# Technical Note Series

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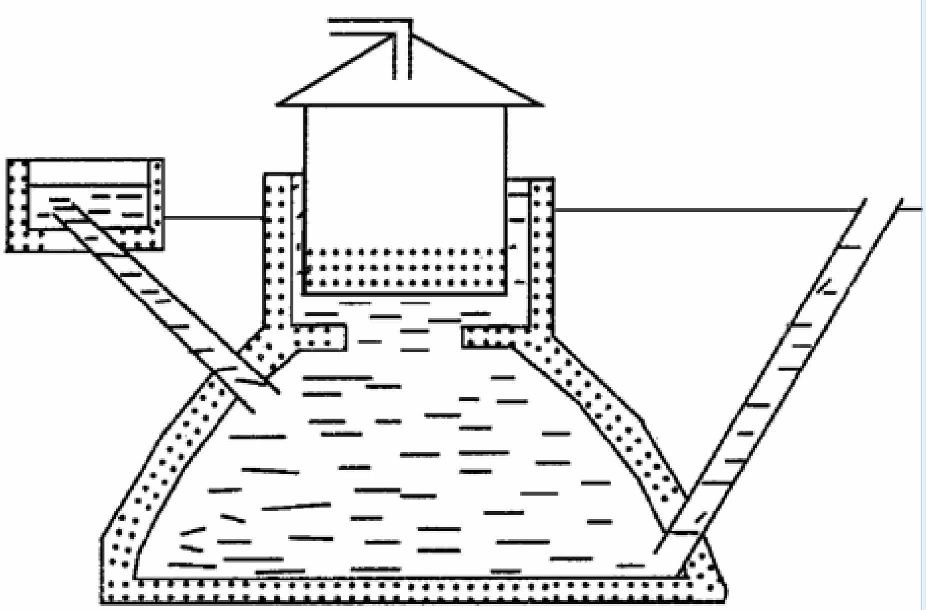
# Biogas Production



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cover: Floating drum plant with dome bottom and cylindrical top digester

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## Introduction

More than 75% of the Kenyan population live in the rural areas, with agriculture as their main occupation. The main farming systems feature cash crops, food crops, fruits and vegetables, forages, livestock, and tree growing.

Results of a study conducted in the coffee-based land-use system of Embu District showed that smallholder farmers heavily depended on trees for many uses including fuel, fencing, building, food/fruits and aesthetics (ornamentals) (Minae and Nyamai, 1988). The tree species diversity and the number of trees per species were grossly inadequate, making the farmers net importers of tree products, especially fuel wood.

Energy plays a significant role in the lives of the smallholder farmers. They need energy for cooking, lighting, warming and drying. Fuel wood is the principal farm-based source of energy but is often in short supply. A detailed study of energy demand and supply in Kenya indicated that fuel woods, charcoal and crop residues account for more than 75% of the total energy consumed). This was projected to drop slightly to 64% by the year 2000. The study also indicated that 95% of household energy was met by wood fuel whose source was getting depleted due to dwindling local resources.

Nation-wide, consumption of wood fuel in 1980 was estimated at 21 million tonnes with a *per capita* consumption of more than one tonne in a year. Replacement rates within the same period were estimated at only 60%, meaning that available wood fuel stocks were rapidly diminishing.

Kerosene (paraffin) is mainly used for lighting in the rural areas but is expensive for the resource-poor households. Its use is not sustainable because it is a non-renewable resource and since it is imported, it drains the meagre foreign exchange.

## Justification for an alternative energy source

The above scenario justifies the exploitation of alternative energy sources, primarily solar, wind, water, geothermal and petroleum sources. In relative terms, biogas holds the greatest promise as a cheap household energy source because it is renewable, simple to generate, convenient to use, and cheap. However, its potential is still under-exploited.

## What is biogas?

Biogas is a combination of gases produced during anaerobic decomposition of organic materials of plant origin. On smallholder farms, biogas is derived mainly from anaerobic decomposition of livestock wastes (dung, urine and waste feeds). The main gaseous by-product is methane ($CH_4$), with relatively less $CO_2$, ammonia ($NH_3$) and hydrogen sulphide ($H_2S$). Ordinarily, these materials decompose in open-air (aerobic) conditions with carbon dioxide ($CO_2$) and water ($H_2O$) as the main by-products, and with limited amounts of other gases. The composition of the gases depends on the chemical composition of the substrate. Biogas from livestock wastes burns well when the methane content is greater than 70%.

