester is charged, digestion occurs, and then the digested residue is removed at the end of the retention period. If the raw materials supply cannot be obtained daily, then batch-fed plants are preferred. It may also be necessary to use this system if the biomass feedstock is coarse material which does not flow smoothly.

In the continuous system, the digester is charged daily or at shorter intervals with small amounts of feedstock. The charged material automatically expels an equal quantity of effluent. Except when the digester is shut down for renovation, there is continuous production of gas. Removing the contents of the digester becomes necessary if its working capacity becomes reduced by floating or settled inert materials. Normally, such removals are carried out every 8 months to one year depending on the nature of the feedstock material.

Digesters are often characterized by the manner in which the biogas is collected and stored. Standard practice in many countries is to use an inverted steel vessel as the cover of the digester. The gas produced is captured in the steel dome, which floats above the digesting liquid and provides storage.

Because of the cost of steel and its tendency to corrode, a low-cost design which avoids use of a steel gasholder has been developed in China. The digester in this case has a fixed rather than floating cover, and the gas is stored in the digester itself by the use of baffles (Figures 5-5 and 5-6). In this case the amount of gas stored is limited because both the digesting liquor and gas storage are contained in the same vessel.

A host of variations to the above two designs have been developed, the most common of which is a fixed cover digester with gas storage in a reservoir located remotely from the reaction basin.

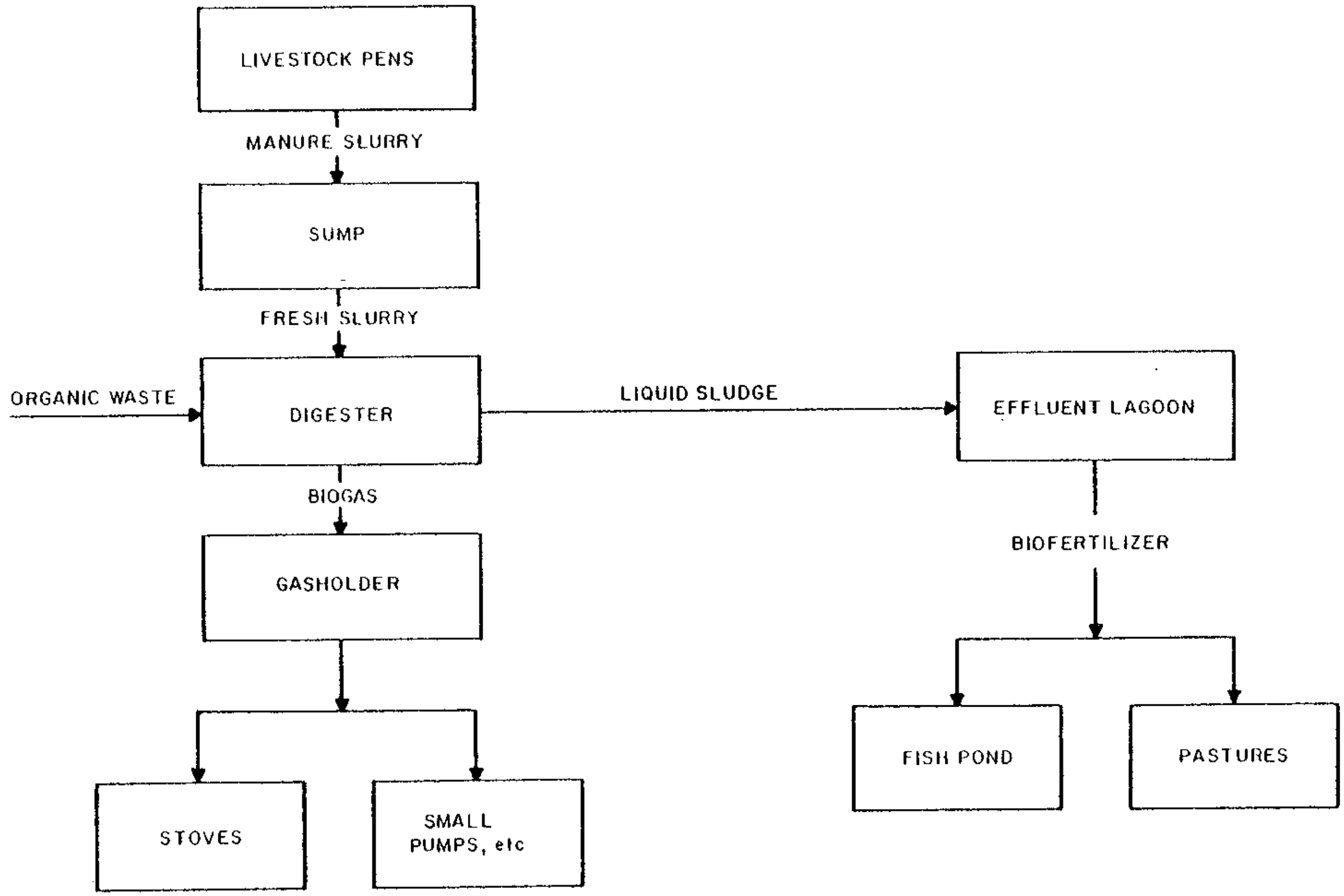


FIG. 5-1 BIOGAS PLANT FLOW DIAGRAM

5.4.3 Biogas Production and Use

Animal wastes and plant materials in an agricultural community represent significant sources of substrates for bio-conversion to methane. The quantities, solid characteristics, and nitrogen and phosphorus contents of manure generated by livestock are shown in Table 5-1. The data show the total amount of waste produced by the animals per day, but in design of a system consideration must also be given to the amount which actually can be collected. For example, beef cattle often roam free, so that their wastes are often not available as biogas feedstock. Dairy cows, however, produce a considerable fraction of waste at the dairy barns during the milking and feeding periods each day.

The amount of methane produced by the digestion process depends primarily on the nature of the raw material, temperature, and the period of digestion. As seen in Table 5-2, the literature on methane generation is far from consistent in the quantity of gas produced from a given quantity of feedstock material. The most common practice among sanitary engineers is to base methane production on the quantity of volatile solids destroyed, but this measurement requires facilities that are not always available at biogas generating plants.

Specific experience with biogas production from dairy cattle waste leads to a rule of thumb figure of 25 to 35 cu ft of gas per head per day from wastes which are collected during the milking and feeding operation. Other rule of thumb figures which may be useful are that 4 to 6 pigs or 40 to 50 chickens produce biogas equivalent to one head of cattle.

Biogas is used most efficiently as a replacement fuel for cooking purposes. Generally, 100 cu ft of biogas per day is enough to supply the cooking needs of a family of six. The quantities of these and other fuels which can be replaced by 100 cu ft of biogas are given in Table 5-3. It can be seen that the use of this quantity of gas per day would replace approximately 2.7 lbs of butane or 1/3 gallon of kerosene -- substantial quantities in this age of energy shortages.

The amounts of biogas consumed per hour for different types of engines and for various home appliances are shown in Table 5-4 and 5-5. It can be seen that gas-powered engines require 15 to 20 cu ft per hour per horsepower. Gas cookers

TABLE 5-1

MANURE PRODUCTION AND COMPOSITION[1]

Animal	Daily Production per 1000 lbs Live Weight			Composition as % of Wet Weight		
	Vol. (ft^3)	Wet Wt. (lb)	Dry Wt.* (lb)	Vol. Solids	Nitrogen	Phosphorus
Dairy Cattle	1.33	76.9	11.4	7.98	0.38	0.10
Beef Cattle	1.33	83.3	12.5	9.33	0.70	0.20
Swine	1.00	56.7	8.5	7.02	8.83	0.47
Sheep	0.70	40.0	6.0	21.5	1.00	0.47
Poultry	1.00	62.5	9.4	16.8	1.20	0.30
Horses	0.90	56.0	8.4	14.3	0.86	0.13

TABLE 5-2

YIELD OF BIOGAS FROM VARIOUS WASTE MATERIALS

Raw Materials	Biogas Production per Unit Weight of Dry Solids		Temperature		CH_4 Content in Gas (%)	Fermentation Time (Days)
	ft^3/lb	m^3/kg	°F	°C		
Cow dung	5.3	0.33	-	-	-	-
Cattle manure	5	0.31	-	-	-	-
Cattle manure	3.6-3.0	0.23-0.50	52.88	11.1-31.1	-	-
Cattle manure	3.1-4.7	0.20-0.29	60.63	15.5-17.3	-	-
Beef manure	13.7	0.86	95	34.6	58	10
Beef manure	17.7	1.11	95	34.6	57	10
Chicken manure	5.0	0.31	99	37.3	60	30
Poultry manure	7.3-8.6	0.46-0.54	90.5	32.6	58	10-15
Poultry manure	8.9	0.56	123	50.6	69	9
Swine manure	11.1-12.2	0.69-0.76	90.5	32.6	58-60	10-15
Swine manure	7.9	0.49	91	32.9	61	10
Swine manure	16.3	1.02	95	34.6	68	20
Sheep manure	5.9-9.7	0.37-0.61	-	-	64	20
Forage leaves	8	0.5	-	-	-	29
Sugar beet leaves	8	0.5	-	-	-	14
Algae	5.1	0.32	113-122	45-50	-	11-20
Night Soil	6	0.38	68.79	20-26.2	-	21

(Modified table from: National Academy of Sciences; "Methane Generation from Human, Animal and Agricultural Wastes", Washington, D.C. - 1977, Reference No. 1)

TABLE 5-3

VALUES OF REPLACING DIFFERENT FUELS WITH BIOGAS

Name of Fuel	Unit	Biogas 100 cu ft	Kerosene gal	Butane lb	Electricity kwh	Charcoal lb	Firewood lb	Cow Dung Cakes lb	Soft Coke lb	Furnace Oil gall	Coal Gas 100 cu ft
Biogas	100 cu ft		2.591	0.370	0.075	0.110	0.046	0.013	0.100	3.046	0.849
Kerosene	gall.	0.386		0.143	0.029	0.042	0.018	0.005	0.039	1.487	0.328
Butane	lb.	2.704	7.006		0.203	0.297	0.125	0.035	0.270	10.417	2.242
Electricity	kwh	13.303	34.436	4.919		1.462	0.613	0.173	1.326	50.000	11.236
Charcoal	lb.	9.104	23.563	3.365	0.684		0.420	0.119	0.908	37.037	7.752
Firewood	lb.	21.691	56.157	8.210	1.632	2.383		0.283	2.165	83.333	18.519
Cow Dung Cakes	lb.	76.774	198.751	28.387	5.770	8.435	3.539		7.640	333.33	66.667
Soft Coke	lb.	10.021	25.950	3.705	0.754	1.101	0.462	0.130		38.462	8.475
Furnace Oil	gall.	0.260	0.673	0.096	0.020	0.027	0.012	0.003	0.026		0.221
Coal Gas	100 cu ft	1.117	3.048	0.446	0.089	0.126	0.054	0.015	0.118	4.532	

TABLE 5-4

BIOGAS CONSUMPTION RATE PER HOUR IN CU FT FOR OPERATION OF DIFFERENT TYPES OF ENGINES[3]

Name of Engine	Fuel System	Cylinder and Cycle Details of Engine	Brake horse power	Horizontal or Vertical	Speed i.e. rpm	Dia. of the Gas Supply Line	Gas Pressure in Water Col. inch Required
1. Sturat, coupled with 250 W 110 V DC generator, made in England	Petrol	Single cylinder 4-cycle	1 bhp	Vertical	High 1800	3/8"	2 to 4"
2. Onan, coupled with 1 kVA 110 V AC generator made in U.S.A.	Petrol	Single cylinder 4-cycle	3 bhp	Vertical	High 1500	3/8"	2 to 4"
3. Kubota, made in Japan	Powrine	Single cylinder	5 bhp	Horizontal	Low 900	1/2"	1 to 3"
4. Kubota, made in Japan	Kerosene oil	Single cylinder 4-cycle	10 bhp	Horizontal	Low 500 to 700	3/4"	1 to 3"

System of Cooling	Gas Consumption (cu ft) per Hour		Working Efficiency of the Engine	
	Normal Load	Full Load	Liquid Fuel	Bio-gas
1. Sturat, coupled with 250 W 110 V DC generator, made in England (Air-Cooled)	16.5	18.5	250 W	225 W
2. Onan, coupled with 1 kVA 110 V AC generator made in U.S.A. (Air-cooled)	48.0	58.0	1000 W	850 W
3. Kubota, made in Japan (Water-cooled)	82.0	93.0	5 hp	4.03 hp
4. Kubota, made in Japan (Water-cooled)	155	175	10 hp	8.2 hp

TABLE 5-5

BIOGAS CONSUMPTION BY VARIOUS DOMESTIC APPLIANCES[3]

Appliance	Size Detail	Gas Pressure in Water Column (inches)	Gas Consumption (cu ft)
Refrigerator	18"x18"x12"	3	2.5
Incubator	18"x18"x18"	3	2.00
Table Fan	12" dia	3	6.00
Space Heater	12" dia	3	5.5
Cooking Stove	2" dia	3	11.5
Cooking Stove	4" dia	3	16.5
Cooking Stove	6" dia	3	22.5
Gas Lamp	2 mantles	3.5	6.5

Observation based on:

(a) Room temperature - 86°F

(b) Calorific value of biogas Btu/cu ft

require 10 to 20 cu ft per hour, depending upon the diameter of the burner, and lighting utilizes 2 to 5 cu ft of gas per hour.

