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Operating and Financing a Family Biogas Plant

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Abstract

The paper studied the overview of activities of biogas operations in different parts of the world and the technology involved in the production of biogas from anaerobic digestion of organic wastes in a biogas plant. Different designs of biogas plants operating in different places in the globe were highlighted. Public health aspects of biogas technology activities were fully treated to allay the fear of infection of bacteria of public health significance by the workers. The paper dwelt extensively on the financial options for consideration during the execution of family biogas digester. Solutions were proffered for the popularization and adoption of family biogas digester for cooking in a clean environment. The paper touched on the socio-economic benefits of the deployment of biogas as a source of energy.

Keywords: operating, financing, family and biogas plant.

1. Introduction

Some countries hampered by natural abundance or inadequate distribution of energy supplies have often adapted biogas generating equipment to meet rural energy needs. Family size biogas generating units have been used in diverse climates and cultures. In the 1970s when renewable energy became recognized as a separate subject, a conference on Biogas was held at Imperial College, University of London. The participants agreed on the big potential for biogas technology in many parts of the world, particularly the developing world (Fry 1974). Nepal's programme started very much in the same way as the India one, with a government initiative. Progress was steady with the aid of Agricultural Development Bank of Nepal and there was rapid expansion in the late 1980s. Experiences in biogas technology have also been reported for Taiwan (Chung 1973), Ethiopia (Megerson 1980), Kenya(Hutchinson 1981), Korea (IAEU 1973), Tanzania (Robson 1975), Uganda(Jeffries 1964), Nigeria(ECN-UNIDO 2003), Malaysia (Sayigh 1996), etc. Animal droppings from cow, pig, poultry and crop residues have been used in different countries. The degree of success of biogas technology varied for the different countries that employed biogas technology for rural energy supply.

Pilot biogas plant projects have been executed in some parts of Nigeria by ECN, UNDP, JICA, and some Tertiary Institution (ECN 2005). 10 m^3 biogas plant at Achara, Nsukka LGA, Enugu State was executed by NCERD\UNN, for women cooperative garri processing. The plant fed on droppings of domestic animals, cassava peels and waste from the milling of cowpea, and bambara nut from the nearby food processing plant. The Ifelodun farmer's cooperative at Ojokoro, Agege, had a piggry farm of about 3000 heads and within the farm they operate an abattoir which processes the swine to pork for sale to members. ECN – SERC/UDU in 1998 built 20 m^3 fixed dome bio-digester which was fed on pig waste and produces gas for cooking and natural manure which members use in their farm. At NAPRI, Zaria, a 20 m^3 biogas plant was constructed in 1996 by SERC and in 1998; the centre constructed 30m^3 biogas digester for Zaria prison, which fed from human wastes. UNDP sponsored construction of 10 – 20m^3 digesters in Kano, Yobe, Kebbi States, etc. Unfortunately most of the biogas plants in Nigeria are no longer functional due to lack of maintenance.

2. Types of Biogas Plant

(i) The Fixed dome: This consists of an airtight container constructed of brick, stone or concrete, the top and bottom being hemispherical. Sealing is achieved by building up several layers of mortar on the digesters inner surface if brick is used for construction. It is relatively cheaper to construct the fixed dome digester than the floating gasholder type.

(ii) The Floating gasholder: The design of this digester was first developed by Indian's Khadi and Village Industries Commission (IKVIC) and consists of a cylindrical container, the height to diameter ratio being in the order of 2.5 – 4.1:1, constructed of brick or concrete reinforced with chicken wire. The cover is usually constructed of mild steel. Cost, corrosion and maintenance of the cover have been the main problem of this design. However, the mild steel cover is gradually been replaced by plastic gasholder.

(iii) The Bag digester: This type of digester comprises of a long cylinder, either polyvinyl chloride (PVC) or a material known as red mud, plastic – developed in 1974 from the residues of bauxites smelted in aluminum production plants. Incorporated in the Bag are inlet and outlet pipes for the feedstock and slurry and a gas outlet pipe. Gas produced is stored in the bag under a flexible membrane. A complete 50 m^3 can be easily installed in a shallow trench. This type of digester is not popular.