Methane is the principal constituent of natural gas and ranks 1st in the series of saturated hydrocarbons known as alkanes. It is a light, colourless, odourless and highly inflammable gas, 2nd only to hydrogen in the energy released per gramme of fuel burnt, hence its potential as a household energy source.

## Historical perspective

Biogas production has been practised for more than 30 years. However, widespread adoption has been hampered by inadequacy of information on its production, and potential benefits, and the prohibitively high costs of earlier designs.

Initially, 2 types of biogas systems—the float-drum type (Indian digester, Figs. 1 and 2) and the fixed dome type (Chinese digester, Fig. 3) were promoted. The main features of the 2 systems were:

- an under-ground digester - may be made of masonry stones, concrete or a strong gauge metal sheet
- an inlet pipe with a substrate receptacle
- an outlet pipe for exhausted slurry
- a floating fixed dome for gas collection
- a gas outlet pipe

Although these systems have been successful in their countries of origin, adoption in Kenya has been minimal because of expensive installation costs estimated at more than KES 50,000 per unit (CAMARTEC, 1990, Silayo, 1992).

Since the mid-1960s, Koru Coffee Research sub-Centre in western Kenya has had an elaborate biogas plant that supplied the offices and staff houses with

energy for lighting and cooking. After a study by the Ministry of Energy on energy demand and supply in Kenya, the ministry demonstrated biogas production technology all over the country in the early 1980s.

