CEER – X-113

BIOGAS POTENTIAL IN THE REPUBLIC OF PANAMA

MICHAEL D. ERDMAN

TABLE OF CONTENTS

BIOGAS POTENTIAL IN THE REPUBLIC OF PANAMA

M. D. Erdman

ABSTRACT

A technological assessment of biogas production potential and the impacts of this technology were undertaken in the Republic of Panama. The assessment data were collected from various National government agencies, during interviews, and from site observations during a two-week period. An estimated 34.1 to 132.3 11.3, 103.1 to 181.4 and 20.5 to 34.5 x $10^6 m^3$ of biogas could be produced annually from readily collectable animal, aquatic, agro-industrial and community wastes, respectively. This biogas would provide 3.1 to 8.71 x 10^9 MJ of energy, which is equivalent to 61.5 to 172.8% of the electrical energy supplied nationwide in 1979. Plant biomass and other organic residues also could be anaerobically fermented to produce biogas. Although biogas production potential exists, limited effort and resources have been devoted to this alternate energy production process in Panama. Three studies and three projects were proposed to evaluate and stimulate biogas production and use. The proposed study or project, estimated time (years) requirement, numbers of staff members and cost requirement (dollars) were: resource and energy study, 1.0, 2.0 and $36,700; biodegradability study, 1.5, 1.0 and $41,620; design and material study, 0.33, 3.0 and $21,800; residential biogas project, 3.0, 11.0 and $996,380; cooperative and community

biogas project, 3.0, 5.0 and $784,630; and industrial and governmental biogas project, 2.0, 2.0 and $109,000, respectively. Biogas production and use could impact: 1) the residential sector where 46% of the population does not connect to the electrical grid; 2) cooperatives and small communities with biomass resources and 3) industrial and governmental sectors producing sufficient organic matter waste by-products during normal operation.

INTRODUCTION

Electricity production in the Republic of Panama is under the authority of the Instituto de Recursos Hidraulicos y Electrification (IRHE). In 1979, IRHE produced a total of $1.4x10^6$ million watt hours of electricity, which was obtained from petroleum (55%) and hydro (45%) sources (2). Due to increasing costs of petroleum fuels and high capital investment costs for hydrogenerating systems, alternative energy resources are being investigated.

Biogas, a mixture composed primarily of methane and carbon dioxide, is produced during the anaerobic fermentation of organic matter. The anaerobic fermentation process is currently viewed as a three-stage process. During the first stage, the fermentative bacteria hydrolize complex carbohydrates, proteins and lipids and metabolize these simpler compounds to fatty acids, hydrogen and carbon dioxide. During the second stage, the acetogenic bacteria metabolize the simpler fatty acids and produce acetate, carbon dioxide and hydrogen. During the third stage, which is strictly anaerobic, methanogenic bacteria metabolize the products of the first two stages (primarily acetate, carbon dioxide and hydrogen) to produce a gaseous mixture of methane and carbon dioxide (5), commonly called biogas.

The advantages of biogas production and use are: the fermentation substrate can come from local origin; the fuel can be used to perform useful work in a variety of ways (i.e., cooking, lighting, refrigeration, electricity production); the fermentation equipment can be fabricated from locally available materials and labor skills and the energy source can be stored (1). The pollution potential of discarded organic matter also can be greatly reduced and many pathogenic microorganisms can be destroyed during the anaerobic fermentation.

Biogas production has been conducted by batch, continuous, plug flow, anaerobic filtration, contact processes and multistage fermentation techniques. These fermentations also have been evaluated under low and high solids loading rates, at various fermentation temperatures and pH (14). A brief review of the various approaches used during the anaerobic fermentation process is presented below.

Batch Fermentations.

In batch fermentation, organic matter and innoculum are added to the fermenter. The fermenter is then sealed to exclude oxygen and the fermentation is allowed to proceed until the substrate supply is depleted or biogas production decreases or stops. The fermenter contents are then removed and the process repeated. Batch fermentations have the advantage of requiring small labor inputs; however, this advantage is offset by a long lag period and discontinuous biogas production. This type of fermentation is generally considered impractical for agricultural waste or biomass fermentations because of the high capital costs for the fermenter.

Continuous Fermentations.

Fermentations of this type are fed on a continual or semi-continual basis. Due to feeding routine and fermenter capacity, an equal amount of material is generally displaced from the fermenter at the time of feeding. The IRHE is currently constructing a fermenter of this type. This fermentative approach has the advantages of continuous operation and relatively constant biogas production. Furthermore, the fermenter capacity can be more closely designed to meet the biogas operating requirements, which reduces capital investment costs. In a plug flow fermentation, the waste substrate is periodically added to the fermenter and successively displaced through the system by subsequent substrate additions. Plug flow fermentations have been reported in Germany (11), South Africa (9), England (4) and Puerto Rico (7).

High-rate Fermentations.

A high rate fermentation uses agitation and temperature control to insure that the fermentation proceeds at a stable optimum rate. This approach was initially developed for use in sewage disposal. This fermentation approach is generally recognized as essential for optimizing fermentation rate (14). Potential disadvantages of the high-rate approach are high energy inputs to maintain agitation and temperature, sophisticated control mechanisms and high capital equipment costs. Since this type of approach has been widely used in human waste treatment plants, much information and technical expertise is available. However, the costs for these services or equipment may be prohibitive.

Anaerobic Filtration.

In an anaerobic filtration process the microbial populations attach and colonize on a support structure within the fermenter. The media substrate is then passed over the microorganisms. In this fermentative approach the microorganisms essentially stay within the fermenter and are not displaced as in the high-rate or plug flow fermentations. Although this approach has been demonstrated, only wastes with a relatively low biological oxygen demand (BOD) of 200 to 10000 mg/l were considered applicable (14).

Anaerobic Contact Fermentation.

The anaerobic contact process returns settleable solids and microorganisms back to the fermenter for further degradation. This approach allows for a rapid fermentation, which decreases the fermenter capacity requirements. The major difficulties with this type of approach are the poor settling characteristic of various wastes, especially those with trapped gas particles attached, and the low solids requirement in the inlet waste stream.