3. Biogas Digester Model

1. Mixing tank with inlet pipe. 2. Digester. 3. Compensating and removal tank. 4. Gasholder. 5. Gas pipe. 6. Entry hatch with gas tight seal and weighted. 7. Difference in level = gas pressure in cm WC. 8. Supernatant scum; broken up by varying level. 9. Accumulation of thick sludge. 10. Accumulation of grit and stones. 11. Zero lone; filling height without gas pressure.

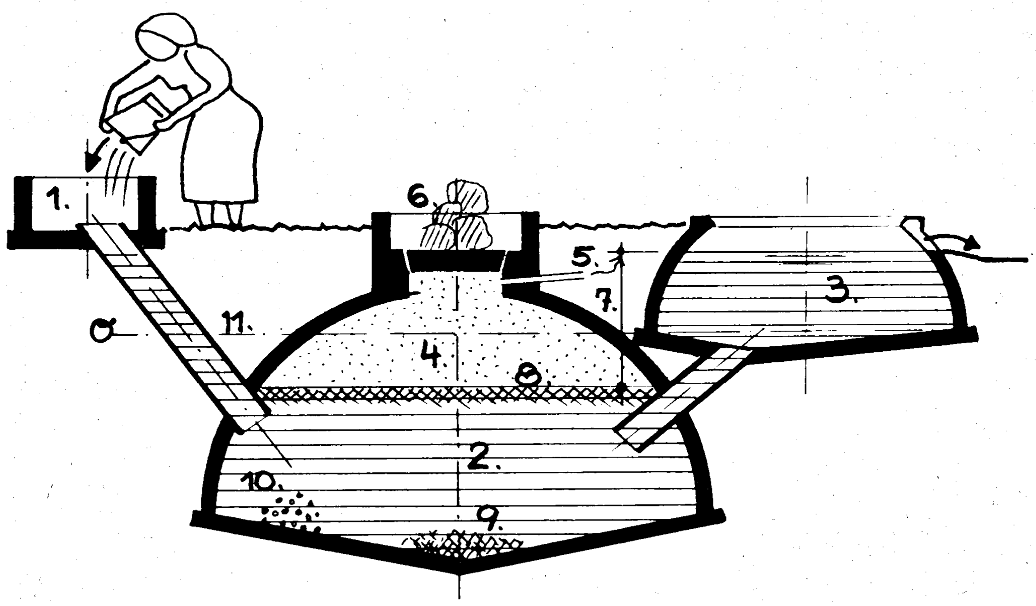

Figure 1. Fixed dome biogas plant

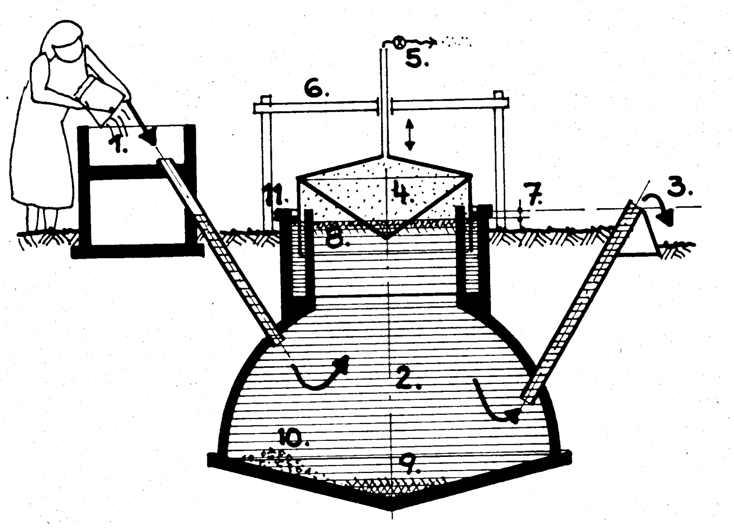

Figure 2. Floating gasholder plant

1. Mixing tank with inlet pipe. 2. Digester. 3. Overflow on outlet pipe. 4. Gasholder with braces for breaking up surface scum. 5. Gas outlet with main cock. 6. Gas drum guide structure. 7. Differences in level = gas pressure in cm WC. 8. Floating scum in the case of fibrous feed material. 9. Accumulation of thick sludge. 10. Accumulation of grit and stones. 11. Water jacket with oil film.