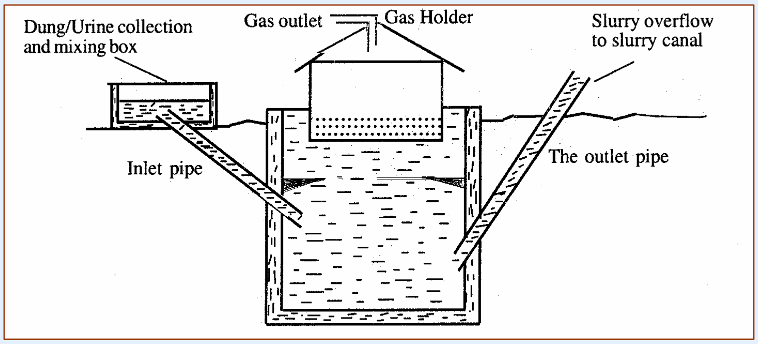


**Fig. 1. Floating drum with cylindrical digester**

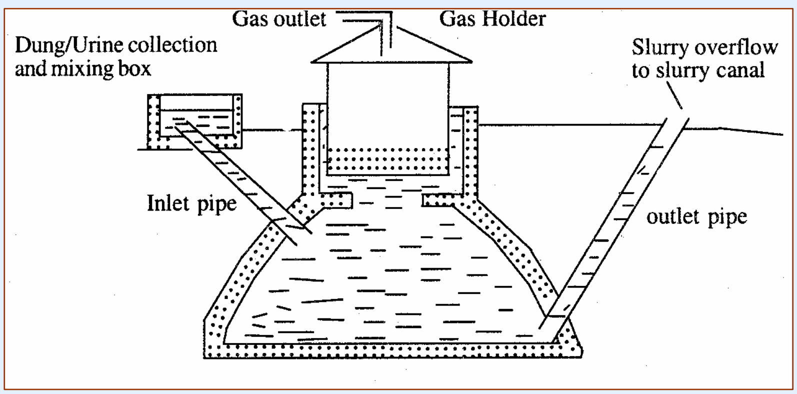


**Fig. 2. Floating drum plant with dome bottom and cylindrical top digester**

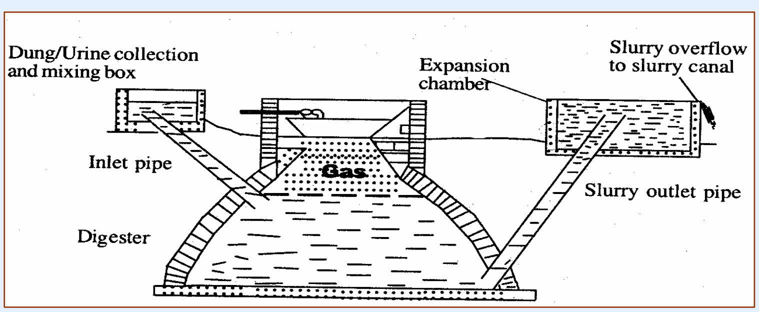


**Fig. 3. A fixed dome bio-digester with a flat bottom, open top and a cylindrical expansion chamber**

In the early 1980s, a low-cost tubular plastic (TP) bio-digester was developed in Colombia. The technology is widely used in Vietnam and Colombia and has been promoted in Kenya and Tanzania in the last 5 years by the FAO/Sida Farming Systems Programme. More than 40 units installed in Tanzania have stimulated interest among farmers as an appropriate technology for use in promoting women's well-being in the rural areas (Lekule, 1996).

The Farm-level Applied Research Methods for Eastern and Southern Africa Project (FARMESA) has actively promoted the TP bio-digester in central and western Kenya (Simalenga and Gohl, 1996).

This Technical Note describes the principles and processes of biogas production, focusing mainly on the TP biogas system. It is based on a publication by Simalenga and Gohl (1996) and the authors' experiences with TP biogas systems at KARI-Embu, Kenya.

## Advantages of bio-digesters

The main physical features, the principles and process of bio-digestion are basically the same, regardless of the type of digester used. In a crop-livestock-tree farming system, Brown (1987), Silayo (1992) and Lekule (1996) cited the following advantages of the biogas technology:

- It provides an alternative source of energy thus reducing the rate of deforestation
- It is a relatively cheap source of energy
- It improves crop-livestock-tree system through nutrient cycling
- It reduces time and workload of collecting fuel wood
- It reduces kitchen smoke-pollution thereby promoting human health
- It promotes good health through safe treatment of manures
- As a renewable source of energy, it provides a reliable power supply that is environmentally friendly
- It is a rich source of nitrogen, phosphorus (P), potassium (K) and other macro- and micronutrients

## The biogas production system

A biogas production system consists of the following features:

### Substrate inlet

This consists of a receptacle for the raw/fresh organic waste and a pipe of at least 10 cm diameter leading to the digester. The connection between the inlet pipe and the digester must be airtight.

### Digester

This is the reservoir of organic wastes in which the substrate is acted on by anaerobic microorganisms to produce biogas.

### Gas storage/reservoir

Depending on the system, this may be simply an empty but enclosed space above the slurry in the digester, an inverted floating drum whose diameter is just slightly smaller than that of the cylindrical digester (Figs. 1 and 2) or an airtight polythene tube with an inlet-outlet outfit (Fig. 4).