A subject of much interest in biogas technology is that of liquefying the gas so that it can be transported readily. Unfortunately, the methane in biogas does not liquefy without the use of low temperature in addition to high pressure. The temperature required to liquefy methane is approximately 100°C below zero, and therefore liquefying biogas is not feasible.

Biogas can be compressed without liquefying for storage purpose, but here again the energy required does not justify the relatively small savings in storage capacity which would result for household and medium size plants. It can be concluded that biogas should be stored in sufficiently large containers so as to require no pressurization, with pipeline transport to its point of use.

5.4.4 Biogas Development in other Countries

The Economic and Social Commission for Asia and the Pacific (ESCAP), a program of the United Nations, adopted the Columbo Declaration in April 1974, which contained a resolution that one of the most urgent priorities for action was the field of energy. Subsequently, a regional project for the development of biogas technology throughout Asia was initiated.

In the preparation for a series of biogas workshops, a UN mission then visited India, Japan, Korea, Pakistan, the Philippines, and Thailand to study the potential and state of development of the biogas industry. The report of this mission emphasized the potential of biogas plants in the Asian region, and suggested an integrated approach in which digester effluents would be used for fertilizer as well as for the growing of algae and the raising of fish and ducks.

ESCAP has supported three workshops on biogas technology. The first was held at New Delhi in July 1975, the second in Manila, October 1975, and the third at the University of the South Pacific in Fiji in June 1977. Proceedings of the first two workshops are included in a text entitled Biogas Technology and Utilization,[3] and the third conference, which covered biogas only briefly, was reported in a publication, Report on the Workshop on Biogas and Other Rural Energy Resources.[4] The workshops and stimuli provided by United

Nations support have been primary factors in the development of several national biogas programs. As a result, hundreds of papers and presentations have been prepared on biogas plant economics, design and operation.

A brief review of biogas progress in those countries which have major programs such as India, Korea, the Philippines, Taiwan, China, and the United States are presented in Appendix B. Many other countries also have biogas programs, and review of experience in various countries with similar characteristics should allow Jamaica to institute a successful biogas program with little initial research and development effort.

5.4.5 Potential for Application of Biogas in Jamaica

As stated previously, conditions in Jamaica are conducive to the successful application of biogas as an alternate energy source. Jamaica can take advantage of the experience in low cost design of biogas plants in other countries. One of the major costs is for steel reinforcing bars and gasholders. Some designs, however, such as those used in China, require only local construction materials and little, if any, steel. Use of such a design can result in a family size unit costing even less than the steel gasholder designs which have been used successfully in large scale biogas programs in other countries.

Many institutions in Jamaica, such as schools and centers for the handicapped, are associated with medium to large size farms, which could provide biogas for cooking. This biogas could substitute for fuel costing several hundred dollars per month per institution.

Large farms especially offer considerable potential for medium or large scale methane energy generation facilities. Such facilities could essentially provide all the energy requirements for cooking, electricity, and stationary engine use.

5.5 STUDY METHOD

5.5.1 Personnel Interviewed

In conducting the study, meetings were held with representatives of numerous agencies and institutions, as well as private individuals, who would or could potentially be included in a biogas program for Jamaica. A partial list of personnel interviewed with whom the team experts interacted in preparing the report findings are shown in Appendix C.

5.5.2 Sites Visited

Visits were made to three sites in the Kingston area where biogas plants presently operate, as well as sites in Kingston and throughout Jamaica, where such plants could be feasible. Included were the waste treatment facilities of the Jamaican campus of the University of the West Indies and the Greenwich waste treatment plant of the city of Kingston. Biogas generated at these plants through anaerobic digestion of sewage sludge is presently not being collected. Biogas plants visited in and near Kingston included household units at Stoney Hill, Golden Springs, and New Kingston.

Approximately 75 potential sites for biogas plants were surveyed with respect to feasibility for biogas works. The team experts participated actively in the site visits.

5.5.3 Surveys Made

The survey of livestock farms in Jamaica as potential biogas sites was carried out between the beginning of September and the first week of November. A brief quesionnaire, a sample of which is shown in Appendix D, was drafted and subsequent information was recorded on these forms. The data recorded on each farm was centered around current energy usage, manure and fertilizer use, and livestock population. A sketch showing the layout of the farms was also made.

The main objectives of the survey were to establish with the farmers the idea of a biogas program in Jamaica, get their reactions to such a program, and gauge the suitability of their farms for future biogas projects. In the limited time available, not all farms could be investigated. Consequently, certain farms were selected from livestock figures provided by the regional offices of the Ministry of Agriculture.

The actual surveys summarized in Appendix E were carried out by two agencies. The Ministry of Agriculture did the survey of government farms, while private farmers were interviewed by personnel from the Ministry of Mining and Natural Resources. At private farms, the persons interviewed were the owners of the farm. Emphasis was placed on interviewing dairy, pig and poultry farmers, as these farms offer the best opportunity for manure collection.

In view of the application of biogas to institutions which provide meals, the survey was not confined to farms only. Certain schools and colleges were encompassed, among which were the Green Island Secondary School, the West Indies College and St. Elizabeth Technical High School.

5.5.4 Pertinent Data Reviewed

While conducting the biogas study and assessment, numerous reports and proposals prepared by others were reviewed. A partial list of the reports reviewed is included as Appendix F.

5.6 FINDINGS

5.6.1 Biogas Potential

Surveys of both small and large farms indicated that there is considerable potential for biogas as an energy source throughout Jamaica. In the rural areas there are a surprisingly large number of families who use butane and kerosene for cooking purposes, even though there are varying quantities of other forms of energy such as wood available. The amount of butane used for cooking was found to vary significantly, depending on family size and cooking habits. A range of 200 to 600 pounds per family per year is not uncommon. The prices of butane and kerosene, approximately J. $38 per 100 pounds and J. $1.60 per gallon respectively in December 1979, have increased steadily over the past five years, and there is no end in sight to price increases.

The energy required for cooking with butane would cost in the range of J. $76 to J. $228 per year, based on the above quantities of fuel use and a butane cost of J. $38 per 100 pounds -- a considerable fraction of the family budget in rural areas. It is not surprising, therefore, that there was a lively interest in biogas energy.

The preliminary surveys were encouraging in that rural dwellers were receptive to the concept of biogas. There appears to be considerable knowledge of biogas at the present time, at least to the extent that many rural farmers were aware of the potential. This could have been the result of news stories on biogas which have appeared from time to time. There was a general interest in learning more about biogas and its practical application at the household level.

Biogas in Jamaica would appear to be a source of alternate energy for farmers who may be generally poor, but not in the indigent category. Basically, a farmer would have to own sufficient livestock or crops in order to generate the biomass for a biogas plant, which would indicate that he would have more resources than those poorest families who would have no animals at all. This would often be the very family who would use butane for cooking, however, since they would probably have sufficient income to utilize this form of fuel. It is thus seen that biogas plants would provide energy for those farmers most likely to be using butane or kerosene at the present time.

Another category of rural dweller who would benefit from biogas is the householder, poor or not, who lives in an area remote from the fossil fuel distribution network. There were found to be many cases of shortages of butane and kerosene in rural areas. In some cases, farms are located in areas without electricity, and here again diesel for generators is becoming increasingly scarce. These are excellent candidates for biogas plants.

It was seen that Agricultural Extension Agents have close associations with farmers at the local level. They understand the needs of the farmers, work with them, and have their confidence with respect to new technology and technology transfer. It would therefore be logical for the Ministry of Agriculture, with approximately 450 Extension Agents, to be heavily involved in assisting farmers to install and operate biogas plants.

It was confirmed in the field surveys that numerous schools and other institutions which utilize large amounts of gas for cooking purposes are associated with agricultural operations. Sufficient agriculture residue materials such as animal wastes are produced at these farms to supply biogas plants, which could generate essentially all the energy required for preparing meals at the institutions.

5.6.2 Present Biogas Development in Jamaica

The SRC has carried out a research, development and demonstration program in biogas technology over the past five years. A design which they have developed and tested represents a combination of Indian, Taiwanese, and possibly Philippine characteristics. For instance, a double wall digester is used, with water between the walls serving as the seal for a floating steel gas collector. The double wall is typical of the Taiwanese design, and the steel gasholder is representative of the Indian design. Development of this combined design appears to be complete, and a family size plant is presently operating on a demonstration basis.

Recently, interest at SRC has focused on the Chinese design, and information recently obtained from China has allowed an accelerated pace of adapting this design to conditions in Jamaica. A demonstration family size plant using a modified Chinese design with a reinforced concrete flat roof is now operating. Two additional family size plants planned to be constructed by April 1980 will be based on the Chinese design. A medium size plant is also under design, and it will probably be constructed as a Chinese style unit.

In summary it would appear that at least one design using a floating steel gasholder and double walls is sufficiently developed by SRC for large scale implementation. The Chinese design is in the initial stages of development, with initial emphasis on design evaluation and determination of the types of building materials available locally which would be consistent with Chinese design requirements.

The Ministry of Mining and Natural Resources (MMNR) requested the evaluation of the designs and calculations in previous MMNR biogas studies by the U.S. Energy Team. This was accomplished, and the design figures and calculations appear to be accurate. In many cases the design concepts have been overly complex, however, such as use of pumps rather than gravity flow, and use of auxiliary heating.

It is recognized that digesters operating at the ambient temperatures of Jamaica result in a lower rate of biogas production than at a higher temperature, but at the same time it would be more cost effective to take advantage of the warm ambient temperatures and use a longer retention time in the digester. A slightly larger digester will allow deletion of costly heating equipment. Numerous pumps are also included in the designs reviewed. All pumps which can be avoided should be omitted, and the system should be designed so that a single pump with proper valving could be used for several waste streams.

The SRC and the Ministry of Mining and Natural Resources hosted a Rural Biogas Generation Workshop for the Caribbean countries in December 1978, and Jamaica was designated to establish a Regional Biogas Coordination Center. This indicates the leadership role of Jamaica in biogas in the Caribbean region.

A basic shortcoming of the Jamaican program in biogas has been a lack of funding for a national program which will provide significant amounts of biogas energy. The SRC has made a contribution in the development to date, and now it remains for the implementation portion to proceed.

5.6.3 Biogas Plant Costs and Economic Analysis

Considerable data exist on biogas plant costs around the world, and there has now been sufficient development of the Indian/Taiwanese design by SRC to arrive at cost factors in Jamaica. The family size demonstration plants designed to date have been approximately 5'x5'x5' in size, or 125 cu ft, and the cost of these plants is estimated to be approximately J. $1000.