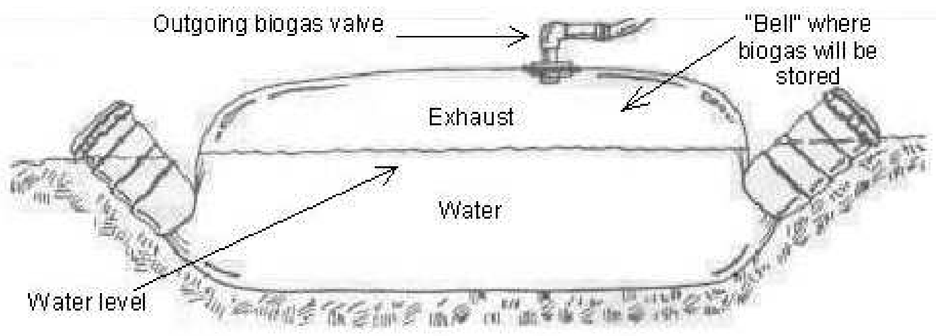

Figure 3. Plastic bag digester

Factors affecting biogas production

The production of biogas is affected and influenced by temperature, composition of the feedstock, pH of the waste and toxicity in the form of ammonia, aromatic compounds, presence of heavy metals and volatile acids. Other factors are loading rate of the feedstock into the digester, retention time of the waste in the digester and the nutrient availability for micro-organisms responsible for the bioconversion (C: N). Details of the factors affecting biogas production is widely published (Megerson 1980).

Table 1. Requirements of digester volumes

Number of persons in the family	Requirement of Biogas for Cooking and Lighting (m^3) per day	Volume of digester required (m^3)	Number of cattle needed.
Up to 4 persons	1	4	2 – 4
5 – 6	1.5	6	4 – 5
7 – 9	2	8	5 – 7
10 – 13	2.5	10	7 – 9
14 – 18	3.75	15	9 – 12
19 – 25	5	20	13 – 15

Table 2. Common problems encountered in operating biogas plants and solutions

S/No.	Problem	Possible reason(s)	Solution(s)
1.	Gas drum will not rise	Scum formation No gas formed Leakage in the system	Patience. The system needs about 4 to 6 weeks to get properly started Stir the digester Dilute the digester by adding some water Ensure that there is no leakage in the system
2.	No gas at the appliance	• No gas formed • Not enough pressure in the system to force the gas from the digester to the appliance • Gas leakage	• Consider solution #1 • Adjust the inlet jet of the appliance
3.	No gas formed	• Toxicity in digester • Inappropriate waste-water mixture	• Flush out the content of the digester with water • Add more waste to the digester
4.	Inadequate quantity of gas being formed	• Inappropriate waste-water ratio • Slurry too thick or too thin • Few population of required microorganisms	• Add a 'seeder' from another plant or a sewage to the digester • Add more waste to the digester
5.	Flame dies off too quickly at the appliance	• Pressure from the digester too high	• Adjust the inlet jet of the appliance • Reduce the weight on the gas holder

Decomposition of Organic Compounds in the Biogas Process

In a biogas process, large organic molecules (proteins, sugars and fats) are successively broken down into methane and carbon dioxide, a gas mixture called biogas. The presence of several different microbial communities is required for the biogas process to work. In order to form biogas as an end product, these active microorganisms also have to work together (Zinder 1984 & Dasonville et al. 2002). This means that both the nutritional and the environmental requirements of a large number of microorganisms have to be met for the biogas process to function as a whole.

Methane Formation

Methanogenesis is the final stage of the biogas process. In this stage, methane and carbon dioxide (biogas) are formed by various methane-producing microorganisms called methanogens. The most important substrates for these organisms are hydrogen gas, carbon dioxide, and acetate, which are formed during anaerobic oxidation. But other substrates such as methyl amines, some alcohols, and formates can also be used for the production of methane (Liu et al. 2008). Just like in other stages of the biogas process, not just one, but several different types of microorganisms are active in this stage. The methane-producing group that usually dominates in a biogas process is the so-called acetotrophic methanogens, which use acetate as substrate. In their metabolism, acetate is cleaved into two parts. One of the carbons is used to form methane and the other to form carbon dioxide. Thus, acetotrophic methane producers are sometimes also called acetate-splitting methanogens. Acetate is the source of about 70% of the biogas produced in a digestion tank (Zinder 1993).