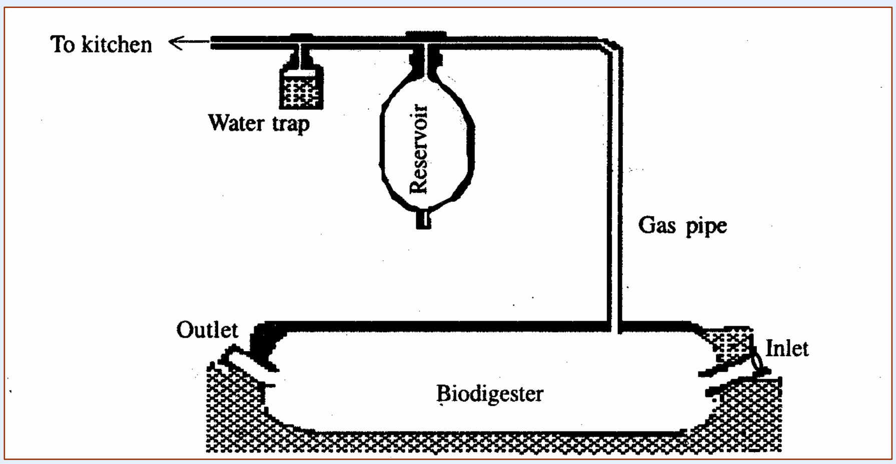


**Fig 4. Essential features of plastic tubular bio-digester**

### Gas burner
This may be a special lighting lamp or a modified burner for cooking (Fig. 5).

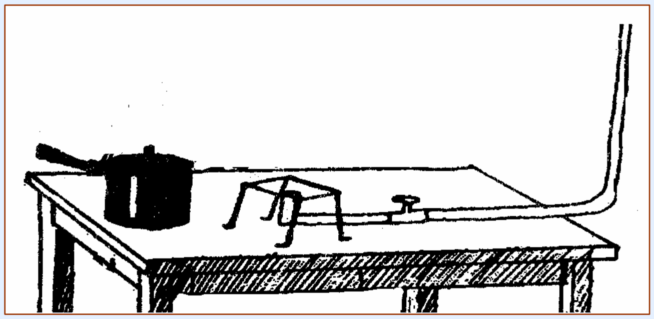

**Fig. 5. A simple kitchen gas stove**

### Exhaust outlet
This consists of a pipe of similar size to the inlet pipe connected to the digester at a slightly lower level than the inlet pipe (Figs. 1-4) to facilitate outflow of exhausted slurry.

## The biogas production process
Biogas is a result of the fermentation of organic wastes under anaerobic conditions and occurs in the following 3 stages:

### First stage
Complex organic compounds are attacked by hydrolytic and fermentative bacteria, which secrete enzymes and ferment hydrolysed compounds into acetate and hydrogen. A small amount of the carbon converted will end up as volatile fatty acids, primarily propionic and butyric acids.

### Second stage
The hydrogen-producing acetogenic bacteria continue decomposing by converting the volatile fatty acids into acetate and hydrogen.

### Third stage
Methane-producing bacteria convert the hydrogen and acetate into methane. There is a certain amount of specialisation in that different bacteria act on

different substrates. In order for these bacteria to work properly and achieve the desired end-products, the following conditions have to be well balanced:

- The dilution of the substrate (amount of water used to dilute the animal waste)
- The optimum temperature (should be 35°C)
- Type of substrate (due to their suitable C:N ratio and total solids content, cattle, pig and poultry manures are recommended)
- Rate of feeding the digester (overfeeding can lead to accumulation of volatile fatty acids)

## Tubular Plastic Bio-digesters

The TP bio-digester was first developed by *Consultorias el Para el Desarrollo Integrado del Tropico* (CONDRIT) based at Cali, Colombia in the early 1980s. The design was based on the *Red Mud PVC* bio-digester (CONDRIT Ltda, 1995) 1st promoted in Taiwan. The technology was introduced to eastern and southern Africa in 1993 through the technical cooperation of FAO in Tanzania. From 1994 onwards, a local NGO known as Foundation for Sustainable Rural Development (SURUDE) embarked on a widescale promotion of the digesters in Tanzania, Uganda and Kenya (Simalenga and Gohl, 1996).

### Requirements

The TP bio-digester can be installed in less than a day using the following locally available material:

- Two polythene tubes of 0.2 mm thickness (Gauge 1000), 90-120 cm diameter and 8-10 m length (for digester)
- Polythene tube of 0.2 mm thickness (Gauge 1000), 90-120 cm diameter and about 3-4 m length (for gas reservoir)
- A PVC pipe of 1.2 cm diameter and one metre long for tapping the gas from the digester
- Two pieces of PVC pipe of 10-15 cm diameter and one metre length to serve as inlet and outlet pipes
- A plastic gas pipe of 1.2 cm diameter and as long as the distance to the point of gas use
- 3 PVC "T" pieces each attached to a 1.2-cm diameter, 30-cm long pipe (for gas storage and water trap)
- Rubber straps to tie all the joints to make them airtight

### Methodology

The digester requires a trough-shaped trench with a top width of 65 cm, a bottom width of 50 cm, a depth of 65 cm and variable length, depending on the number of animals. For a 2-cow or 8-pig unit, 8-10 m is adequate. The trench should have a flat floor, firm sides and a gentle slope (about 5%) to ensure outflow of exhausted slurry. One of the 2 polythene tubes is inserted into the other to create a double layer for added strength. Each of the 2 openings of the plastic tube is folded around the one-metre, 10-15-cm diameter PVC pipe and an airtight joint is formed using the tyre-tube straps to ensure air-tightness. One end becomes the inlet while the other becomes the outlet (Fig. 4). A small hole (about one centimetre in diameter) is punctured through the 2 walls about 1 metre from the inlet end. A piece of 1.2-cm diameter, 30-cm long PVC pipe is then inserted into the dome and an airtight joint made. The gas pipe is fitted to the external end of this pipe. The gas pipe passes through the 1.2-cm diameter PVC "T" whose stem is a 30-cm PVC pipe.