It is normal for the Chinese design plants to be somewhat larger in size, since gas storage is maintained internally. Since little if any steel is used in the Chinese units, however, cost and especially foreign exchange costs are significantly reduced. It is estimated by SRC that a Chinese type family size plant would cost as little as J. $300 in Jamaica on the basis that they are reported to cost about J. $80 in China. It is felt that J. $300 is an optimistic figure, however. Costs have not been developed for medium size plants but it would appear that there could be economies of scale, and therefore a medium size plant should be approximately the same or even possibly lesser in cost per cu ft.

There are two methods to evaluate the economics of biogas plants. In one, the actual value of butane or kerosene now being used, which would be replaced by biogas, is emphasized. As stated previously, the range of butane consumption per family is large, but a conservative estimate based on 250 pounds per year at J. $40 per 100 pounds, would be a cost of J. $100 per year. The capital cost of a J. $400 biogas plant would then be repaid in four years.

Another method of economic analysis is to calculate the actual Btu energy value of the biogas produced. Here, the value of any excess biogas beyond that needed for cooking would be included. In this case, at energy factoring of 500 Btu per cu ft and biogas production of 100 cu ft per day, approximately 18 million Btu would be produced per year. This would have a butane value of nearly 1000 pounds and a potential economic benefit of approximately J. $400. The pay back period for a household plant costing J. $400 would be about one year. By either method of evaluation it can be seen that the economics of biogas plants are quite favorable, and will continue to be more so as the price of imported oil continues to increase.

The above economic considerations are on the basis of energy production only. As a matter of fact, there are several other benefits from biogas plants which could be considered in an economic analysis. One of these is the chemical benefit in which the nutrients are held in the digested residue, which increases the fertilizer value. Another is the potential use of the digested residue as feedstock for growth of plants and animals. Fish farms using waste residues are well known in the United States, the Philippines and other countries. The digested residue is also sometimes processed and re-fed to animals. In these cases re-feed value of the residue is three to five times the value of biogas produced in the digestion process. Pollution control is another potential benefit from biogas plants. In summary, it can be seen that there are many benefits beyond energy alone which improves the cost effectiveness of biogas facilities.

5.6.4 Biogas Generation at the University of the West Indies Mona Campus

One of the sub-tasks in the biogas study was to evaluate the potential of biogas collection and use on the Jamaican campus of the University of the West Indies. The campus was visited and the waste treatment facility was inspected. The unit sewage works is located in the southeast corner of the Campus and the outfall flows to August Town Gully and then to Hope River. The plant is a conventional secondary trickling filter waste treatment plant, with the omission of biogas collection from the sludge digesters. Addition of gas collection would require numerous pumps, extra piping, and safety controls which are not now required.

The amount of gas which is produced from human wastes is limited to an average of about 1 cu ft per capita per day. The value of the small amount of gas collected would not justify the cost of retrofitting the sludge digester so as to collect biogas.

Even if gas were to be collected at the sewage treatment plant, there would be little effective use of it. It would not be sufficient to pump the treated sewage to irrigation, or to warrant the cost of installing other equipment powered by gas.

On the basis of the observations made, it is recommended that no effort be made at this time to add a biogas collector to the sewage treatment plant at the Jamaica Campus of UWI. In the event that the plant were to be expanded at a later date, the addition of biogas collection should be reconsidered at that time.

5.7 DISCUSSION OF FINDINGS

5.7.1 Existing Plans and Programs

Although the SRC has developed one biogas plant design, and has tested it to satisfaction so that it could be used in a program of implementation, a national program of implementation has apparently not been planned. Meager funding available to date has been expended on a continuation of R&D efforts. A low cost design is presently being evaluated for application in Jamaica.

5.7.2 Implementation Plan

The sectors of the economy which would be affected by biogas as a source of energy would be largely rural households and institutions such as schools. The plants would be most applicable to those rural farmers who have sufficient animal populations (3 to 5 cattle, 10 to 20 hogs, or 400 to 800 chickens) to provide the necessary biomass feedstock materials.

Based on a preliminary assessment of a small cross section of the rural agricultural sector of Jamaica, it would be appropriate to begin implementing a large scale national program in biogas now. Populations in rural areas are looking to the Government for direction and assistance. (See Appendix E for a summary of the biogas survey conducted in Jamaica).

5.7.3 National Program Options

It is the purpose of this section to develop a national biogas plan with three program options for funding by one or several lending agencies or donors. The proposal is based upon discussions with the Biogas Working Group, but the concepts are primarily those of this study effort. It would be anticipated that modification would occur with additional review and study in preparation of documentation to funding agencies for program support.

It is necessary, during the first two years of any option considered, that a full market study and analysis be undertaken. The survey would provide the baseline information necessary to assess full market potential and provide a systematic mechanism for program implementation. The potential for biogas unit installation could approach 20,000 household units in the rural sector. This is an estimated figure only, which represents 10% of the rural population or 5% of the total population of Jamaica.

5.7.3.1 <u>Option A - Baseline Five Year Plan</u>

A basic five year plan of demonstrating and commercializing biogas plants on a country-wide basis is proposed. The first two years would be demonstration, or more correctly "popularization"; commercialization would be carried out during the last three years of the five year plan. During the five years there would be ongoing functions of research and development, demonstration, commercialization, and training. It is emphasized that research and development, which is primarily the evaluation of alternate designs in order to develop modifications and allow use of materials which are suitable for Jamaica, should be done concurrently with the implementation plan in order not to lose time. It should also be understood that though this study and report focus on smaller biogas units designed to provide methane for use in cooking, a large scale demonstration unit for electricity generation should not be ignored. A further consideration is to explore the feasibility of such a unit for technology gains and possible use in Jamaica and other Caribbean countries.

For planning purposes and to provide various alternatives for consideration by funding agencies, two options are considered in addition to the baseline program. Options are presented in terms of the size of the program and number of units to be constructed each year during the five year period. Different funding agencies may fund parts of the program, or a single agency may select more than one option.

The baseline program consists of a combination of family size (100 cu ft/day) and medium size (2000 cu ft/day) plants. The family size plant would serve the energy needs of a single family, while medium size plants would provide energy for schools or to power stationary equipment and motor generators on large farms. A family size plant would produce energy equivalent to 987 lbs. of butane or 148 gal. of kerosene per year. Likewise, a medium size plant would produce 365,000,000 Btu/yr, equivalent to 19,740 lbs. of butane or 2820 gal. of kerosene. The cost in place of the plants are taken to be J. $500 and J. $12,000, respectively.

One of the conditions of the program of implementation is that R&D, as well as training, must go hand-in-hand with demonstration and commercialization. Demonstration here means popularizing throughout the country the production and use of biogas. Although biogas technology was first proven more than 50 years ago, the public must see actual operating facilities in order to become fully convinced of biogas potential. Therefore, the initial period for all options is to provide this type of country-wide popularization.

The baseline five year program consists of family and medium size plant construction as per the schedule shown in Table 5-6. Three or more household size plants would be built in each parish and one medium size plant in each region (Cornwall, Middlesex, and Surrey) per year of a two year demonstration period. Commercialization would then proceed over the next three years, with a total of 2700 family size units and 41 medium size units constructed at the end of five years. The biogas energy produced per year along with equivalent butane and kerosene values are also shown in Table 5-6. In addition to existing designs, other plant designs will be continuously developed and used as they become tested. Two designs would predominate, the steel gasholder type already developed and the Chinese design now being studied by SRC. Evaluation would continue as an ongoing function, and design would be modified or a particular model terminated if a better one were to prove itself.

The cost of the baseline five year program which includes construction, operation and maintenance, training and management costs, is shown in Table 5-7. Research and development should be heavily funded initially in order to develop and test low cost designs. When these designs are completed, research and development can diminish. As the program is undergoing commercialization in the third, fourth and fifth years the budget for management, training, and operation/maintenance will increase accordingly.

5.7.3.2 Option B - Accelerated Program

Option B would begin implementation of a biogas program at the same rate as the baseline program during the first year, but would accelerate much more rapidly thereafter. At the end of five years under Option B, there would be 11,450 family size and 79 medium size plants constructed. The five year construction schedule and the equivalent energy produced on an annual basis is shown in Table 5-8.

Option B would provide a much larger number of family size units and therefore would have more impact on individual families in rural areas. The cost of the program would be considerably greater than under the baseline program, however. Since the first year would be the same in scope, the

TABLE 5-6

ENERGY DERIVED FROM PROPOSED BIOGAS PROGRAM - OPTION A

YEAR	BIOGAS UNITS	Btu/YR (Million)[1]	EQUIVALENT OIL (Barrels) at 6 MM Btu/bbl	EQUIVALENT[2] BUTANE/YEAR (1000 lb)	EQUIVALENT KEROSENE/YR[3] (1000 Imp. Gal.)
1	50 household	912	152	49	7
	3 medium	1,095	182	59	8
	TOTAL	2,007	334	108	15
2	100 household	1,824	304	98	14
	6 medium	2,190	364	118	17
	TOTAL	4,014	668	216	31
3	300 household	5,472	912	294	42
	11 medium	4,015	669	217	31
	TOTAL	9,487	1,581	511	73
4	700 household	12,768	2,128	686	98
	21 medium	7,665	1,278	414	59
	TOTAL	20,433	3,406	1,100	157
5	2700 household	49,248	8,208	2,645	378
	41 medium	14,965	2,494	809	116
	TOTAL	64,213	10,702	3,454	494

Calculations based on equivalent Btu values, and the following data:

1. 100 cu. ft. of biogas has energy content of 50,000 Btu.
   Household unit yield of 100 cu. ft./day.
   Medium unit yield of 2,000 cu. ft./day.
   All units operating 365 days/year.

2. 1,000 lb. of butane has energy content of 18.6×10^6 Btu.

3. 1,000 Imperial Gallon of kerosene has energy content of 130×10^6 Btu.

TABLE 5-7

PROPOSED FIVE-YEAR FUNDING OF BIOGAS PROGRAM
OPTION A

YEAR 1	J $
Management	10,000
R & D	80,000
Construction	61,000
Operation and Maintenance	7,000
Foreign Consultancy	6,000
Training - 24 man months at $1,000	24,000
1 Vehicle	20,000
YEAR 2	
Management	10,000
R & D	80,000
Construction	61,000
Operation and Maintenance	15,000
Foreign Consultancy	10,000
Training - 36 man months at $1,000	36,000
YEAR 3	
Management	18,000
R & D	60,000
Construction	160,000
Operation and Maintenance	30,000
Foreign Consultancy	10,000
Training - 36 man months at $1,000	36,000
1 Vehicle	20,000
YEAR 4	
Management	18,000
R & D	60,000
Construction	320,000
Operation and Maintenance	45,000
Foreign Consultancy	10,000
Training - 36 man months at $1,000	36,000
YEAR 5	
Management	36,000
R & D	40,000
Construction	1,240,000
Operation and Maintenance	75,000
Foreign Consultancy	10,000
Training - 48 man months at $1,000	48,000
1 Vehicle	30,000
5 YEAR TOTAL	J. $2,722,000

TABLE 5-8

ENERGY* DERIVED FROM BIOGAS PROGRAM OPTION B

YEAR	BIOGAS UNITS	Btu/YR. (Million)	EQUIVALENT OIL (Barrels) AT 6 MM Btu/ BBL	EQUIVALENT BUTANE/YR. (1000 LB.)	EQUIVALENT KEROSENE/YR. (1000 IMP. GAL.)
1	50 Household	912	152	49	7
	3 Medium	1,095	182	59	8
		2,007	334	108	15
2	150 Household	2,736	456	147	21
	9 Medium	3,285	547	176	25
		6,021	1,003	327	46
3	450 Household	8,208	1,368	441	63
	19 Medium	6,935	1,155	373	53
		15,143	2,523	754	116
4	1,550 Household	28,288	4,715	1,520	53
	39 Medium	14,235	2,372	765	109
		42,523	7,087	2,285	162
5	11,450 Household	208,960	34,827	11,234	1,607
	79 Medium	28,835	4,806	1,550	222
	TOTAL	237,795	39,633	12,784	1,829

*CALCULATIONS BASED ON EQUIVALENT Btu VALUES AS PER TABLE 5-1.

accelerated program should be capable of being implemented by sufficient planning and design development for an intensified effort in years 2, 3, 4, and 5. This is provided a previously mentioned full market study is performed, confirming the market potential to warrant implementation of this option.