Multistage Fermentation.

A multistage fermentation is designed to isolate and optimize the individual metabolic conditions for the major groups of bacteria involved in the process. Theoretically, this would result in improved fermentative efficiency and reduced capital and operating costs. Pfeffer (12) reports that a multistage fermentation is more efficient than a complex mix system, but if the system is stressed, failure of the multistage system is more rapid (14).

All the preceding fermentation approaches have been successfully demonstrated. The advantages and disadvantages of each approach, however, vary depending upon many variables, such as: substrate type and supply; operating parameters; biogas needs; labor; economic and social considerations.

The objectives of this study were to identify geographic areas where biogas production and utilization would interface in the Republic of Panama; identify and evaluate existing biogas technologies; identify studies and resources to develop biogas production potential; develop a national biogas plan and identify a series of projects to be developed within five years to expand the national biogas program.

METHODS AND MATERIALS

The assessment data was obtained from various national governmental agencies in the cities of Santiago and Panama, during interviews and at site visits during a two-week period (March 23 to April 3, 1981). An itinerary for the assessment period is presented in appendix 1. Summary reports of the site visits and interviews are presented in appendix 2.

RESULTS

Current Biogas Program in the Republic of Panama.

A biogas development program was initiated in 1979 by IRHE through an Agency for International Development (AID) grant program. The biogas program was situated within the Alternate Energy and Conservation group of IRHE. The program is directed by an engineer who is presently the only full-time program member, operating with a budget (excluding salary and overhead) of twenty thousand dollars for the two-year program. IRHE is currently installing a 20-m^3 flexible, horizontal, plug-flow, semi-continuous anaerobic fermenter at a farming cooperative near the city of Santiago. The fermenter is being constructed of hypalon and will use a solar collector operating by thermosyphon for auxiliary heating. Swine waste (SW) solids will be manually collected from a concrete-floored farrowing building and diluted with water to approximately 10% total solids. The mixture will then be added to the fermenter daily. The design resembles the Taiwan, Republic of China, red-mud plastic methane converter (3) fitted with a premixing tank commonly found in the Gobar design from India (13). Materials for the fermenter construction and monitoring are being supplied by IRHE. Land, construction labor, daily operating labor and monitoring will be performed by the farm cooperative members under the supervision of IRHE.

A second fermenter is currently being designed by IRHE for installation at another site. Both IRHE fermenters are expected to cost approximately twenty thousand dollars.

The Instituto Agropecario Jesus Nazarano (see appendix 2) has an operating 14-m^3 anaerobic fermenter with 20-m^3 of biogas storage capacity. This fermenter has been in operation since 1979 and the biogas is being used for cooking in the school cafeteria. Digested effluent from the fermenter is added to an aquaculture pond, which is harvested annually. The amount of SW produced at the farm was greater than the fermenter capacity; therefore, maximum biogas production potential has not been obtained.

A red-mud plastic flexible fermenter has been ordered and is awaiting arrival and installation at the school. The additional fermenter capacity is expected to provide sufficient biogas for all cooking at the school and the excess will be used in spark-ignited, internal combustion engines.

No other biogas plants have been located within the Country at the present time, although plans are being considered for a biogas plant installation at a municipal slaughterhouse currently being constructed.

<u>General Characteristics and Geographic Sites for Biogas Production</u>.

Biogas production, in order to be economical and energy efficient, must be located near substrate resources. The Republic of Panama is politically subdivided into nine major provinces and a nonprovincial area known as Comarca de San Blas. Due to the low population and limited accessibility of the San Blas area, little information was available for consideration in this report.

The national economy of Panama is based primarily upon agriculture and services. The principal agricultural commodities are bananas, sugar, rice and coffee. Secondary agricultural products of importance are meat and animal by-products, vegetables and root crops and fruits.

The data presented in Table 1 lists some general characteristics of the Country. The population of Panama is approximately 1.8 million and 45% of the population reside within the province of Panama. The provinces of Darién and Bocas del Toro have the lowest populations and densities within the Nation. The population density varies from 0.4 to 0.7 persons per hectare (HA) in Darién and Panamá, respectively. Provincial densities are comparable for low density areas of Darién and Bocas del Toro, intermediate areas of Los Santos and Veraguas and average density areas of Coclé, Colón, Chiriquí and Herrera.

The greatest production of cattle, swine and poultry occurs in the areas of Chiriquí, Veraguas and Panamá, respectively. The lowest animal production areas are Darién, Bocas del Toro, and Colón. Chiriquí and Coclé produce the greatest amount of coffee and rice, while the least amount of these commodities is produced in Bocas del Toro and Darién. Banana and sugar cane production (data not presented) are greatest in the areas of Chiriquí and Bocas del Toro, Coclé and Panamá, respectively.

ns[3])	Principal slaughter houses	Slaughtered[3]		Production[3] (Kg)			
		Cattle	Pigs	Coffee	Rice	Corn	Beans
.1	--	1161	588	13608	1778112	489888	9072
.4	4	34388	10009	1161216	22920408	3157056	108864
.6	2	9277	8975	548856	2444904	2839536	140616
.1	5	47769	12372	3356640	78304968	8677368	1310904
.4	--	202	589	4536	2272536	4826304	72576
.1	--	5644	4623	263088	8827056	7838208	322056
.4	2	27692	13062	90720	13363056	17041752	254016
.4	6	45598	47065	362880	12546576	7420896	195048
.2	1	24803	7763	344736	19926648	12201840	852768
.7	20	196534	105046	6146280	162384264	64492848	3265920

The electrical power distribution characteristics are presented in table 2. In 1979, IRHE provided electrical service to a total of 220,058 customers. The distribution of residential, commercial and industrial users was 90.1, 9.5 and 0.4%, respectively. The numbers of residential customers were greatest in Panamá, Los Santos, Colón and Herrera provinces and represented 76, 55, 53 and 49% of the total number of families within these provinces. Currently an estimated 46% of the nation's families are without electricity and could, therefore, be greatly impacted upon by the biogas technology for nonelectrical cooking, lighting and refrigeration. Although electricity production from biogas is feasible, the capital investment costs and low efficiency preclude this method for the residential sector. The areas and relative importance of biogas production are greatest in Bocas del Toro > Darién > Veraguas > Coclé > Chiriquí > Colón > Los Santos > and Panamá.