The 3-4-m polythene tube is sealed on one end by folding and tying it into an airtight joint while the other end is folded and connected to the stem of the PVC "T", thus completing the gas storage structure (Fig. 4). The gas tube then passes on to yet another PVC "T" whose stem dips into a container of water to allow bubbling of gas in excess of the gas storage capacity. The gas tube is finally connected to a 1.2-cm diameter piece of GI pipe which is equipped with a gas control valve and connected to the gas burner or stove (Fig. 5).

To set the system in motion, the digester is laid horizontally in the trough-like tunnel with the inlet, outlet and gas tube facing upwards. An animal waste:water mixture in the ration of 3:1 is fed into the digester until it is about 75% full. The system is then given about 1 week to activate, after which the gas can be used. To keep the system active, it should be fed with a thoroughly stirred mixture of 1 20-litre bucket of animal waste and 3 similar buckets of water.

### Management of the TP biogas system

For successful operation of the TP biogas system, a number of factors should be taken into consideration. They include:

- Protection
  - The digester should be covered with grass straw, crop stover, canvas or GI sheets to protect it from direct sun rays (ultra-violet radiation). A fence of fine wire mesh should be used to protect the digester from

damage by children, pets and livestock.

- Availability of water
  - Areas where water supply is unreliable are unsuitable for TP biogas installation.
- Regular feeding
  - Underfeeding reduces the amount of gas produced while overfeeding results in incomplete digestion and hence less gas production. Green effluent suggests overloading. A 5 $m^3$ digester requires 19 kg of waste and 47-57 litres of water to produce enough gas for a day.
- Use of cow dung
  - Cow dung is the ideal substrate for bio-digesters because it is not acidic. If livestock wastes and garbage have to be used, cattle dung should be used as a starter substrate.
- Effluent recycling
  - Recycling some of the digested slurry improves the performance of the bio-digester. Where possible, about 30-40 litres of the effluent should be fed immediately after charging the digester.
- Gas pressure
  - The amount of gas produced is a function of the size of the bio-digester, its feeding regime, type of substrate and environmental conditions such as aerial temperature. The mean volume of a 2-cow bio-digester is about 5 $m^3$. This will produce enough gas to cook for about 3 h. Within this period, gas pressure drops and there is need to hang an object weighing 3-5 kg at the bottom of the gas reservoir to increase pressure.
- Temperature
  - Maximum gas production will occur at 35-40°C. Mesophilic methane bacteria operate best within 20-40°C. Gas production declines as temperature drops and will cease at 10°C. TP bio-digesters are therefore not suitable for the cold highland areas.

### Cost and benefit of TP systems

While it is fairly easy to quantify the cost of installation and maintenance of a TP biogas system, quantification of both social and economic benefits would depend on factors such as the size of the unit, the location (environmental conditions), availability of alternative energy sources, and even dietary habits. Experiences at KARI-Embu have indicated that a biogas system fed by 2 dairy cows would produce enough gas to cook light dishes such as tea, rice, porridge (*ugali*) for a family of 4 but may not be adequate for dishes like *Githeri* (boiled maize and beans). It can supply 30-40% of the total energy needs of such a household.

Studies in Tanzania where animal and human wastes were mixed as a substrate indicated that wood fuel could be reduced by up to 60% (Lekule per. comm.; Lekule, 1996). A detailed household energy demand and supply study indicated that a family of 6 used 3 bags of charcoal and 121 litres of kerosene per month. This translated into USD 8 for charcoal and USD 49 for kerosene which represented a major saving (direct benefit) when biogas was used.