The hydrogenotrophs are another important group of methanogens, for which the primary substrate for the formation of methane is hydrogen gas and carbon dioxide. Today there are only two known groups of methanogens that break down acetate: *Methanosaeta* and *Methanosarcina*, while there are many different groups of methanogens that use hydrogen gas, including *Methanobacterium*, *Methanococcus*, *Methanogenium* and *Methanobrevibacter* (Zinder 1993 & Garcia et al. 2000). Methanosaeta and Methanosarcina have different growth rates and also differ concerning their ability to utilize acetate (Westerman 1989). *Methanosarcina* grows faster, but finds it difficult to use acetate at low concentrations, when *Methanosaeta* has an advantage. However, the presence of these organisms is affected not only by the acetate concentration, but also by factors such as loading frequency and mixing (Zinder 1993).

Table 3. Doubling time and the lowest acetate concentrations with Methanosarcina an d Methanosaeta

Because methane producers generally grow very slowly, this is often the rate-limiting stage of the biogas process (Zinder 1993). Generation time, i.e. the time required for a microorganism to divide itself in two, is between 1 and 12 days for methane producers.

Metanogens	Doubling time	Lowest acetate concentration used
Methanosarcina	**1 day**	**~ 20 mg/L**
Methanosaeta	**2-12 days**	**~ 4 mg/L**

The growth rate of methanogens often sets the limit for how short the retention time in continuous biogas process can be. Too short retention time (less than 12 days) increases the risk that these organisms will be washed out of the process, because they do not have sufficient time to increase at the same rate as the material is pumped into and out of the digestion tank.

Methanogens differ from the other organisms in the biogas process, because they are not common bacteria. Instead methanogens are part of a group of organisms called Archaea (Garcia et al. 2000). The Archaea are a separate group of organisms that have evolved in parallel with the bacteria (prokaryotes) and fungi (eukaryotes). Because of their unique character, methanogens are easily distinguished from other "common" bacteria in the microscope.

Methanogens contain a compound (F420) that allows them to fluoresce with a green-blue colour when illuminated in the wavelength range of around 350-420 nanometres (Zinder 1993). The fact that methanogens do not resemble other organisms also means that they are not as robust as many other microbes in the process. The methanogens are often the first to be affected by various disturbances such as pH changes or the presence of toxic compounds such as heavy metals or organic pollutants (Chen et al. 2008). Because these organisms are also of great importance to the function of anaerobic oxidation, inhibition/disruption of methanogens can seriously affect the entire process.

Alternative Methane Production Pathway from Acetate

An alternate pathway for methane production from acetate is increasingly being described in scientific articles (Fig.4 ;(Schnürer et al. 1999, Hattori 2008 & Schnürer et al. 2008). The importance of this route of decomposition is currently unknown. Not considering reactions occurring in the natural environment, this reaction pathway has only been demonstrated for some Danish biogas plants and a few Swedish co-digestion plants (Schnürer et al. 2008, Schnürer et al. 1999 & Karakashev et al. 2006). Factors that are considered to influence the development of this path in a biogas process are the content of ammonia and acetate, and the types of active methanogens. Retention time in the biogas process has also proven to be significant, along with temperature. With this methane formation pathway, biogas is not directly generated from acetate by acetotrophic methane production (so-called acetate splitting). Instead, acetate is first converted by non-methane-producing bacteria into hydrogen gas and carbon dioxide. These products are then used by hydrogenotroph (hydrogen gas-consuming) methane producers to form biogas.

This cooperation between two different groups of organisms is called syntrophic acetate oxidation (SAO). For the conversion of acetate to hydrogen gas/carbon dioxide to take place, the hydrogen gas pressure must be kept low, which is taken care of by the methane producers. This methane formation path from acetate is slower than that of the acetotrophic (acetate splitting) methane producers, which results in slower breakdown of organic matter and biogas production when the SAO path is used.

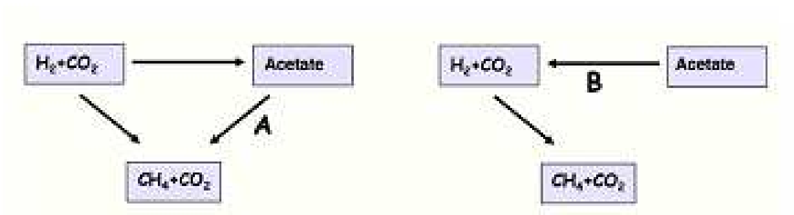

Figure 4.