The residential and commercial energy sources used in Panama are presented in table 3. Wood provides an estimated 70.4% of the total energy requirement used in the residential and commercial segments within the Nation; electricity and refined gas represent the other major energy sources currently used. In areas without electricity, wood and charcoal, kerosene and refined gas would increase in importance.

The major uses of biogas are presented in table 4. Biogas production has been used for cooking, lighting, refrigeration,

Table 2. Electrical power distribution characteristics

Province	IRHE Customers[1] Residential	Commercial	Industrial	Families[2]	Residential families with electricity (%)	Residential families without electricity (%)
Bocas del Toro	441	59	--	10759	4.10	95.90
Cocle	9236	798	44	28177	32.78	67.22
Colon	17816	2162	6	33421	53.31	46.69
Chiriqui	20573	2483	472	57791	35.60	64.40
Darien	517	99	--	5321	9.72	90.28
Herrera	8020	862	38	16439	48.79	51.21
Los Santos	7708	828	17	14096	54.68	45.32
Panama	126474	12863	231	166722	75.86	24.14
Veraguas	7531	712	68	34778	21.65	78.35
Total	198316	20866	876	367504	--	--

[1] 1979.

[2] Estimated using the average of 4.98 persons/family; population numbers from table 1.

Table 3. Residential and commercial energy sources and uses in the Republic of Panama[1]

Energy Form	(%)	Use
Electricity	17.5	Lighting, Refrigeration, etc.
Refined Gas	10.4	Cooking, Transportation
Kerosene	1.5	Lighting
Wood	70.4	Cooking
Charcoal	0.1	Cooking

[1]IRHE, 1978.

Table 4. Biogas uses

Uses	Specification	Quantity (m^3/hr)	Efficiency
Cooking	per person/day	0.34-0.42[a]	high
Lighting	per 100 candle power lamp	0.17[a]	intermediate
Refrigeration	per m^3 capacity	1.20[a]	intermediate
Industrial hot water or steam	per liter of boiling water	0.11[a]	high
Electricity generation	per hp, 25% efficiency	0.45-0.51	low (11-15%[b])

[a]From National Academy of Sciences, 1977

[b]From Hashimoto et al, 1980

steam and electricity production. The major uses and relative importance ranking of biogas production in the residential areas of Panama are for cooking > lighting > and refrigeration.

A list of identified, underutilized resources of potential biogas production value and estimated annual biogas production potential are presented in table 5. Five major sources of organic matter have been identified: animal residues, plant biomass, agro-industrial residues, commercial residues and residues accumulated as a result of governmental services. An estimated 34.1 to 132.3, 11.3, 103.1 to 181.4 and 20.5 to 34.5 x $10^6 m^3$ of biogas could be produced annually from readily collectable animal, aquatic, agro-industrial and government collected wastes, respectively. The biogas would provide 3.1 to 8.71 x 10^9 MJ of energy, which is equivalent to 61.5 to 172.8% of the electrical energy supplied nationwide in 1979. Plant biomass and other organic residues also could be anaerobically fermented to produce biogas.

Animal, plant and human residues appear to be the greatest potential resource base for the residential sector outside the capital city. Although animal residues are produced in the greatest amounts, the usual non-confinement housing of animals throughout the Nation greatly limit the amount of waste which is readily collectable.

In the capital city, garbage and human residues are the residues of greatest importance. Both renewable resources are under

Table 5. Biogas production potential from underutilized resources

Residue sources	Annual production Kgx10^8 (wet basis)	Readily collectible waste (%)	Biogas production per unit weight[4] (m^3/Kg)	Annual biogas production potential from collectible wastes (x$10^6 m^3$)
Animal				
Cattle	129.0	5-20	0.3	30.0-120.0
Swine	2.4	10-30	0.7-0.8	2.1- 6.3
Poultry	2.5	10-30	0.3	2.0- 6.0
Plant				
Grasses	UNK[1]	20	0.5	--
Aquatic plants[2]				
<u>Hydrilla</u> <u>verticillator</u>	7.5	50	0.3	11.3
Banana	UNK	40-60	--	--
Coffee	0.003	40-60	0.5	0.14
Citrus	UNK	40-60	0.3-0.4	--
Agro-industrial				
Slaughterhouses	0.3	80-100	0.3	2.3- 2.9
Distilleries	8.4-11.9	80-100	0.15	100.8-178.5
Commercial				
Cafeteria wastes	UNK	80-100	0.3	--
Store wastes	UNK	80-100	0.3	--
Vegetable wastes	UNK	40-60	0.3	--
Governmental				
Garbage[3]	1.7-2.0	100	0.014	2.4- 2.8
Human	8.2	70-100	0.38	18.1- 31.7

[1]UNK - defined as unknown.

[2]Canal Zone only.

[3]Panama City only.

[4]Dry basis.

governmental regulation, and produced in large amounts.

Although only five major sources of organic matter have been identified, essentially all organic matter could be a potential fermentative substrate for biogas production. Optimization and exploitation of additional microenvironments with suitable resources and energy needs also could enhance biogas energy production.

Recommended Studies to be Undertaken to Fully Assess the Biogas Potential.

Resource and Energy Study.

The first step in evaluating the potential for biogas production in Panama would be to make an accurate resource and energy assessment for the entire Country. This study would be subdivided into two sections: 1) resource identification, characterization and supply; and 2) energy requirements. The major objective of the study would be to identify and quantitate all potential resources and energy interface locations within the Nation. This information could be obtained through surveys, site visits and laboratory analysis. A partial list of important physical and chemical parameters to be identified during the study are listed in appendix 3.