Research and development costs would be only slightly higher than those of the baseline program. The costs involved in operations and maintenance, construction, management, and research and development are shown on a year-by-year basis in Table 5-9.

5.7.3.3 Option C - Expanded Medium Size Plants Program

It has been the general consensus in the Philippines and other countries that large biogas plants have greater potential for success than small plants. There are several reasons for this. First, large plants would have full time operators, who would provide more consistent operation and maintenance than can be achieved in small plants. Second, other benefits can be advantageous at large facilities because of their size, such as re-feed of digested residues back to the animals.

In Option C the same number of family size units would be constructed, as in the baseline program, with the distinguishing feature being construction of more medium size plants. The five year program would thus consist of 2700 family size and 153 medium size plants, as shown in Table 5-10. Energy produced on a year-by-year basis is also shown in Table 5-10, and costs are shown in Table 5-11.

An attractive feature of Option C is that the additional medium size facilities could be selected for funding by a particular agency which might be different from that which funds the baseline program.

A summary of the energy produced and the cost of the three program options is presented in Table 5-12 for comparison.

TABLE 5-9

FIVE YEAR FUNDING OF BIOGAS PROGRAM
OPTION B

	Jamaican $
Year 1	
Management	10,000
R&D	100,000
Construction	61,000
Operations & Maintenance	7,000
Foreign Consultancy	6,000
Training - 24 man months at $1,000	24,000
1 Vehicle	20,000
Year 2	
Management	10,000
R&D	120,000
Construction	122,000
Operations & Maintenance	14,000
Foreign Consultancy	10,000
Training - 36 man months at $1,000	36,000
1 Vehicle	20,000
Year 3	
Management	18,000
R&D	100,000
Construction	320,000
Operations & Maintenance	45,000
Foreign Consultancy	10,000
Training - 48 man months at $1,000	48,000
1 Vehicle	20,000
Year 4	
Management	20,000
R&D	80,000
Construction	740,000
Operations & Maintenance	75,000
Foreign Consultancy	15,000
Training - 60 man months at $1,000	60,000
1 Vehicle	20,000
Year 5	
Management	35,000
R&D	80,000
Construction	5,500,000
Operations & Maintenance	300,000
Foreign Consultancy	15,000
Training - 150 man months at $1,000	150,000
2 Vehicles	60,000
5 YEAR TOTAL	$8,271,000

TOTAL NO. OF UNITS -

11,550 FAMILY SIZE
79 MEDIUM SIZE

TABLE 5-10

ENERGY* DERIVED FROM BIOGAS PROGRAM OPTION C

YEAR	BIOGAS UNITS	BTU/YR. (Million)	EQUIVALENT OIL (Barrels) AT 6 MM BTU/BBI	EQUIVALENT BUTANE/YR. (1000 LB.)	EQUIVALENT KEROSENT/YR. (1000 IMP. GAL.)
1	50 Household	912	152	49	7
	3 Medium	1,095	182	59	8
		2,007	334	108	15
2	100 Household	1,824	304	98	14
	130 Medium	4,745	790	255	36
		6,569	1,094	353	50
3	300 Household	5,472	912	294	42
	33 Medium	12,045	2,000	648	92
		17,517	2,912	942	134
4					
	700 Household	12,768	2,128	686	98
	73 Medium	26,675	4,440	1,432	205
		39,413	6,568	2,118	403
5	2,700 Household	49,248	8,208	2,645	378
	153 Medium	55,845	9,307	3,002	430
	TOTAL	105,093	17,515	5,647	808

*CALCULATIONS BASED ON EQUIVALENT Btu VALUES AS PER TABLE 1

TABLE 5-11

FIVE YEAR FUNDING OF BIOGAS PROGRAM

OPTION C

YEAR 1	J $
Management	10,000
R&D	30,000
Construction	61,000
Operation & Maintenance	7,000
Foreign Consultancy	6,000
Training - 24 man months at $1,000	24,000
1 Vehicle	20,000
YEAR 2	
Management	10,000
R&D	100,000
Construction	140,000
Operation & Maintenance	18,000
Foreign Consultancy	6,000
Training - 36 man months at $1,000	36,000
YEAR 3	
Management	18,000
R&D	80,000
Construction	360,000
Operation & Maintenance	30,000
Foreign Consultancy	10,000
Training - 48 man months at $1,000	48,000
1 Vehicle	20,000
YEAR 4	
Management	18,000
R&D	60,000
Construction	680,000
Operation & Maintenance	40,000
Training - 48 man months at $1,000	48,000
Foreign Consultancy	10,000
1 Vehicle	20,000
YEAR 5	
Management	36,000
R&D	60,000
Construction	2,200,000
Operation & Maintenance	100,000
Foreign Consultancy	10,000
Training - 150 man months at $1,000	150,000
2 Vehicles	60,000
5 YEAR TOTAL	J$4,376,000

Total No. of Units - 2,700 Family Size
133 Medium Size

TABLE 5-12

SUMMARY OF FIVE YEAR PROGRAM OPTIONS

ENERGY PRODUCED, AND COSTS

OPTION	NO. OF UNITS FAMILY	NO. OF UNITS MEDIUM	EQUIV. OIL (BBLS/YR)	EQUIV. BUTANE (1000 LB/YR)	EQUIV. KEROSENE (1000 GAL/YR)	COSTS J$
A (recommended)	2,700	41	10,700	3,450	490	2,722,000
B	11,450	79	39,600	12,800	1,830	8,271,000
C	2,700	153	17,515	5,650	808	4,376,000

5.8 CONCLUSIONS AND RECOMMENDATIONS

5.8.1 Present Biogas Program

On the basis of field surveys, data analysis, and meetings with the Biogas Working Group and other associated personnel, it is concluded that a national biogas program would be successful in Jamaica. Indicators used in arriving at this conclusion were climate, percentage of the population living in rural agricultural areas, animal numbers, and Jamaica's dependence on imported oil and gas. Jamaica is behind Asian countries who are developing this alternate energy source, in spite of studies of biogas by SRC over the past several years.

Designs which have been slow in developing have finally emerged to the point where at least one such design has been field tested and found to be satisfactory. There is thus sufficient design development now to proceed with at least an initially modest biogas program. Design will be the key to the degree of ultimate success of the program. Design development should therefore be accelerated with SRC in a major role, and as much support as is required should be provided so that this responsibility can be accomplished in a timely manner.

5.8.2 Specific Recommendations

The specific recommendations of this report are as follows:

(1) Finalize one of the SRC family size and medium size biogas plant designs for use in a large scale implementation program. Select the specific design based on available development, qualifications and prototype test results, and commercialization considerations.

(2) Postpone any consideration to install a biogas collector for use at the UWI Mona Campus sewage treatment plant. In the event that the plant were to be expanded at a future date, the addition of biogas collection may be reconsidered at that time.

(3) Implement the Option A baseline five year program immediately. Develop, demonstrate and deploy 2700 family size and 41 medium size biogas plants in Jamaica at the earliest possible time.

(4) Initiate a detailed marketing study and analysis to assess the specific commercialization potential of the selected Jamaican biogas plant designs in Jamaica as well as other countries, particularly those in the Caribbean region.

(5) Study the feasibility of developing and demonstrating a large size biogas demonstration unit to generate electricity at a remote site.

(6) Re-examine the feasibility of implementing the Option B accelerated five year program after the detailed marketing study has been completed within the first year of the baseline program.

(7) Explore the specific interest of other government agencies, international organizations and international financial institutions to fund the additional 112 medium size biogas plants defined in the Option C program.

(8) Establish a Jamaican Government biogas program organization to implement the recommended five year program. Organizational infrastructure is discussed in the next Section.

(9) Establish a comprehensive training program and a broad rural public information program to support the implementation of all facets of the recommended five year program. Both training and public information programs are discussed in the next Section.

5.8.3 Recommended Program

The recommended program includes the following elements:

5.8.3.1 Organizational Infrastructure

The proposed organization for carrying out the biogas program is shown in Figure 5-2. The role of the Energy Division of the Ministry of Mining and Natural Resources would be primarily planning, funding, policy decisions, and monitoring the work of the interacting groups in the biogas program. The role of SRC would be primarily R&D in the development of low cost design, as well as training development. Training assistance may also be desirable from

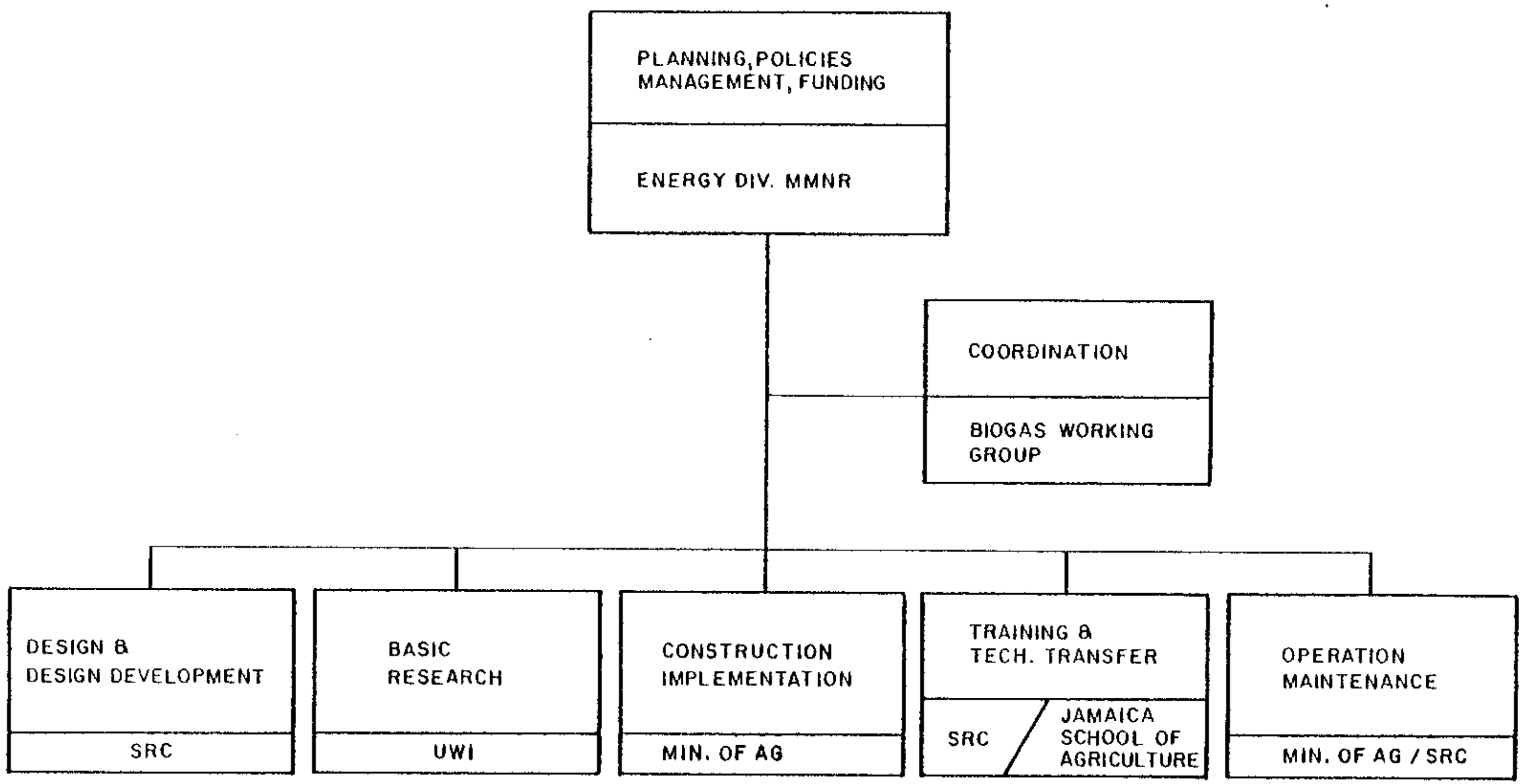


FIG. 5-2 BIOGAS PROGRAM ORGANIZATION

academic institutions and the Ministry of Agriculture. SRC would be called upon as experts to assist in technical matters of the biogas program, and MMNR would then proceed with managing the overall construction and implementation program.

