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Development
Organisation

DOMESTIC BIOGAS COMPACT COURSE

Technology and Mass-Dissemination Experiences from Asia

Postgraduate Programme Renewable Energy

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HAND-OUT FOR STUDENTS

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Introduction: Why Domestic Biodigesters?

The Millennium Development goals and the Biodigester Dissemination

Over 2 billion people worldwide lack access to clean, safe and sustainable domestic energy services.

The UK's Department for International Development (DFID) acknowledges that energy plays a crucial role in underpinning efforts to achieve the MDGs: "Lack of access to adequate, affordable, reliable, safe and environmentally benign energy is a severe constraint on development".

At the World Summit on Sustainable Development in Johannesburg, there was acknowledgement that the vicious cycle of energy poverty needs to be broken in order to achieve the MDGs for reducing world poverty. A lack of access to clean and affordable energy should be considered a core dimension of poverty.

Of the eight Millennium Development goals, domestic biogas has a very direct relation with four the availability of these services:

MDG 1 Eradicate extreme poverty and hunger

Target 1 To halve extreme poverty

Biogas plants reduce financial and economic costs expended on fuel for cooking and to a lesser extent also lighting. The produced bio-slurry is a potent organic fertiliser and may reduce the use of chemical fertiliser. In general, biogas households are not typically the ones in developing countries that suffer from extreme poverty, although many of them are poor. However, the biogas dissemination process and the resulting reduced claim on common ecosystem services do affect the livelihood conditions of (very) poor non-biogas households as well through:

- Construction and installation of biogas creates employment for landless rural people.
- Biogas saving on the use of traditional cooking fuels increases the availability of these fuels for (very) poor members of the community.

MDG 3 Promote gender equality and empower women

Target 4 Eliminate gender disparity in education

Women and girls predominantly spend time and energy on providing traditional energy services. Housekeeping and absence of proper illumination creates barriers for women and girls in accessing education and information as well as their mobility and participation in 'public' activities:

- Domestic biogas reduces the workload –collection of firewood, tending the fire, cleaning soot of cooking utensils - with 2 to 3 hours per household per day.
- Biogas illumination is highly appreciated for lighting, facilitating reading / education / economic activities during the evening.

MDG 6 Combat HIV/AIDS, malaria and other diseases.

Target 8 Halt / reverse the incidence of malaria and other major diseases

Half of the world's population cooks with traditional (mostly biomass based) energy fuels of which the collection becomes increasingly cumbersome. Indoor air pollution from burning of these fuels kills over 1.6 million people each year, out of which indoor smoke claims nearly one million children's (<5) lives per year. Diseases that result from a lack of basic sanitation, and the consequential water contamination, cause an even greater death toll, particularly under small children (<5 mortality caused by diarrhoea is approximately 1.5 million persons per year):

- Biogas stoves substitute conventional cook stoves and energy sources, virtually eliminating indoor smoke pollution and, hence, the related health risks (e.g. respiratory diseases, eye ailments, burning accidents).
- Biogas greatly reduces the workload involved in the collection of traditional cooking fuels like wood.
- Biogas significantly improves the sanitary condition of farm yard and its immediate surrounding, lowering the exposure of household members to harmful infections generally related with polluted water and poor sanitation.
- Proper application of bio-slurry will improve agricultural production (e.g. vegetable gardening), thus contributing to food security for the community.

MDG 7 Ensure environmental sustainability

Domestic biogas can help to achieve sustainable use of natural resources, as well as reducing (GHG) emissions, which protects the local and global environment. Application of bio-slurry increases soil structure and fertility, and reduces the need for application of chemical fertilizer.

Target 9 Integrate the principles of sustainable development into country policies and program and reverse the loss of environmental resources.

- Particularly larger biogas dissemination programmes have a considerable governance component. As such, they positively influence national policies on sustainable development (e.g. agriculture, forestation) as well as promote participatory governance involving women and other disadvantaged groups.

Target 10 Halve the proportion of people without sustainable access to safe drinking water and basic sanitation.

- Biogas reduces fresh water pollution as a result of improved management of dung. Connection of the toilet to the biogas plant significantly improves the farmyard sanitary condition.