Successful collection of this information would document and identify the size, potential and impact of developing the biogas technology in the Country. The information collected also would assist engineers in matching the biogas plant size to the present and future energy needs of the area.

The estimated time, staff and budget requirements necessary to carry out this study are presented in appendix 5. It is estimated that two staff members could complete this study within one year with an operating budget of $36,700.

Biodegradability Study.

The primary objective of this study would be to determine the biodegradability rate and biogas production potential for the individual substrate resources previously identified. The biodegradability rates could be determined by any of three approaches: literature review, *in-vitro* and *in-vivo* assays. A literature review approach would rapidly reveal previous research efforts for common substrates such as animal wastes, thereby reducing the time, effort and costs incurred in laboratory evaluations. Uncommon resources or resources with limited published data would require biodegradability assays using the *in-vitro* fiber analysis procedures (6) and chemical determinations (see appendix 3). These procedures are rapid and can be easily performed in analytical fiber and forage laboratories. The *in-vitro* approach is advantageous when compared to *in-vivo* assays because many different resources can be evaluated rapidly (generally within one week) and economically. The disadvantage of this approach is that actual biodegradability is only assumed.

The *in-vivo* method to evaluate biodegradability of a resource is to conduct controlled, laboratory-scale anaerobic fermentations and determine the chemical changes and the biogas yield. In this approach the actual biodegradability is determined and the fermentation parameters (i.e., pH, total and volatile solids loading rate, retention time and temperature) are optimized for each resource type. This type of evaluation provides the necessary information to enable engineers to design a biogas plant when supplemented with the data collected in the resource and energy study. The disadvantages of this approach are the long time requirements and the high equipment and labor costs. For example, a single substrate could require up to two years to be fully evaluated in a well-equipped laboratory.

Due to time and economic restraints, it would appear most advantageous to perform the literature and *in-vitro* evaluations first, and then conduct the *in-vivo* analysis only on resources of major importance.

The estimated time, staff and budget requirements necessary to carry out this study are presented in appendix 6. It is estimated that 1.0 staff member could complete this study within 1.5 years with an operating budget of $41,620.

Design and Material Study.

The primary objective of this study would be to educate, select the optimum biogas design, construction materials, and produce working designs for residential, cooperative, community and governmental sized biogas plants in Panama. This relatively short study would essentially demonstrate to the engineering staff the various approaches and materials that have been used throughout the World. The information collected along with the engineering skills and knowledge of the economic, cultural and social characteristics in the Country would allow for selection of an optimum system for local use.

Economic and social conditions within Panama would tend to reflect the need for the fermenter to be economical and simple to construct, operate and maintain. The residential fermenter designed and built in the People's Republic of China (8) and India (13) may be best suited for use in Panama. These fermentation systems are generally constructed from locally available materials and at relatively low cost. Construction is also labor intensive and would result in increased employment potential for the labor force. The plants basically contain a masonry constructed fermenter and biogas storage system. The biogas produced is used primarily for cooking and lighting. Alternatively, the red-mud flexible line from the Socialist Republic of China is easy to install and can be operated almost immediately. However, the cost of importing the fermenter to Panama may be economically prohibitive. Development of a locally produced, flexible, self-contained fermenter system may be desirable if an economical, durable liner can be produced,

Biogas fermentation equipment has been constructed out of various types of steel, reinforced concrete, ferro-cement, concrete block and mortar, plastic, glass and flexible covered pits. The selection of construction materials can greatly influence the cost and economics of the complete biogas system, and should, therefore, be carefully considered at the system design stage. An ideal construction material would be one which is: locally available; durable and resistant to material fatigue; easily installed and repaired in place with local labor skills. The construction material also should be economical and easily modified.

Pipe lines for biogas transfer between fermenter, storage and end-use locations have been made from plastic, rubber, metal and glass tubing. Important considerations in selecting the correct tubing would be one which has a minimum of joints which tend to become susceptible to leakage with time. Although conventional standard lengths of PVC piping have been successfully used for biogas transfer, the number of connections required and the detrimental effects of insolation to the exposed pipes may reduce its cost advantages. Continuously extruded PVC pipe, which is buried or protected from insolation and mechanical damage, would reduce the possibility and danger of biogas leaks.

The estimated time, staff and budget requirements necessary to carry out this study are presented in appendix 7. It is estimated that 3.0 staff members could complete this study within 0.33 years with an operating budget of $21,800.

<u>National Biogas Plan</u>.

The primary objective of a national biogas program would be to develop biogas production from underutilized resources for use as a petroleum substitute in residential areas, cooperatives and small communities with biomass resources, and the industrial and governmental sectors. Secondary objectives would be to: increase the net available energy within the Country; improve the standard of living for people without electrical power; increase overall national employment; and recycle valuable nutrients present in the fermented effluent and residue. Implementation of this program would reduce the rate of petroleum importation and environmental pollution currently resulting from the direct discharge of wastes into waterways.

The national biogas plan should be designed to provide the greatest impact to the areas within the population where the need is the greatest and the technology is most applicable. Three potential targeted areas of impact have been identified: individual residential housing areas without electrical grid connections, water or municipal sewage disposal facilities; cooperatives and small communities with biomass resources; and the industrial and governmental sectors producing sufficient organic matter waste by-products. The rural communities appear to offer the greatest impact potential for this technology.