Local contact with farmers could best be carried out by the Ministry of Agriculture personnel, who have more than 400 Extension Agents located throughout the rural area. The Ministry of Agriculture is most aware of the energy needs of farmers and is keenly interested in assisting the rural population by providing biogas information and advice to them.

5.8.3.2 <u>Construction and Implementation Program</u>

The construction and implementation program should be carried out by a combined effort of private industry and government. It would perhaps be appropriate to call in general contractors and consultants from the private sector to work with government officials so that all could be involved in a program to achieve highest quality of workmanship at least cost. Replication of constructed plants by the same team should be encouraged, in order to apply experience in initial plants to the construction of follow-on units. It may be practical to contract out the construction of several biogas plants as a group to the lowest bidder, so that the successful bidder could then build a number of plants. Each successive plant constructed would then be easier to construct, and the workmanship would improve. Alternatively, if each farmer constructed his own unit it would probably be his first and only effort in this type of construction, and the workmanship problems he would encounter would be so reflected. It would be exceedingly difficult for a farmer with few tools and little know-how in masonry to construct a satisfactory biogas plant with proper slopes and conditions of gas-tight biogas storage.

In summary, a national group comprised of the Ministry of Mining and Natural Resources (MMNR), Project Analysis and Monitoring Company, Ltd. (PAMCO), private contractors, SRC, the Ministry of Agriculture, and possibly other ministries would contribute to the construction and implementation program. Actual construction itself, however, would perhaps be best carried out by the private sector to obtain professional quality workmanship at lowest cost.

5.8.3.3 Funding

Funding requirements for the Five Year Program, Options A through C, are shown in Tables 5-2, 5-10, and 5-12 respectively, and are summarized in Table 5-3. It is recommended that funds be provided either to the Energy Division of the Ministry of Mining and Natural Resources, or to an agency designated by this Division, from which they would then be allocated to those organizations who participate in the program.

Biogas programs in most countries have been partially subsidized by government in order to provide incentive to stimulate rapid development. An incentive formula is recommended for Jamaica, the exact nature of which may be determined in final development of financial aspects of the program. It would appear suitable to provide a 50 to 75% subsidy during the initial two year demonstration phase, and 25% in the commercialization phase.

The remaining construction costs could be loans from a revolving fund. It would be desirable to expedite to the degree possible, by simplified processing forms, the issuing of such loans to the owners at a favorable rate of interest. Repayment of the loans could be on a monthly rate schedule which would be less than the cost of the energy normally purchased by the householder. In this way the farmer would pay out no actual funds over and above the costs he now bears for energy.

5.8.3.4 Training

It is envisioned that a substantial training program will be necessary in order to achieve the effects desired from the biogas program. This training would best be carried out by SRC, possibly in conjunction with academic institutions and the Ministry of Agriculture.

Training will be necessary in many facets of the program. Of primary importance is training of Agricultural Extension Agents as to the nature of biogas plants, how they operate, and the basic principles of their design and construction. The major purpose here would be to develop a cadre of personnel who could provide general information to farmers who have interest in biogas plants.

A major objective of training would be to provide sufficient knowledge to Ministry of Agriculture personnel for them to replicate follow-on training programs and supervise construction and start-up of biogas facilities since fermentation in a biogas plant is a biological process, with many types of bacteria involved, a general knowledge of the biology of methane generation is necessary in order to provide assistance in routine plant operating problems. Knowledge is also desirable of certain analytical tests to indicate biological problems which may occur, especially during plant start-up. The owners who operate biogas plants also require training in safety, uses of biogas, and operation and maintenance of their plants. Different levels of training are required for small, medium sized and large biogas plants, with the requirement for knowledge increasing with size of facility. Included in the category of training is also the need to inform the general public about biogas through a newsletter. It was found in the survey that there was a great interest on the part of farmers to be kept informed of biogas plans and programs. All wanted to be included in any mailing or newsletter list for additional information.

A newsletter could be an excellent general training medium by including some facet of biogas construction or operation, in layman's terms, in each issue.

5.8.3.5 Public Education

Since a family size biogas unit can be constructed quite simply, there is a great opportunity for enterprising and energy conscious homeowners to build their own units separate from the government program. In many cases, local cast-off containers and materials are available, and use of the farmers' own labor could result in an extremely low cost facility.

In order to reach more families who would have such an interest, a program to include the basic concepts of biogas energy into the public and private school system is recommended. Prepared material should include an introduction to biogas energy, how it can be produced and used, general features of design, and locations where additional information and assistance can be obtained. If such material were made available by the Energy Information Service of the Energy Division, it could be incorporated at several levels of education and would even probably result in construction of biogas demonstration units as student projects at educational institutions.

5.9 REFERENCES

1. Methane Generation from Human Animal and Agricultural Wastes, National Academy of Sciences, Washington, D.C. (1977).

2. Report of the Prepatory Mission on Workshops on Biogas Technology, United Nations Economic and Social Commission for Asia and the Pacific, Bangkok, Thailand (1975).

3. Biogas Technology and Utilization, United Nations Economic and Social Commission for Asia and the Pacific, Bangkok, Thailand (1977).

4. Report on the Workshop on Biogas and Other Rural Energy Resources, United Nations Economic and Social Commission for Asia and the Pacific, Bangkok, Thailand (1977).

5. Biogas Technology and Utilization, Chengdu Seminar, Sichuan Provincial Office of Biogas Development, (1979).

5.10 APPENDICES

APPENDIX A - Terms of Reference

The study shall assess the feasibility of biogas generation in rural agricultural areas. Included in the assessment shall be an examination of the following: size of livestock holdings, feasibility of collecting animal wastes, and the possible use of biogas to provide cooking and lighting in rural areas that are without access to electricity.

Particular attention should be paid to medium-scale instalations (approximately 100 cattle or equivalent in animal waste) and installations appropriate for agricultural research stations, agricultural schools and other schools and rural communities to be specified by the Government of Jamaica.

The study should also address the feasibility of the generation of biogas as an integral part of the sewage treatment facilities of the Jamaican campus of the University of the West Indies.

Pertinent projects already initiated by the Ministry of Mining Energy Division, the Scientific Research Council, and others should be reviewed in detail. The report should include recommendations for follow-on projects that might be undertaken. In such projects, adaptive programs should be emphasized, rather than basic research.

APPENDIX B - Biogas Programs in Selected Countries

(1) India

India produces annually only about one-third of its national energy requirements, and therefore an extensive program of biogas research and plant construction has been carried out over the past 30 years. The first biogas plants were constructed in 1951, with 8,000 units being built in various parts of the country prior to the 1973 energy crisis. By 1979, the number had reached 50,000, with an ultimate target of 100,000 units. The Government of India has attached great importance to the program because of both energy production and the shortage of fertilizer.

A considerable amount of information is available on biogas research and development in India. The text, Biogas - Achievements and Challenges,[1] was prepared by M. A. Sathianathan and published in 1975 by the Association of Voluntary Agencies for Rural Development. This text and its references serve as an excellent source material. Another text, Biogas Systems in Asia,[2] by S. K. Subramanian, was published in 1977 by the Management Development Institute of India. It provides an update on biogas technology throughout Asia, as well as an interesting analysis of social and economic issues.

The development of biogas plants in India has resulted in preparation of standard designs utilizing concrete tanks, concrete inlet and outlet basins, and steel covers serving as floating gasholders. These standards designs were published by the KVIC (Khadi and Village Industries Commission) as a text entitled Drawings and Estimates of Vertical Gobar Gas Plants,[3].

The digesters have no pumps, motors, mixing devices or other moving parts, and digestion takes place at ambient temperature. Retention time by volume is generally about 50 days. The digesters contain a baffle in the center to prevent short circuiting. The Indian Agricultural Research Institute has developed similar designs, and the National Environmental Research Institute at Nagpur has designed plants to include human wastes in addition to cattle waste. A schematic diagram representative of Indian standard plans is shown in Figure 5-3.

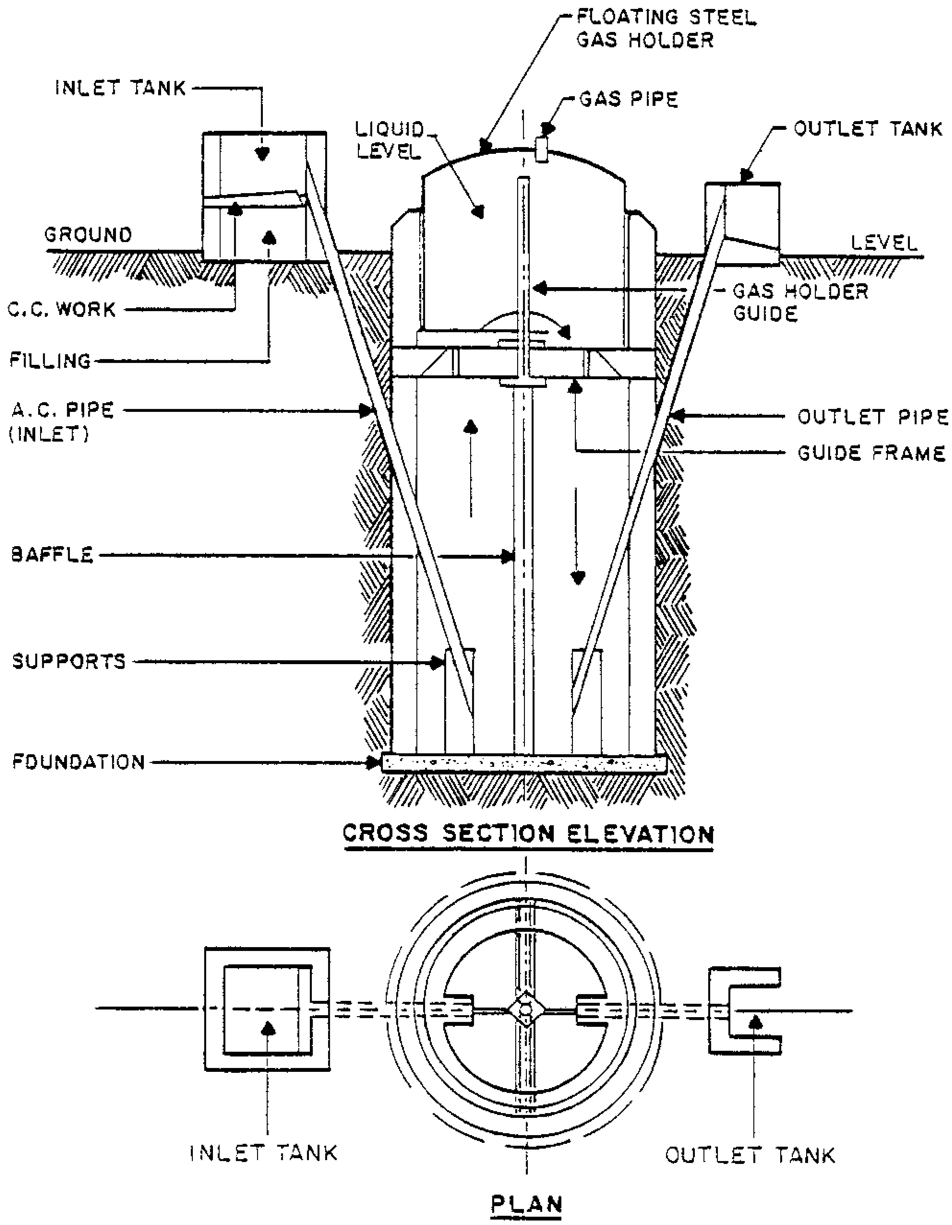


FIG. 5-3 STANDARD INDIAN DESIGN BIOGAS PLANT
WITH FLOATING STEEL GAS HOLDER

The biogas program has had strong governmental support in India[4]. The KVIC provides a technical staff of 400 to approve designs, assist homeowners to obtain biogas plant loans, and aid in construction. Commercial banks, The Reserve Bank of India, and management institutions have been engaged in financial aspects of biogas feasibility. The government policy has been to provide a 25 percent subsidy and loans at prevailing rates for the remaining costs. A benefit-cost appraisal of community biogas plants was made by Srinivasan and Ghosh[5], who reported benefit-to-cost ratios of greater than unity in all cases.