Two different methane production pathways from acetate are known: splitting of acetate by an acetotrophic metanogen (A) or oxidation of acetate to hydrogen gas and carbon dioxide by a non-metanogenic bacterium (B) followed by a reduction of carbon dioxide to methane by a hydrogenotrophic methane producer.

Public Health Aspects of Biogas Technology

Potential Hazard

The potential hazards inherent in the anaerobic digestion of wastes are the result of two practices-the handling involved in the use of human faeces (night soil) as part of the waste feed to the digesters and the use, in crop production, of the sludge produced in these digesters as fertilizers. Although the use of wastes from diseased animals may entail some danger (e.g. Leptospirosis) (Diesch 2000), it would be less than that involved in the use of human faeces.

The nature and variety of diseases that can be transmitted through improper handling of human excrement, together with their causative agents are well documented in textbooks on clinical bacteriological parasitology (Noble 1971). These diseases can be viral, bacterial, protozoan and helminthic origin.

The public health hazards associated with the use, as fertilizer, of sludge from an anaerobic digester, when untreated or minimally treated human excreta constitute part of the raw material feed, depend on these factors:

The incidence on viable pathogenic organism found in fecal waste material.

- The survival rate of theses organism in the sludge; and
- The storage time of sludge prior to its application to the land.
- These health hazards maybe assessed on the bases of available information on the occurrence and survival of pathogenic organisms in raw sewage digesters and in sludge used in the field.

Precautionary measures

Perhaps precautionary measures could not easily be imposed on methods of collecting night soil, loading and unloading the digester, and using the residue. The most desirable situation would be to establish a system of village latrines that are directly connected to the digester. In this way, handling the night soil would be eliminated. Failing this, however, vessels used for transporting the wastes should be used exclusively for that purpose. Spillage should be avoided during transport. Storage could be minimized by operating the digester continuous culture, to the extent of loading it once each day. In all of the steps, the handler should avoid direct contact with any fecal material.

On the basis of current knowledge, it seems clear that using the sludge from unheated digesters as fertilizer will pose a much smaller health hazard than the present use of untreated night soil, because of the reduction in the number of pathogenic organisms in the anaerobic process. The use of heated digester, however, will reduce the hazard considerably more, though not necessarily to zero.

In summary, without safeguards that would not be economically feasible in developing countries, some degree of health hazard, however minimal, would be involved in biogas production in such countries, at least insofar as human faeces are used. However, the degree of hazard would be significantly less than that to which the people are currently exposed in the traditional disposal or use of night soil. Indeed, the institution of biogas scheme could be very could very well serve as a spur to the construction and use of household latrines, based on the economic value of the fuel (and fertilizer) obtained. In this way, the public health hazard of the common practice in the rural areas of defecating in the fields would be minimized. Furthermore, connecting the latrines directly to household (or institutional) biogas generators would eliminate any health hazard of direct handling of human faeces (Briscoe 1976).

Gender Benefits

Several benefits have been documented of the decrease in the workload of rural women, which results from the addition of a biogas plants to household (Mathews 2000). The principal benefit comes from the reduction of time and labour required for the gathering of fuel for cooking and cooking itself. Collection of fuel wood is generally the responsibility of rural women, requiring a lot of their time as well as the physical effort of carrying the fuel wood long distances and over steep terrain. In addition biogas stoves are more efficient shorten cooking time and do not spoil pots and pans with soot, which is common with fuel wood stoves. On the negative side, biogas plants require some time for the collection of water and mixing of dung water to keep the biogas plants operational. Time required for collection of dung, herding, collection of fodder application of dung to the field is not affected by the operation of a biogas plant.

In the surveys, most women express great satisfaction, particularly with the cooking aspects of biogas indicating that biogas is quicker than fuel wood (Bishau et al. 1995). They also state that biogas is smokeless and does not require constant attention or blowing on the coals. The women indicate that they can put a pot on the burner and do other activities while the food is cooked. Biogas stoves generate less ambient heat during cooking, which is appreciated for most of the year except during the winter months. Most women also reported noticeable improvements in the respiratory health and reduction in eye problems. In some cases, older women who were no longer able to cook over an open fire were able to cook again with biogas.