The national program goals should be to: identify, colate and disseminate vital statistics on the size and description of the currently available underutilized resources throughout the Country (a list of important physical and chemical characteristics of the resources and the energy needs near the resource areas are presented in appendix 3); determine the energy needs and biogas applications in the targeted impact areas; collect available published information concerning biogas production from World sources (a partial list of potential information sources is presented in appendix 4); identify the biogas production potential of available resources (see appendixes 3 and 4); disseminate available information; educate the targeted area groups of the biogas technology; secure funding and/or establish loan programs from the Government and private sectors to finance actual construction (alternative sources of funding may be obtained through grants or direct loan programs by the U.S. AID, the Food and Agriculture Organization of the United Nations, the World Health Organization of the United Nations, the World Bank and the Caribbean Development Bank); make available designs for cost effective biogas plants; provide information and advise on operating, maintaining and troubleshooting biogas plants; assist in the development of large-scale biogas plants; provide technical assistance to individuals and groups within the targeted impact areas; strive to improve the energy concentration and yield of biogas from available resources; and improve the efficiency of devices using biogas fuel.

The national biogas plan should be designed to increase the knowledge and use of this technology wherever applicable throughout the Country. Seminars, bulletins and public affairs advertisements may stimulate interest and development. Attempts to stimulate interest within the universities, technical schools and secondary schools would further result in improved interest, knowledge and development of a biogas resource base.

Biogas Projects to be Developed.

Three major areas have been identified where biogas production could impact the Panamanian energy situation. These impact areas are the rural residential family units currently without electricity, cooperatives and small communities with biomass resources and electrical energy limitations, and industrial and governmental sectors with sufficient organic matter resources.

Electricity availability within the Nation is generally confined to the relatively level southern regions along the major roadway. Therefore, development of the biogas technology in areas removed from the grid or future grid areas would appear most desirable. Although hydro resources abound in the western region, electrical development and grid connections may require a considerable time frame in order to connect the rural homes in the mountainous regions. Therefore, biogas development in this area may be applicable.

The relative abundance of wood, compared to the low population densities in the eastern region, tend to support the continued use of wood for cooking. However, since biogas can be used for lighting and refrigeration (1), development of this technology in this area may also be desirable. The northern coastal region, which has limited electrical resources, also appears to be a region ideally suited for the residential and community development of the biogas technology.

The western and northern regions of Panama and the more arid southern region appear to be best suited for development of biogas technology.

Residential Biogas Project.

The rural residential housing areas appear to offer the greatest opportunity to impact upon the largest population (46%) within the Country. In order to develop this area, a residential biogas project is proposed. The objectives of the project are to educate the rural community of the importance and benefit of the biogas technology and to install regional demonstration biogas plants at homesites. The design to be used for these biogas plants should be as economical and as simple as is technically feasible.

The biogas produced in the residential units would most easily be used for cooking, lighting and refrigeration. Simple and cost effective designs for burner and mantle lamp construction have been reported (8,13). Since 70% of the energy needs of rural Panama is derived from wood, the biogas technology could greatly reduce overall wood consumption and cost. Also, the use of readily available underutilized resources (i.e., human and animal wastes and plant biomass) would reduce labor requirements currently expended for wood collection or charcoal production and distribution.

The fermented residue and effluent from the anaerobic fermentation have good nutrient and irrigation value (1,8). These by-products should be recycled upon the soil to increase crop productivity, which is not possible when wood is directly combusted, since most of the nitrogen is lost to the atmosphere.

Public health hazards can occur when human waste is used in biogas fermentations or the residue and effluent are used as fertilizer and irrigation water. The Academy (1), however, states that in spite of the survival of some pathogens and parasites, the literature documents no disease outbreaks associated with the use of digested night soil and animal wastes in crop production. Furthermore, they state that the inhabitants of most villages or rural areas in developing countries are probably already exposed to the enteric diseases indigenous to their area. The introduction of anaerobic digesters for night soil or animal wastes, therefore, should not create any new or additional health hazards; on the contrary, it should reduce the present health hazards significantly (1).

The rural biogas fermentation system generally contains the fermenter, biogas storage container and the piping connections necessary to complete the system. An economical, durable and simple design should be used. The design should attempt to reduce material deterioration (i.e., metal rusting), biogas loss due to leakage, fermenter contents leakage and feed and effluent line plugging. The unit should be sited to take maximum advantage of gravity feeding whenever possible, and installed in such a manner (i.e., underground) so that the agricultural productivity of the biogas plant land area is not lost. The fermenter should also be situated away from water supplies to reduce the potential of water contamination. The Chinese design constructed from masonry materials appears to be the most desirable fermentation system for immediate construction in Panama.

Two construction methods can be employed to develop this project: an individual approach where each recipient of the fermentation plant constructs the system from a common design; or an assembly line approach. The estimated resources necessary to develop the individual construction program would be core staff members to develop the design and educational materials, field staff members to transfer the technology in actual demonstration programs, and capital to partially subsidize the biogas plant construction. The subsidy program should have within its design a means of collecting the money loaned so that future units can be constructed.

The estimated time, staff and budget requirements necessary to carry out this project are presented in appendix 8. It is estimated that 11 staff members could complete this project within 3.0 years with an operating budget of $996,380.

Cooperative and Community Biogas Project.

Many agricultural cooperatives and small communities exist throughout the Nation. These groups have the advantages of increased labor supplies, land resources and capital, which could be directed toward construction and operation of a centralized biogas plant. This type of centralized plant would be more cost effective due to the benefit derived from economy of scale, also the distribution of the biogas could affect a greater number of people within a given area.

The primary objective of the project is to establish community-sized centralized biogas plants throughout the Country. Secondary objectives of the project are to increase the standard of living in the targeted areas, the stability of the economy, and reduce environmental pollution resulting from the direct discharge of the underutilized resources.

In order to accomplish the project objectives, the following tasks have been identified: quantitate and qualitate the characteristics of the cooperatives and small cities, identify the energy needs and substrate resources in these areas, design the biogas system to best accommodate the area, conduct an economic and social impact evaluation of the proposed project and construct the system, if the previous evaluations were positive.

The goal of the project should be to establish a minimum of one plant per province to act as an educational and demonstartion facility.

The estimated time, staff and budget requirements necessary to carry out this project are presented in appendix 9. It is estimated that 5.0 staff members could complete this project within 3.0 years with an operating budget of $784,630.

Industrial and Governmental Biogas Project.