Even with government encouragement, the biogas program in India is not moving ahead as rapidly as initially anticipated. High construction costs and interest rates are major problems. A family unit of 140 to 210 cu ft (4-6 cu m) capacity costs up to Rupees 4,000 (J. $875) in 1979, and the price is likely to increase because of the cement and steel used in construction. Daily labor requirements resulting from the particular designs used are key factors.

Although digested manure is a good soil fertilizer, this is apparently not sufficient incentive to create a continuing national movement to small biogas plants without government stimulation in the form of subsidies and loans.

(2) Republic of Korea

In the Republic of Korea, research and development on biogas has been carried out under the direction of the Organization of Rural Development (ORD), and 30,000 digesters have been installed. Since 1969, the ORD has launched a major campaign to encourage biogas plants which use both animal manure and human wastes as feedstock. The Institute of Agricultural Engineering and Utilization and the Rural Guidance Bureau are in charge of development and application, respectively. The normal Korean digester is of 175 to 280 cu ft (5-8 cu m) capacity. It consists of a concrete tank with inclined inlet and outlet pipes, and has a steel or PVC gasholder. Feeding of the digester varies from once a week to once a month, and consists predominantly of livestock wastes. Gas production is satisfactory except during the colder months of the year, when the temperature drops to as low as -15°F. The gas production then decreases considerably and even ceases at the peak of winter. The cost of digesters in Korea is estimated to range from J. $175 to J. $265. A Korean design manual[6] has been published.

Biogas technology in Korea has been propagated through publications, movies, and slide shows and has been guided by extension workers. A major part of the construction has been carried out by the farmers themselves, and to accelerate the program, the government initially subsidized 33 to 50 percent of the cost. The subsidy was later discontinued and the number of new units being constructed declined.

Only 4,000 new units were constructed in 1975. The severe Korean winter has an inhibiting effect on the biogas program, since extensive heating of the digesters is required just at the time when the energy produced is needed most urgently.

(3) Philippines

In the Philippines, fuel for rural villages is provided primarily by firewood. There is a growing interest in biogas systems, however, which stems from the combination of energy requirements, pollution control, and public health aspects. Livestock wastes used as feedstock to date is primarily hog manure, although cattle manure is used on occasion. The Philippine experience is of interest because of similarities to Jamaica in climate and agricultural practices.

At Maya Farms, where an integrated agro-industrial complex of 10,000 hogs has been established, 48 digesters of 22 cu m each are operating on a batch cycle of 45 days. Stirring of the digester contents is carried out for two minutes each day, and digested sludge from finished batches is used as starter material for new batches. The gas is used within the farm-processing complex as a source of fuel for canning, rendering, cooking and other purposes. Maya Farms is a prime example of the successful development of biogas in the Philippines. An excellent text on the Maya Farms and other biogas facilities in the Philippines has been prepared by Maranba.[7]

(4) Taiwan

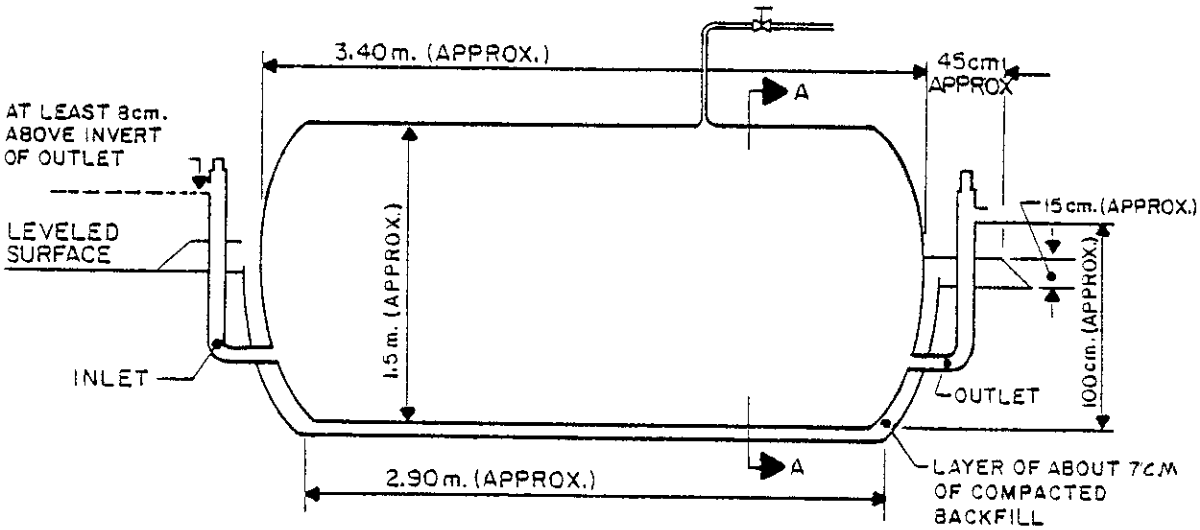
Nearly 7,500 biogas units were reported to be in operation in Taiwan in 1973[8]. Most family size units are designed to handle household and livestock wastes. A unique feature of design is the incorporation of a simple mixing device consisting of three crossed PVC pipes. The pipes are attached to a plastic rope which is taken outside the digester through the outlet pipe. Pulling and releasing the rope brings about the desired agitation of the surface of the digester contents, which assists in reducing the build-up of a scum layer. The use of bag digesters is also reported to have originated in Taiwan[8]. The bag digester, Figure 5-4, consists of a sausage-shaped bag made of 0.55 mm thick Hypalon, laminated with neoprene and reinforced with nylon. It is provided with a PVC inlet and outlet. The advantages of bag digesters are reported to be low cost, mass production capabilities, and easy transportability. They are available in both circular and rectangular configurations and in sizes from 175 to 3500 ft (5-100 cu m).

(5) People's Republic of China

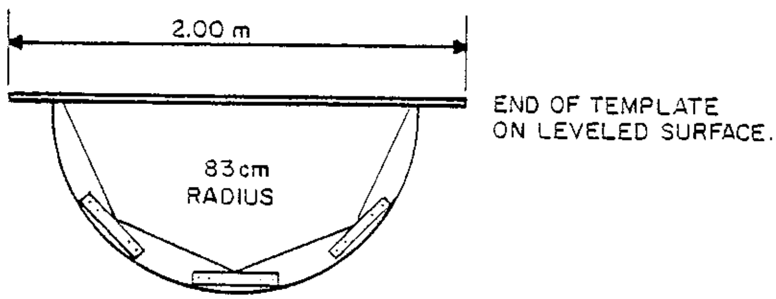
The People's Republic of China has, for many years, processed human waste with other organic matter such as garbage, animal waste and plant materials to produce biogas and fertilizer. More than seven million plants are reported to have been built, and emphasis has been placed on digester design which produces a slurry that can be safely applied to crops.

The following are two reports of biogas plant experience in the People's Republic of China: A Compilation of Data Experience and Sanitary Management of Excreta and Urine in the Village[9] and Experiences in the Treatment of a Fully Enclosed Biogas Plant[10]. These reports have been edited and combined into a single publication, Compost, Fertilizer and Biogas Production from Human and Farm Wastes in the People's Republic of China, by McGarry and Stainsforth[11]. A publication entitled The Construction Technique of Rural Biogas Digesters in China[12], provides the design information.

A significant feature of the People's Republic of China design is incorporation of the gas storage compartment



(a) GENERAL ARRANGEMENT



(b) TEMPLATE FOR MAIN EXCAVATION E.G. SECTION A–A

FIG. 5-4 $5m^3$ BAG DIGESTER (4)

within the fermentation vessel by means of bottles. Diagrams of the Chinese design are shown in Figures 5-5 and 5-6. In Figure 5-5, gas pressure in holding compartment C forces the digester supernatant into the liquid pressure compartment E. This liquid returns to the digester as gas is used, and the pressure of the biogas inside the gas storage compartment is maintained relatively constant by the automatic adjustment of the liquid pressure.

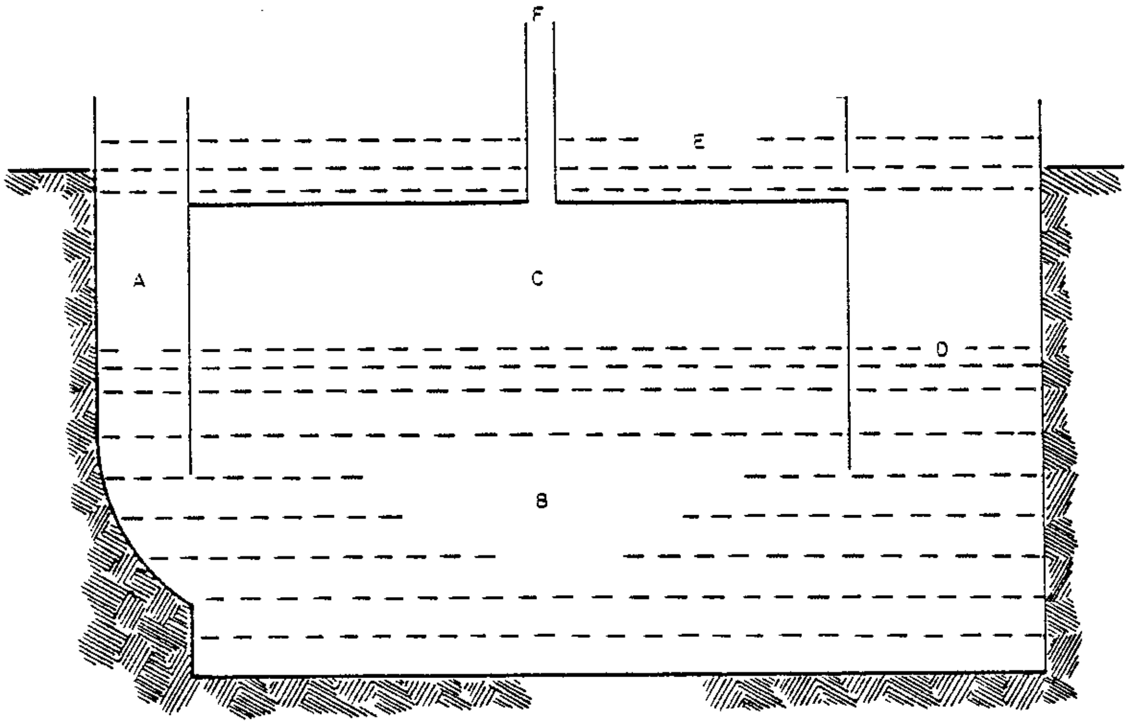
The biogas plant, shown in Figure 5-6, allows removal of the middle layer of digested material through use of an effluent underflow chamber, designated in the Chinese literature as an "applied excreta tank". Use of this chamber is reported to aid in destruction of parasites and eggs present in human wastes in the household units. The middle and upper layers of digested material flow into the effluent chamber through an underwater orifice, representing an underflow condition. Digestion using this design is reported to reduce parasitic eggs by 98%.

(6) United States

The United States has been a leader in biogas research and development from the standpoint of pollution control for the past 50 years. A renewed interest in the generation of methane from agricultural residues occured in the early 1970s, as problems of fuel costs and availability were experienced. United States efforts to improve the technology have been supported by both private and public sectors. Major research on energy from agricultural wastes is underway at universities in Illinois, California, Wisconsin, Minnesota, and New York, with smaller projects being carried out at numerous other universities.