Introduction of biogas in some countries did not necessarily change entrenched traditional pattern in the division of labour. In the Nepalese context, reduction of workload is to be considered as a pre-condition to make opportunities available for women earn additional income, organize and attend meetings, increase awareness, achieve literacy and gain financial security.

Environmental benefits

Biogas helps to reduce greenhouse gas emissions by displacing the consumption of fuel wood and kerosene. The biogas is assumed to be produced on a sustainable basis, and therefore CO_2 associated with biogas combustion is reabsorbed in the process of the growth of the fodder and foodstuffs. In the case of fuel wood if it is consumed on non-sustainable basis then all the CO_2, CH_4 and N_2O emissions that are associated with the combustion of fuel wood can be accounted as being displaced when replaced by biogas plants(Vim Van 1995).

Properly stored, treated and applied to the fields, the biogas slurry has a higher fertilizing value than ordinary farmyard manure and is able to increase the soil fertility. Use of biogas slurry is more favorable when compared to the ashes of agricultural and animal waste collected after combustion. Besides savings in nutrients, the biogas slurry contributes to maintain the content of organic matter in the soil.

Impacts on Poverty

The primary impact of biogas plants on poverty alleviation have been to reduced the economic and in many cases, the financial costs expended on fuel for cooking and lightening (Shelat 1993). Although most of the adopters of biogas technology have been among the larger and small medium scale farmers, smaller scale farmers have been increasingly attracted to the programme. The policy of a flat rate subsidy favours smaller plant sizes and smaller scale farmers' more than large scale farmers. In addition increasingly active involvement of NGOs in the promotion, organization financing and construction of biogas plants on the basis of self-help has the added benefit of bringing biogas plants within the reach of smaller farmers with fewer cattle.

Financing Biogas Project

The initial investment for a biogas plant is generally very high and it usually requires the application of sound financing tools (ADB 1997 & ADB 2002).

The following list includes the investments and costs for a typical family biogas plant:

- Costs for planning: engineering costs, costs for permits, taxes, certificates, etc.
- Costs for equipment (investment costs): technical equipment, buildings, storage facilities, infrastructure, grid connection, etc.
- Costs for feedstock
- Operation and maintenance costs: spare parts, repair, material, digestate management, etc.
- Costs of financing: interest, fees, etc.

The following list describes the revenues of biogas projects:

- Electricity and heat sale/savings
- Public subsidies
- Green certificates
- Revenues from tipping fees in biogas plants for waste
- Revenues from sales of digestate as organic fertilizer
- Savings from manure management (disposal fee)

Depending on the size of the biogas projects and the feedstock type, typical investors in biogas plants are single farmers, several farmers jointly investing in one biogas plant and industry. In some cases also other investors are involved, such as municipalities or waste companies (PREGA 2005 & EPA 2006).

Financing bodies will finance biogas projects depending on the expected financial performance compared to the project risks and depending on the credit worthiness of the investor.

A family size biogas digester does not depend on elaborate financial scheme compared to agricultural farm or industrial biogas digester.

In general, profitability of investment in biogas project strongly depends on availability of the national supporting scheme (either as feed-in tariff or green certificates) and assurance that the project in question will be eligible to benefit from the support system at the operational phase. Due to the high capital costs, usually debt capital is required for the implementation of biogas projects. Furthermore, equity capital of 20-30% of the total capital cost is usually required. In some countries, it is possible to receive a certain amount of project funding from public sources such as UNDP/ BOI or to obtain low-interest credits. Public sources should be considered and included in the calculation/financial planning process. Subsidies for biogas plants can be received for various fields of interest: agriculture, regional development, renewable energy projects, environment, structural funds, etc.

Common financing methods are credits from private banks.

There are two main types of typical financing for biogas projects: **traditional**

Financing by loans and **project financing**.

Traditional loan financing and project financing concepts

For traditional financing the credit history of the investor plays an important role. On the one hand, the liability of the family depends on the assets of the biogas plant. Decisions of the financing bodies depend upon the annual financial statements of the investor. This is the typical financing tool for a family investing in biogas projects (ADB 2005).

In the framework of the project financing, the biogas project itself is regarded as legal entity. This tool is often used for projects in which several shareholders are involved (e.g. several farmers). Main criteria of this future oriented concept are rates of return and success of the project. Decisions regarding loans are on the assets and the cash-flow of the biogas project.