Certain industrial and governmental sectors within the Nation have resource potential for biogas production. The biogas produced at these locations could easily be used to replace a portion of the costly petroleum fuels currently used. A partial list of industrial and governmental residues with biogas potential is given in table 5. Therefore, the goal of the industrial and governmental biogas project should be to educate the respective groups and to promote biogas production within these sectors.

The estimated time, staff and budget requirements necessary to carry out this project are presented in appendix 10. It is estimated that 2.0 staff members could complete this project within 2.0 years with an operating budget of $109,000.

Specific Recommendations.

The following specific recommendations are made:

(1) IRHE should continue to develop and promote biogas technology within the Republic.

(2) IRHE's program should be expanded to include a residential biogas project, a cooperative and community biogas project, an industrial and governmental biogas project, and energy studies.

(3) IRHE should expand its biogas program by including individuals from academic, private and governmental sectors.

(4) IRHE should attempt to stimulate biogas construction and demonstration units throughout the Nation.

(5) IRHE, in cooperation with the academic sector, should develop teaching aids and regional conferences to educate the citizens of this alternative energy form.

CONCLUSION

The advantages of developing biogas production in Panama are the year-round tropical environment, which is conducive to optimum biomass growth, high insolation levels, relatively low labor costs, available labor force, a genuine need for the energy in areas not serviced by the electrical power grid and a lack of known petroleum or coal resources. Development of this technology would increase the standard of living in rural areas and retain the national currency within the local economy by reducing petroleum expenditures to foreign countries.

The most advantageous approach to biogas production in Panama should satisfy the below listed criteria. The biogas system should be economical: simple to construct and operate; incorporate gravity feeding and effluent and digested residue removal and secondary use as a feed and/or fertilizer; provide manual agitation capability or mechanical agitation by wind or water driven impellers; use solar heating by thermosyphon to maintain optimum fermentation temperatures; insulated to reduce heat losses; minimize the use of and loss of dilution water from the system; and recover and use the valuable nutrients in the digested effluent and residue. In addition, the construction requirements should use skills that are already present within the society or can easily be learned. Education of the citizens to the background theory and practical operating requirements for the anaerobic fermentation process would greatly increase biogas development success.

Biogas production and use can improve the standard of living within the Country. However, the biogas technology may not be the complete answer to solving the energy shortage and distribution limitations within the Nation. However, for today, and the near future, this technology appears well-suited for use in the Republic of Panama.

ACKNOWLEDGMENT

The technical assistance of engineers B. A. Martinez and T. Bryson is greatly appreciated.

This work was performed for the Republic of Panama, contract number 31-80-DG, project for the master plan for the development of the renewable energy resources in Panama. This work was funded in part by a grant from the United States Agency for International Development, contract number 5250207, through the University of Delaware, in cooperation with the University of Puerto Rico.

BIBLIOGRAPHY

1. Ad Hoc Panel. 1977. Methane generation from human, animal, and agricultural wastes. National Academy of Science, Washinton, DC.

2. Anonymous. 1980. Consumo de energia electrica in la Republica por Provincias años 1974A1979. IRHE, Direccion de desarrollo, departamento de energia Y tarifas, seccion de estadisticas.

3. Anonymous. 1980. Red-mud plastic material methane converter. Lupton Engineering Corp., 803 World Trade Building. 50 HSIN S Heng S. Rd., Sec. 2, Taipei, Taiwan.

4. Anonymous. 1981. Biogas Plant, Eastbourne Lane, Midhurst, Sussex.

5. Bryant, M. P. 1979. Microbial methane production - theoretical aspects. J. Anim. Sci., 48:193-206.

6. Chandler, J. A., W. J. Jewell, J. M. Gossett, P. J. Van Soest and J. A. Robertson. 1980. Predicting methane fermentation biodegradability. Biotechnol. Bioeng. Symp. 10:93-107.

7. Erdman, M. D., B. A. Erdman and R. Paton. 1981. Energy-integrated farm-scale anaerobic fermentation system. Abs., 73rd Ann. Mts. Amer. Soc. Animal Science. North Carolina State Univ.

8. Food and agriculture organization of the United Nations. 1978. China-Azolla propagation and small-scale biogas technology. FAO soils bulletin. 81 pp.

9. Fry, J. L. 1976. Practical building of methane power plants. Standard Printing, Santa Barbara, CA.

10. Hashimoto, A. G., Y. R. Chen, V. H. Varel, and R. L. Prior. 1980. Anaerobic fermentation of agricultural residue. *In* Utilization and Recycle of Agricultural Wastes and Residues, M. L. Schuler (Ed.), CRC Press, Inc., Boca Raton, FL.

11. Noaek, W. 1955. Biogas m der Landwirtschafe, Elsner, Dormstadt.

12. Pfeffer, J. 1978. Biological conversion of biomass to methane. U.S. Department of Energy, Contract EY-76-S-02-2917.

13. Singh, R. B. 1971. The biogas plant, generating methane from organic wastes, gas research station, Ajitmal, Etawah, U.P., India.

14. Stafford, D. A., D. L. Hawkes and R. Horton. 1980. Methane production from waste organic matter. CRC Press, New York, NY. 264 pp.