Initial studies of biogas potential on farms were funded by the U.S. National Science Foundation. The U.S. Department of Energy provided financial support for demonstration programs, and the Department of Agriculture participated in large scale agricultural biogas projects. These programs have led to the testing of numerous agricultural biogas facilities.

United States studies have led to the conclusion that, in order to develop a successful biogas program, process design must minimize the use of equipment. This results in a simple plant which is easy to operate, and optimizes the use of each



A — INTAKE CHAMBER
B — DIGESTER
C — GAS STORAGE
D — OUTLET CHAMBER
E — LIQUID PRESSURE COMPARTMENT
F — GAS PIPE

FIG. 5-5 ENCLOSED BIOGAS PLANT SCHEMATIC

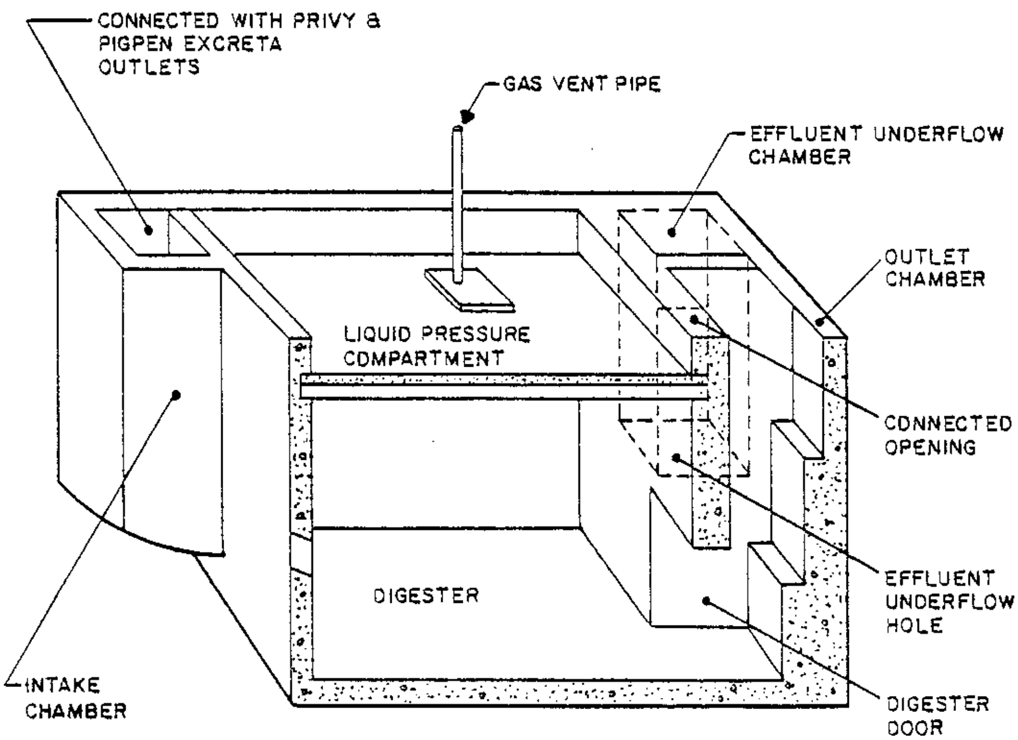


FIG. 5-6 ENCLOSED BIOGAS PLANT SECTION

item of major cost. For example, if expensive fixed wall digesters are used, they should be sized for high loading rates and low retention times. On the other hand, if inexpensive pits were used, other optimization could be carried out to take advantage of providing a longer retention time. This could be reduction of heating, less mixing, or less exact laboratory control. Low-cost gas safety equipment should also be incorporated in digester designs. Topography sould be taken into account in designs in order to take advantage of slope, gravity flow into the digester, and flow by gravity from the digester to disposal lagoons.

References

1. Sathianathan, M.A., Biogas - Achievements and Challenges, Association of Voluntary Agencies for Rural Development, New Delhi, Sagar Printers and Publishers (1975).

2. Subramanian, S.K., Biogas Systems in Asia, Management Development Institute, New Delhi, Statesman Press (1977).

3. Drawings and Estimates of Vertical Gobar Gas Plants, Khadl and Village Industries Commission, Bombay (March 1974).

4. Skrinde, R.T., "Biomass to Energy Technology, International Solar Energy Society Congress, New Delhi", Report to U.S. Department of Energy (1978).

5. Srinivasan, T.G. and Ghosh, U., "A Social Benefit - Cost Appraisal of Community Gobar-Gas Plant", Energy Management, Vol. 1, No. 4, pp. 243-248 (October-December 1977).

6. Design Manual for Methane Gas Producing Facilities, Institute of Agricultural Engineering and Utilization, Division of Agricultural Engineering, Republic of Korea (1976).

7. Maramba, F.D., Sr., Biogas and Waste Recycling - The Philippine Experience, Regal Printing Company, Manila (1979).

8. Po, Chung, "Production of Methane Gas from Manure", Proceeeding, International Biomass Energy Conference, Winnepeg, Canada (1973).

9. A Compilation of Data on Experience and Sanitary Management of Excreta and Urine in the Village, People's Hygiene Publisher, People's Republic of China (1977).

10. Experience in the Treatment and Re-Use of Excreta - Removal from the Middle Layer of a Fully Enclosed Biogas Plant, Revolution Committee, District of Mien Chu, Province of Szechuan, People's Republic of China (1977).

11. McGarry, M.G. and Stainforth, J., Compost, Fertilizer, and Biogas Production from Wastes in the People's Republic of China, International Development Research Centre, Ottawa, Canada (1978).

12. The Construction Technique of Rural Biogas Digesters in China, The Szechuan Provincial Industrial Architectural Design Institute, Province of Szechuan, China.

APPENDIX C - Personnel Interviewed

Ministry of Mining and Natural Resources

Dr. H.G. Lowe	Director of Energy
W.R. Ashby	Senior Energy Engineer
E.H. Haughton	Senior Energy Conservation Engineer
C.A. Rowe	Energy Conservation Engineer
E.C. Alexander	Energy Engineer
P.N. Dowding	Energy Engineer
Mrs. H.E. Daley	Project Coordinator
C.J. Williams	Project Assistant

Scientific Research Council

Dr. K.C. Lee	Senior Principal Scientific Officer
Dr. D.A. Minott	Senior Principal Scientific Officer
G.I.D. Williams	Principal Scientific Officer
K.A. Oxford	Scientific Officer

University of the West Indies, Mona Campus

Prof. G. Lalor	Pro-Vice Chancellor
Dr. D. Radlein	Lecturer in Chemistry
C.E. Simpson	Deputy Estate Manager

Ministry of Agriculture

C.J. Franklyn	Deputy Director, Production Unit
V.G. Stanley	Livestock Development Officer
E.L. Morgan	Livestock Development Officer
V.D. Barrett	Livestock Development Officer

Petroleum Company of Jamaica

W.V. Saunders	Managing Director

Water Commission

Dr. P. Bergeron	Consultant Engineer on Waste Water
M. White	Hydro Geologist

National Planning Agency

Dr. O. Davies	Director, Regional and Social Planning

Private Individuals

L. Cushnie
H. Campbell
C. McKenzie

APPENDIX D - Biogas Survey Questionaire

1. Name and address of farmer ____________________

2. Location of farm ____________________

3. Size of farm ____________________

4. Size of Farm Family ____________________

5. General Contour of Farm:

	Proportion	Location on Farm
Flat		
Sloping		
Hilly		
Other		
Total		

6. Is water readily available on your farm? __________

7. What is the source of water?
   Surface __________
   Ground __________

8. What kind of fertilizer do you use?

	Quantity	Value
Manure		
Commercial		

9. If manure, how do you use it? ____________________

10. ENERGY USES:
What stationary farm and household equipment type do you operate?

	Type	Quantity
Pumps		
Motor		
Machine		
Cooler		
Stove		
Others		

11. Present source of energy:

	Use	Quantity	Value $
Gas			
Charcoal			
Kerosene			
Electricity			
Other			

12. Source of Biomass:

Type	Number	Hours Confined
Cattle		
Hogs		
Poultry		
Sheep		
Goat		
Others		

13. Would you be interested in generating your own energy from the manure on your farm? ____________________
____
____

14. What crops are grown on your farm which require drying? ______________________________
____
____

APPENDIX E - Summary of Biogas Survey

A preliminary survey of private farms and institutions was conducted by the Ministry of Mining and Natural Resources. The period of the survey was from September 17 to October 31, 1979. The results are contained in Table 5-13.

TABLE 5-13
PRELIMINARY SURVEY OF PRIVATE FARMS

PARISH	FARMER	LOCATION	LIVESTOCK PIGS	CHICKENS	CATTLE	BIOGAS POTENTIAL
Kingston & St. Andrew	George Beckford	Content Valley	2,000			Good
	Vincent Morrison	Green Valley	150			V. Good
	Clinton McGann	Mavis Bank	120	20,000		V. Good
	O. C. Johnson	Temple Hall	200		50	V. Good
	Pleasant Hill Piggery	Pleasant Hill	420			Good
St. Thomas	F. E. Fisher	West Albion	70	3,500	15	Good
St. Mary	A. B. Creed	Belfield	150			Good
	Wilfred Cargill	Allepo		12,000		Good
	M. Habber	Tremolsworth	350			Good
	Donald Spence	Hampstead	900	4,000	4	V. Good
	D. Binns	Crescent	430	30,000		V. Good
St. Ann	D&D Farms	Kensington	150			V. Good
	L. C. Todd	Fairfield	33	7,000		Good
	Alcan Ja. Ltd.	Grier Park			2,500	Good
	Neville East	Epworth	200		90	V. Good
St. Catherine	Mr. Thomas	Bog Walk				Poor
	I. Ramsah	Linstead		12,000		Poor
	Bodles Agr. Research Stat.	Bodles	300		3,000	V. Good
Clarendon	A. C. McDonald	Kellits	100			V. Good
	Stanley Boorasingh	Sandy Bay		40,000	20	Good
	Whitehall Farms	Decoy		105,000		V. Good
Manchester	West Indies College	Mandeville			17(200)	Fair*
	Owen Foote	Knock Patrick		12,000		Good
	Vernon Hanson	New Forest	150			Good

*Potential listed as fair, as interest is very high, but there was not enough livestock to provide sufficient biogas.

APPENDIX E - Summary of Biogas Survey (Cont)

TABLE 5-13 (CONT)

PARISH	FARMER	LOCATION	LIVESTOCK PIGS	CHICKENS	CATTLE	BIOGAS POTENTIAL
Trelawny	Arnold Simms	Sherwood content	3		15	Fair
St. Elizabeth	ADC, Goshen	Goshen			200	V. Good
	Ralph Bromfield	Goshen		2,000		Good
	Locksley Beadle	Santa Cruz	2,000			Good
	St. Elizabeth Tech. H.S.	Santa Cruz		5,000	65	Good
Hanover	Stephen Bygrave	Hopewell		400		Fair
	Green Island Secondary School	Green Island		4,000		Fair*
	Sam Edwards	Haughton Grove			60	V. Good
	Collin Wright	Haughton Grove			330	Good
St. James	Howard Reid	Chatham	510			Fair
Westmoreland	Ken Gardner	Cedar Grove	500	1,700		Good
	JBR Williams	Cedar Grove	80 sows		750	V. Good
	Horace Chapman	Struie	9 sows		21	Fair

In all a total of 37 farms and institutions were visited.

Schools showed a great interest in biogas, as their gas bills at present are very high. However, their livestock population is at times insufficient to meet their energy demands with biogas.

St. Elizabeth Tech. High School is favorably located next to an adjoining farm. It is possible that this farm could satisfy their biogas needs.

* Potential listed as fair, as interest is very high, but there was not enough livestock to provide sufficient biogas.

APPENDIX E - Summary of Biogas Survey (Cont)

A survey of government farms and institutions was conducted by the Ministry of Agriculture.