The cost of installing a TP biogas system in Kenya varies but for a 2-cow unit, it was estimated to cost between KES 5,000 and 6,000 in 1996/1997 depending on whether materials are bought on wholesale or retail basis (Table 1). This is about 10% of the cost of the conventional floating or fixed dome biogas units. In Tanzania, the cost of a standard (2-cow) TP biogas unit is estimated at less than USD 100 compared to about USD 1,000 for a conventional biogas unit.

**Table 1**. Estimated cost of a TP biogas system for 2-cow based on year 2000/2001 in Embu

| Item | Quantity | Cost (KES) |
|---|---|---|
| Polythene tube | 25 m | 2,500 |
| Gas pipe (36 m) | 1 | 800 |
| PVC "T"s and elbows | 6 | 200 |
| PVC pipe for inlet and outlet (3 m) | 1 | 350 |
| GI pipe with gas valve | 1 | 300 |
| PVC pipe (10 mm diameter) | 1 | 70 |
| Tyre tube straps | 2 bundles | 100 |
| Installation labour (incl. trench) | — | 500 |
| Burner and other misc. expenses | Assorted | 680 |
| Total | | 5,500 |

### Limitations of the TP biogas system

Soon after the introduction and on-farm demonstration of the TP biogas system, the demand by the smallholder farmers was immediate but adoption was slow due to the following reasons:

**The durability of the TP digester material**. The most significant limitation of the TP biogas system was the short life of the digester polythene tube initially thought to be 5 years but later confirmed to be only 2 years. A butyl rubber digester would be most ideal and long lasting but it would be expensive and less readily available (Karanja pers. comm.).

**Inadequate performance data**. Performance data for Embu units were based on 1 on-station and 2 on-farm units located in the coffee zone in the central Kenya highlands where temperatures are often on the lower end of the optimum or below. There is need to test the performance of the TP biogas system in the lower, hotter and drier areas.

**Type of substrate**. While cattle waste has been the primary substrate in Kenya, use of non-ruminant waste including human waste, boosts gas production. Yet this may not be feasible due to socio-cultural reasons.

**Poor management of the digester**. This includes inadequate feeding, use of wrong waste:water ratios, inadequate stirring and inadequate protection of the digester and gas reservoir against damage by children, pets and livestock.

## Conclusion

On-farm biogas production is a feasible and sustainable option for generating alternative low-cost domestic energy. The gas can be used for cooking and lighting and the scale of production depends on the farmers' resource endowment. The TP biogas system is especially suitable for smallholder farmers with 2 cows and the cost is about KES 5,000. The main limitations of the TP biogas system include the relatively short life of the digester material as well as the need for close attention (management). There is need for further testing using different digester materials and in different agroecological zones, particularly the lower drier areas.

## References

[1] Brown, N. (1987). Biogas systems in development. *Appropriate Technology* 4(3), 5-7.

[2] CAMARTEC, (1990). Centre for Agricultural Mechanization and Rural Technology. Tanzania biogas extension service, GTZ.

[3] CONDRIT Ltda, (1995). Improvement and promotion of tubular biogas digesters. Mission report submitted to FAO/Sida Farming Systems Programme.

[4] Karanja, G.M. (2001). Low-cost on-farm biogas production. Unpublished handouts and personal communications. Regional Research Centre, Embu, Kenya.

[5] Lekule, F.P. (1996). Technologies for improving the well being of rural women in Tanzania. Final report submitted to FAO/Sida Farming Systems Programme.

[6] Lekule, F.P and Sarwatt, S.V. (1996). Use of biogas as an alternative source of domestic energy to reduce deforestation. Paper presented at the SPW/ Environmental Course.

[7] Minae, S. and Nyamai, D. (1988). Agroforestry research proposal for the coffee-based land-use system in the bimodal rainfall highlands of Central and Eastern provinces, Kenya. AFRENA Report No. 16. ICRAF. Nairobi, Kenya.

[8] Simalenga, T.E. and Gohl, B. (1996). Tubular Plastic Bio-Digester: Design, Installation and Management. FARMESA. Harare, Zimbabwe.

[9] Silayo, V.C. (1992). Small biogas plants. Design, management and use. Agrotec publications.

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