Appendix 1 - Itinerary

March 23, 1981 - Travel to Panama City, Panama

23 - Met with Drs. K. Soderstrum and R. Lompart to discuss project and work plan

24 - Met Ing. B. Martinez and travelled to Santiago. Worked at IRHE - Santiago

25 - IRHE

Interviewed Dr. R. Pretto Malca
National Aquaculture Director
MIDA
Santiago

IRHE

26 - IRHE

Visited IRHE flexible biogas plant construction site

27 - Interview and site visit - Ing. M. Seiplay
Nestlé Co.
Nata, Coclé

Site Visit - Biogas digester aquaculture pond
Instituto Agropacreario Jesuś Nazarano
Atalaya

Site visit - 2 dairy farms in Santiago

Site visit - State operated duck farm (Bontyo)

Site vitit - Santiago municipal slaughterhouse

28 - IRHE

Returned to Panama City

29 - Site visit - Canal Zone

30 - Open

31 - IRHE, Panama City

April 1, 1981 - IRHE, Panama City

2 - IRHE, Panama City

3 - IRHE, Panama City

Appendix 2

Sites Visited

Nestlé Company

Ing. Martin Seiplay

Jefe Depto. Tecnico

Cia. Panameña De Alimentos

Fabrica De Nata

Nata. Prov. De Coclé, R. De Panama

The Nestlé Company has two plants within the Republic of Panama (Los Santos and Nata). The products produced are canned condensed milk, tomato products, vegetables and soups. The plant can process 200,000 liters of milk/day. Currently the plant is running at 67.5% milk capacity due to low milk production. The site has 1500 KW installed electrical capacity (IRHE) and is using between 60-70% of the installed capacity. The plant operates 24 hrs/day year-round. Bunker fuel (1135.6 liters/day) is used to fuel the steam generators at the plant. The plant also has an 800 and a 400 KW diesel backup generator to operate when the grid fails. The two factories employ 1000 personnel during maximum production periods and the overall plant in Nata is operating at 60% of capacity during the harvest seasons.

The plant in Nata does produce waste; however, all of the waste is returned to the adjacent farms and used as an animal feedstuff.

Low temperature solar collectors appear to be the best method to impact upon the energy demands of the factory. Also, the reduction in use of artificial lighting would reduce electrical demand.

Thursday - Site Visit - Instituto Agropacreario Jesuś Nazarano Atalaya

This institute is a parochial high school and an agriculture training center where students come and live during class periods. The students are also trained on the farm operations connected with the school. The students live and eat at the school in a dormitory environment. Student numbers vary from 130-160 students.

In order to reduce costs and to recover energy in the waste, an anaerobic digester was constructed and began operation in October 1979.

The school maintains a 34 sow farrow to finish farm. Swine waste (SW) is manually flushed from some of the pens into a settling tank (2.24 m^3). The settled solids are then diverted into another tank for further solids separation. The supernatant is drained to an aquaculture pond and the solids are added to the fermenter. The second tank is flushed 12-13 times/day and the solids added to the fermenter. The fermenter (14.0 m^3 waste capacity with 4.0 m^3 gas storage) consists of a cylindrical concrete tank buried in the ground with a floating metal cover. A 16 m^3 waterluted gas holder is also used for gas storage. Following digestion the fermented solids are retained in a sack filter and the effluent enters the aquaculture pond. The pond is stocked with tolapia and carp and is drained, harvested and cleaned annually. The fish are consumed at the school or sold. The small fermenter capacity is insufficient for the herd. A second fermenter (red-mud plastic) has been ordered and is currently awaiting arrival and installation at the site. The added capacity will give greater gas production potential to the school; currently an estimated 90% of the cooking is conducted with biogas. The added capacity would be used for cooking and for operating internal combustion engines.

The school staff are proposing to compress and use the extra biogas in mobile engines, which does not appear to be energetically efficient. It would also appear that since so much labor is used in separating the solids by settling, it may be simpler to collect the solids by hand and add them to the final separating tank. This would decrease H_2O usage and probably reduce production costs since swine normally defecate in one area of the pen.

The mariculture pond at the farm receives the digested effluent. The pond is 400 m^2 and is 1.5 m deep in the center and 1.25 m deep at the edge. The pond density is 2.5 fish/m^3.

Dairy Farm Visits.

Two dairy farms were visited near Santiago. The first farm was an unautomated farm, which had a 45-cow milking population. The cows were individually roped and brought to the milking area. The cow's calf was then released and allowed to suck until milk let down occurred at which time the calf was tied and the cow milked by hand. The milk was then transferred to milk cans and left alongside the road for pickup and transportation to the Nestlé Company. The cows were then placed out on pasture until the next milking period. This farm used no electricity and the small amount of waste collected in the corral area was deposited near the parlor.

The second farm was semi-automated and consisted of a 4-cow milk parlor. A single electrically driven vacuum pump connected to 4 bucket milkers was used at the farm. Following milking, the milk was transferred to milk cans for transportation to the processing plant.

A third dairy was observed in which the cows were herded and milked by hand. The milk was placed in the bulk cans and transported by horseback to the roadway for truck transportation to the processing plant.

Although cattle produce an estimated 1.29×10^{10} Kg of waste annually, current cattle husbandry techniques in Panama do not result in a concentrated waste problem. The only periods when collection would be feasible is during the milking period. All other times the animals are generally on pasture, which makes collection impractical.

A state operated duck farm (Montjo) was visited. The operation maintained a 200 head duck flock. The objective of the farm was to educate and develop a duck population within the Country. Waste from the site was collected periodically from the ground and could be used for biogas; however, the small flock population and long exposure time to the environment would result in nutrient losses.

The Santiago municipal slaughter plant was also visited. The plant processes 90 head daily (cattle and swine). All blood, feces, rumen and intestinal contents are flushed into an anaerobic lagoon. The plant employs 30 workers and 10 administrators and operates 6 days a week. The plant consumed 12,080, 12,400, 11,360 KW of electricity during August, September and October, respectively. The plant also used diesel fuel to power some of the equipment.

This plant appears to offer great potential for biogas production. A careful analysis of the power requirements and demand periods would define the biogas impact potential for the facility. Also an analysis of the biodegradability of the waste stream would be needed to fully estimate the biogas production potential.

A floating cover over the existing lagoon would probably provide the simplest solution for the fermenter. If biogas production was sufficient, the gas could be used for hot water/steam production or refrigeration. Use of the gas for electricity is also a potential since the plant uses about 520 KW of electricity/day. If the demand is relatively constant, a 75 KW generator would be able to meet this demand.