PRELIMINARY SURVEY OF GOVERNMENT FARMS AND INSTITUTIONS

PARISH	FARM	LOCATION	LIVESTOCK Pigs	Chickens	Cattle	Other*	BIOGAS POTENTIAL
Kingston & St Andrew	Bellvue Hospital	Winward Rd.		4,000			Fair
	4-H Training Center	Salisbury Plains		1,000		350	Good
St. Mary	Orange River Agr. Station	Highgate	500		20	3	V. Good
	Richmond Prison	Richmond	114	2,000	33	6	V. Good
St. Ann	Hill Top Juvenile School	Bamboo	23		2		Fair
	Minard ADC	Minard			1,100		Poor
St. Catherine	Tamarind Farm Prison	Spanish Town	50	5,000	34		Good
	Amity Hall ADC	Bushy Park			1,096		Good
	4-H Training Center	Rose Hall				330	Fair
	Dinthill Tech. High School	Linstead	50	10,000	35		V. Good
Clarendon	4-H Training Center	Vernamfield			48		Good
	Denbigh Draal ADC	Four Paths			369	450	Good
	Frankfield Comp. High School	Frankfield	70	2,000	2		V. Good
	Rhymesbury ADC	Rhymesbury			285		V. Good
	Vere Technical High School		30	12,000	23	64	V. Good
Manchester	Grove Place Agr. Station	Grove Place			100	157	Good
	Holmwood Tech. High School	Holmwood	26	900	4	19	Good
	Cobbla Youth Community	Cobbla	75	1,800	110		Good
	Roxborough ADC	Roxborough				268	Good
	Holtz ADC	Holtz				222	Good
St. Elizabeth	St. Elizabeth Tech. High School	Santa Cruz		5,000	65	20	Good
	Munro College	Malvern		850	56		Good
	Goshen ADC	Goshen			400		Good
Hanover	Green Island Sec. School	Green Island		200			Fair

At the time of tabulation of these results, the response had not been evaluated from institutions. The response to a proposed biogas program was very good overall.

APPENDIX F - Data and Reports Reviewed

1. "Jamaica - A Case Study of Energy Planning", by Dr. Trevor A. Byer, National Resources Forum, United Nations, 1979.

2. "Five Year Development Plan, 1978 - 1983", Government of Jamaica, Energy Sector Plan, Ministry of Mining and Natural Resources and The National Planning Agency.

3. "Caribbean Alternative Energy Programme, Report on the Rural Biogas Generation Project Formulation Meeting", Kingston, Dec. 11-13, 1978.

4. Project Profile, "Regional Centre for Biogas Research and Development", Ministry of Mining and Natural Resources, Kingston.

5. "Preliminary Assessment of Biogas Generators for Jamaica School of Agriculture", Ministry of Mining and Natural Resources, Feb. 12, 1979.

6. "Preliminary Assessment of Biogas Plant For Jose Marti School" Ministry of Mining and Natural Resources, Feb. 15, 1979.

7. Project Profile, "Family-Size and Medium-Scale Rural Biogas Generators", Scientific Research Council, May 4, 1979.

8. Project Profile, "Medium Scale Rural Biogas Generators' Scientific Research Council (undated).

9. "Development Plan for the Mona Campus - University of the West Indies (undated).

10. "Conversion of University of the West Indies Sewage Plant to a Biogas Demonstration Unit", UWI Proposal, May 1979.

11. "Proposal on the Recovery of Methane and Electricity from Sewage and Market Garbage", by Dr. Phillipe Bergeron, July 1979.

APPENDIX G - Final Report Conference - Splinter Group Discussion

Before the U.S. Energy Team members left Jamaica, a Final Report Conference was held at the Jamaica Pegasus Hotel, on November 13-14, 1979. During the first day of the conference, the U.S. Energy Team members and Jamaican counterparts presented the findings, conclusions and recommendations of each of the specialized studies. For greater exposure and increased audience participation, splinter group discussions were held during the second day. Each of the studies had a 2-3 hour questions and answer session in which study parameters were reviewed and results highlighted. The following is a synopsis of the Biogas splinter group discussion.

Respondents: Dr. K.C. Lee, Scientific Research Council
Dr. Rolf Skrinde, U.S. Energy Team Member

Q.5.1 When designers experienced difficulty with the stirrer seal, they managed to eliminate the stirrer. However, isn't it true that after a period of time, the mixture surface will harden and prevent gas from forming?

A.5.1 (Dr. Lee) We found that the stirring process greatly increased the reaction of a vegetation waste and animal manure mixture. For animal waste alone, we do not need a stirring process because no hard crust forms. If vegetation matter is used exclusively, the hard crust will eventually form and prevent gas from forming. We also found that if the suspension is sufficiently diluted (9% or less of solid matter) no hard crust forms. So, a good seal stirring device would be necessary only for exclusively vegetation material.

Q.5.2. We have 12 stirring designs in our ministry. I really think SRC should spend time researching the stirring process.

A.5.2. (Dr. Lee) SRC definitely would spend time on stirring device research.

Q.5.3. Will the reaction be affected by a rise in pressure?

A.5.3. (Dr. Lee) Since this is a bacteria reaction, not an ordinary chemical reaction, it does not respond to pressure changes. But, temperature change will affect the bacteria reaction.

A.5.3. (Dr. Skrinde) I would like to add some comments on pressure and stirring. Hollow, concrete pipes under water developed anaerobic reactions; gas pressure rose to such an extent that the pipes exploded. So we see that very high pressure could not stop anaerobic reactions. As for stirring, that is only a mechanical problem. Gas bubbles naturally adhere to fiber and, in doing so, form a crust. Vegetable or plant materials are fibrous, while animal manures are not so fibrous.

Q.5.4. When gas pressure builds up, must we either use or release it?

A.5.4. (Dr. Lee) Pressure generated by biogas usually will not damage the dome, but may cause leakage at the connecting pond. If such leakage occurs, then we will have to release some gas.

A.5.4. (Dr. Skrinde) Gases are maintained in the dome about 3 feet deep into a 10-foot high digester. When the 3 ft deep area is filled with gas, any gas generated beyond that point would react with the effluent and be dissipated into the atmosphere.

Q.5.5. Could we use local material like clay or brick to build the dome?

A.5.5. (Dr. Lee) Clay or brick would be very useful and would reduce the cost of the domes.

Q.5.6. Can we design furnaces that use biogas?

A.5.6. (Dr. Lee) We want to research that possibility, but in the later stages of our program. More important now is that the public be educated about biogas usage.

A.5.6. (Dr. Skrinde) A home industry, biogas plants would provide work and some technological development in Jamaica. It seems quite easy to make the dome out of fiberglass once the mold is cast, and the island already has a fiberglass manufacturer. Can we have some open discussion of this topic?

A.5.6. I incorporated fiberglass, bricks and plastic into the SRC design, all of which decreased the cost.

Q.5.7. Using the Chinese design, is there any possibility of worms or bacteria choking the gas pipe?

A.5.7. (Dr. Lee) No. China has built 7-8 million plants using that design and has never had a problem with clogged pipes.

Q.5.8. (Dr. Skrinde) Research indicates that there is an optimum temperature for biogas production. Can someone suggest how we might use solar energy to achieve this temperature?

A.5.8. (Dr. Lee) Yes. Energy for heating the bacteria is needed, especially at high ground where the temperature is less than the surface. This energy could be supplied by solar power.

Q.5.9. What is the optimum temperature for bacteria reaction?

A.5.9. (Dr. Lee) Mesophilic bacteria reaction decreases as the temperature increases, and finally stops at a temperature of 100 degrees to 105 degrees Fahrenheit. Thermophilic bacteria reaction increases with an increase in temperature. The optimum temperature seems to be 95 degrees Fahrenheit.

Q.5.10. Have you ever used ferrous cement as a material for the domes?

A.5.10. (Dr. Lee) No, but we will look into that.

Q.5.11. In Japan, urban waste is used to build bricks. Do you feel we can try this?

A.5.11. (Dr. Lee) Yes, but it is not appropriate for the biogas project.

Q.5.12. The Kingston Waterfront Sewage Treatment Plant seems to be an appropriate place for a biogas plant, although to date the organic material has been destroyed by the sewage.

A.5.12. (Dr. Skrinde) Unfortunately, no treatment occurs at the plant presently because of mechanical failure. There are several solutions. One is simply to repair the equipment. Another is to spray the partially treated sewage back onto the land as a fertilizer that would save the nutrients and not pollute the harbor.

A.5.12. (Dr. Lee) The plant is not very effective, anyway. It is based on gravity settlement, which leaves a large amount of suspended material in the effluent. I suggested to plant authorities that

A.5.18. (Dr. Lee) Filtering can be instituted with sewage before it enters the treatment plant. Recent treatment plants are not equipped with filters.

Q.5.19. Biogas is composed of methane, carbon dioxide and hydrogen sulfide. Since only the methane burns, would the other gases build up and cause a problem?

A.5.19. (Dr. Lee) The mixture of gases is generally 60 percent methane, 30 percent carbon dioxide, and 10 percent hydrogen sulfide. This mixture burns without any purification process.

A.5.19. (Dr. Skrinde) During combustion, the methane burns and the other gases escape into the atmosphere. Therefore, no build-up occurs in the reactor vessel.

Q.5.20. (Dr. Skrinde) In some countries, the government subsidizes biogas plants. Do you think the Jamaican Government will subsidize development and, if so, how much will be direct grants and how much will be in loan form?

A.5.20. The government should definitely devise a subsidization program.

Q.5.21. How would the government subsidize a family which produced more biogas than it could easily use itself?

A.5.21. (Dr. Skrinde) Community biogas plants could be built, but in the long run they would create too many maintenance problems to be worth the trouble.

Q.5.22. (Dr. Skrinde) How could we implement this program so that it would reach rural people?

A.5.22. Farmers burn wood, as a rule, and use butane on rainy days. The pay back period might, therefore, be longer than you estimate. Moreover, many farmers cannot afford a biogas plant right now.

Q.5.23. Conversion to biogas would cost rural people more because they would have to buy biogas stoves. Does your study reflect the actualities of rural life?

A.5.23. (Dr. Skrinde) We tried to reflect as many particular circumstances as possible, but biogas is obviously not feasible for every family.

Comment (Dr. Lee) As time runs short, I would like to suggest that the government subsidize 20 percent, lend 70 percent for a 3 year period, and require the farmers themselves to pay 10 percent.

Comment If the biogas report concludes that biogas systems are feasible for farmers, the Ministry of Agriculture would review this report and appropriate funds for such a program.

A.5.23. (Dr. Skrinde) Also, the SRC has done some research and development on adapting regular stoves to biogas use.

Q.5.24. Hydrogen sulfide has a very unpleasant odor. Did you find any hydrogen sulfide at your demonstration plants?

A.5.24. (Dr. Lee) At one of our demonstration plants, there was no odor at all. At the other, there was some. In either case, the actual chemical reaction within the plant is not affected.

Q.5.25. Are you implying that there is no odor during the gas generation process?

A.5.25. (Dr. Lee) Yes, a properly constructed generator is odorless because it is air-tight.

A.5.25. (Dr. Skrinde) Biogas has only a small amount of hydrogen sulfide. The problem it poses is not its odor, but its corrosive quality.

A.5.25. (Dr. Lee) The Chinese have found that corrosion does not occur in the engine because the temperature is too high. Corrosion does occur, however, in the exhaust pipes.

A.5.25. (Dr. Dague) A possible solution of the corrosion problem is to use the iron sponge technique (wood chips with iron oxide) to remove sulfide. You can regenerate the iron sponge by exposing it to air.

Q.5.26. Is it possible to use biogas for farming needs other than cooking?

A.5.26. (Dr. Skrinde) Unfortunately, there is no economical way to convert biogas to fertilizer, but it can provide fuel to run engines. It is generally good for household appliances.

A.5.26. (Dr. Lee) Biogas could be used to pump water for irrigation and to generate electricity. It would be difficult to use biogas in tractors because you have to go through a dangerous and expensive process to liquefy the biogas.