The predictability of the cash-flow is thereby the important parameter/criteria, depending on following factors:

- Technology of the project
- Contracts of electricity and heat sale
- Availability and price of feedstock material
- Legislation and insurance
- Qualification and knowledge of the operator

Due to the good and predictable framework conditions, this cash-flow based concept is widely applied, for instance, in Germany.

Another financing tool is investment funds. An investment fund involves money from several small investors. All of them are investing in one biogas project. Costs and benefits are shared between the investors upon the consortium or joint venture agreement. Families can form a cooperative where each family has a share in biogas revenues proportionally to the provided substrate and its biogas yield and methane content.

Furthermore, another financing option would be the cooperation with energy contractors. A contractor is usually a company specialized in biogas production. The type of cooperation with these contractors is manifold. The contractor may enter into agreement on the mode of payment of services to the families before execution of community biogas plant for them.

Table 4. Cost estimate of a typical 20 m^3 fixed dome biogas digester

MATERIALS	QTY	UNIT PRICE	AMOUNT N:K
14mm	4	2,500	10,000.00
12mm Rod	20	1,800	36,000.00
10mm Rod	20	1,200	24,000.00
Binding Wire bundle	1	5,000	5,000.00
Sand trip (Sharp)	4	8,000	32,000.00
Chipping	1 trip	30,000	30,000.00
Bags of Cement	60	1,700	123,000.00
Blocks	200	60	12,000.00
Ceiling Board	12	1,150	13,800.00
2" x 3" 12" wood	20	450	9,000.00
2" x 2" 12" wood	20	400	8,000.00
1" x 12" 12" wood	10	800	8,000.00
3"; 4"2" and 3" 1 ½" Nails	1 ½ bag	-	4,000.00
2.5m P.V.C pipe 20cm diameter	2	6,000	12,000.00
Paraffin wax (slab)	4	2,000	8,000.00
Cooker/Digester Accessories	1	25,000	25,000.00
Excavation	-	-	50,000.00
Mason workmanship	-	-	120,000.00
Carpenter workmanship	-	-	100,000.00
Iron Bender workmanship	-	-	90,000.00
Transportation of materials	-	-	40,000.00
Supervision by Expert	-	-	300,000.00
Miscellaneous	-	-	50,000.00
TOTAL			N1,109,800.00

Other Costs

Site studies	50,000.00
Launching	50,000.00
Commissioning and testing	100,000.00
Monitoring and Evaluation	100,000.00
Training and Handing over	100,000.00
Grand Total	N1, 505,800.00

Some Pilot Biogas Projects

Figure 5. 10 m^3 Floating Biogas plant digester at FCE(T) Chemistry Laboratory, Asaba, Nigeria on 03/09/2011 (Designed and Constructed by Authors).

The cost is N700, 000.00.

Figure 6. Floating Biogas plant digester at Costa Rica

Figure 7 & 8. Plastic bag biogas plant digester/ cooker at Costa Rica

Figure 9. Fixed Dome Biogas Plant at NCERD, Nsukka, Nigeria

4. Conclusion

Utilization of biogas technology is no longer in doubt and for effective utilization of biogas technology; the following conditions should be met:

Awareness: To encourage the use of biogas requires an awareness of the consumers of the process.

Demonstration: In order to have a facility where those interested can see what can be done with biogas, demonstration projects can be utilized.

Incentives: To overcome the initial reluctance to change, incentives should be offered.

Environmental Protection Agency: The environmental protection agencies should map out wastes collection centres in both urban and rural areas. They should ensure that provisions are made for collection of organic wastes separately in wastes collection centres.

Government Participation: Government should take active part in biogas project as it is done in other countries like China, India, and Nepal, etc.

Philanthropic Organization: should be lobbyed to build biogas plants for schools and hospitals for cooking of foods and production of fertilizer.

Education/ Training: local artisans should be trained to construct digesters when required. It needs skill to construct the dome and seal the digester; it is very difficult for a beginner without instruction on a demonstration unit to undertake the necessary construction satisfactorily. Biogas technology should also be taught in schools under renewable energy programme.

Technical Information: Technical Information should be made available to artisan and engineers for biogas construction and utilization.

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