Appendix 3. Physical and Chemical Survey of Available Resources

Waste Characteristics	Energy Needs
Amount produced/time	KWH electricity
Total solids	Peak power demand
Volatile solids	Power demand profile/unit
Ash content	Steam or hot water requirements
Mineral composition	
Total nitrogen content	
Ammonia nitrogen content	
Total carbon	
Inorganic carbon	
Organic carbon	
pH	**Other**
BOD	1. Land area available for biogas plant
COD	2. Potential funding sources
Gross energy	3. Current waste disposal history
Amino acid profiles	4. Discharge locations
Mineral composition	5. Proximity to other buildings, residential areas
Viscosity	
Particle size distribution	
Lignin content	
Cellulose content	

Appendix 4. Sources of biogas information

Libraries

Journals

- Biotechnology and Bioengineering
- Compost Science
- Conservation and Recycling
- J. Animal Science
- Poultry Science
- Transactions of the American Society of Agriculture Engineers
- Agriculture Experiment Stations in the United States, Canada, United Kingdom, India, Taiwan

Commercial firms producing biogas production

- Biogas of Colorado, Inc.
- Sheaffer and Roland, Washington, DC
- Hamworthy Engineering Ltd., U.K.
- The Energetic Hog, P.R.
- Hamilton Standard, Inc.
- Koplan Industries, Bartow, FL

Commercial human waste treatment firms

- Organizations
  - National Academy of Sciences, U.S.
  - Department of Energy, Washington, DC

Appendix 5. Resource and Energy Study Requirements

Objectives: Identify and quantitate all potential biogas resources and energy requirements and energy interface locations within the Nation

Duration : 1.0 years

Staff : 2.0 - Formal education to include a degree in Science and/or engineer. Prior experience in energy auditing techniques and anaerobic fermentation techniques.

Budget :

Salaries and wages	$20,000.00
Equipment	
Drying oven	1,000.
Muffle furnace	3,000.
Portable pH meters (2)	1,200.
Chemical analysis	5,000.
Office supplies	1,500.
Travel	
Domestic (2 vehicles)	5,000.
Total	$36,700.

Appendix 6. Biodegradability Study Requirements

Objectives: Determine the biodegradability rate(s) and biogas production potential(s) of identified resources

Duration : 1.5 years

Staff : 1.0 - Formal education to include a degree in biochemistry or bioengineering. Experience in anaerobic microbiology techniques and assay procedures.

Budget :

Salaries and wages	$18,000.
Equipment	
Large water heating/cooling bath	3,500.
Jar fermenters/tubing/glassware	5,000.
pH meter	700.
Balance	2,500.
Laboratory contingency	1,170.
Chemical analysis (commercial)	8,000.
Office supplies	1,500.
Travel	
Domestic	500.
Literature searches, photocopy fees	750.
Total	$41,620.

Appendix 7. Design and Material Study Requirements

Objectives: Educate engineering staff; select the optimum biogas design and construction materials; and produce working designs for residential, cooperative, community and governmental sized biogas plants

Duration : 0.33 years

Staff : 3.0 - Formal education to include engineering degree and applied microbiology degree. Drafting and knowledge of culture characteristics desirable.

Budget :

Salaries and wages		$19,800.
Office supplies		2,000.
	Total	$21,800.

Appendix 8. Residential Biogas Project Requirements

Objectives: To educate the rural community of the importance and benefit of the biogas technology; installation of regional demonstration biogas plants at homesites

Duration : 3.0 years

Staff : 11 - 1 coordinating and education staff member to be formally educated in engineering and bioengieering technology; 9 regional field staff members to work in each province. Regional field staff members to have formal education in engineering and training and experience in biogas technology. The field members will secure participants, adapt biogas designs for use at specific homesites, supervise construction, operating techniques, biogas plant maintenance and repair and be capable of trouble-shooting field problems. 1 secretary.

Budget : Salaries and wages

Coordinating and education staff member ($20,000/yr)	$ 60,000.
Regional field staff ($10,000/year)	330,000.
Secretary ($6,500/year)	19,500.

Equipment

Office supplies ($20,000/year)	60,000.
Portable pH meters	5,400.
Construction tools (tapes, saws, shovels, trowels, etc) for each regional staff member	4,500.

Transportation

Vehicles (10)	100.000.

Subsidy loan program, assuming an $800 material cost/residential biogas plant, 50% loan from the government, and the construction of 10, 20 and 30 residential biogas plants in years 1, 2 and 3 for each region		216,000.
	Subtotal	905,800.
Contingency		90,580.
	Total	$996,380.

Appendix 9. Cooperative and Community Biogas Project Requirements

Objective: Establish community-sized centralized biogas plants in each province

Duration : 3.0 years

Staff : 5 - 1 coordinating and education staff member to be formally educated in engineering and bioengineering technology; 3 regional field staff members, each to work in a 3 province area. Regional field staff members to have formal education in engineering and training and experience in biogas technology. The field members will secure project participants, adapt biogas design for use at specific cooperatives and communities, supervise construction, operating techniques, biogas plant maintenance and repair and be capable of trouble-shooting field problems. 1 secretary for main office.

Budget : Salaries and wages

Coordinating and education staff member ($20,000/yr)	$ 60,000.
Regional field staff ($10,000/year)	90,000.
Secretary ($6,500/year)	19,500.

Equipment

Office supplies ($10,000/year)	30,000.
pH meters	1,800.
Construction tools (tapes, saws, shovels, trowels, transits for each regional staff member)	4,000.

Transportation

[illegible]

Appendix 10. Industrial and Governmental Biogas Project Requirements

Objective: Educate the industrial and governmental sectors of the potential impact of the biogas technology to their individual operations

Duration : 2.0 years

Staff : 2.0 - 1 coordinating and education staff member to be formally educated in engineering and bioengineering technology. 1 secretary.

Budget :

Salaries and wages	
Coordinating and education staff member ($20,000/yr)	$ 40,000.
Secretary ($6,500/yr)	13,000.
Equipment	
Office supplies and training aids ($20,000/yr)	40,000.
Transportation	
Vehicle (1)	10,000.
Fuel and maintenance ($3,000/yr)	6,000.
Total	$109,000.