The Contribution of Biodigester Technology to Development at Different Levels

Farmers may want to substitute inputs such as fertilisers, household and engine fuels by biodigester slurry and the biogas itself. A biogas system can relieve farmers from work that they have spent on dung disposal or dung application on their fields. By using biogas for cooking, lighting and heating, life quality for the whole family can improve. Improved stables, if they are part of the biogas system, can increase the output of animal husbandry. Improved farmyard manure may raise the yield of plant production.

Craftsmen, engineers and maintenance workers are finding employment due to the existence of a biodigester industry. A well developed biodigester sector opens up market niches for masons, plumbers, civil engineers and agronomists; they are often the most effective promoters of biogas technology.

Governments have macro-economic interests that may render biogas technology an interesting option in overall development plans. On a national scale, a substantial number of working biogas systems will help reduce deforestation, increase agricultural production, raise employment, and substitute imports of fossil fuels and fertilisers. If macro-economic benefits are obvious and quantifiable, a government may even consider subsidising biogas systems to bridge a micro-economic profitability gap.

International community is profiting from the reduction of greenhouse gas emissions and the absorption of greenhouse gasses due to lesser pressure on fuelwood resources and better manure management. Less poverty also results in better future perspectives for a population and therewith less economical refugees.

1 Biogas

This is the mixture of gas produced by methanogenic bacteria while acting upon biodegradable materials in an anaerobic condition. Biogas is mainly composed of 50 to 70 percent methane (CH_4), 30 to 40 percent carbon dioxide (CO_2) and low amounts of other gases as shown in the table below.

Table 1.1
Composition of Biogas:

Substances	Symbol	Percentage
Methane	CH_4	50 - 70
Carbon Dioxide	CO_2	30-40
Hydrogen	H_2	5- 10
Nitrogen	N_2	1-2
Water vapour	H_2O	0.3
Hydrogen Sulphide	H_2S	Traces

Biogas is about 20 percent lighter than air and has an ignition temperature in the range of 650° to 750° C. It is an odourless after burning and colourless gas that burns with clear blue flame similar to that of LPG gas.

The **calorific value** of biogas is about 6 kWh/m^3 (20 mega joule) - this corresponds to about half a litre of diesel oil. The net calorific value depends on the efficiency of the burners or other user appliances; a conventional biogas stove has an efficiency of 50-60 %. Methane is the valuable component under the aspect of using biogas as a fuel.

Table 1: Comparison of Different Fuels

Biogas compared with other fuels

Fuel	Unit U	Calorific value kWh/U	Application	Efficiency %	U/m^3 biogas
Cow dung	Kg	2.5	cooking	12	11.11
Wood	Kg	5.0	cooking	12	5.56
Charcoal	Kg	8.0	cooking	25	1.64
Hard coal	Kg	9.0	cooking	25	1.45
Butane	Kg	13.6	cooking	60	0.40
Propane	Kg	12.0	cooking	60	0.39
Diesel	Kg	12.0	engine	30	0.55
Electricity	KWh	1.0	motor	80	1.79
Biogas	m^3	6.0	cooking	55	1

1.2 Methanogenic Bacteria or Methanogens

These are the bacteria that act upon organic materials and produce methane and other gases in the process in an anaerobic environment. As living organisms, they tend to prefer certain conditions and are sensitive to the micro-climate within the digester.

There are many species of methanogens and their characteristics vary. The different methane forming bacteria have many physiological properties in common, but they are heterogeneous in cellular morphology. Some are rods, some cocci, while others occur in clusters of cocci known as sarcine. The family of methanogens (Methanobacteriacea) is divided into following four general groups on the basis of cytological differences (Alexander, 1961).

A. Rod-shaped Bacteria
(a) Non-sporulating, Methanobacterium
(b) Sporulating. Methanobacillus

B. Spherical
(a) Sarcinae, Methanosarcina
(b) Not in sarcinal groups, Methanococcus

A considerable level of scientific knowledge and skill is required to isolate methanogenic bacteria in pure culture and maintain them in a laboratory. Methanogenic bacteria develop slowly and are sensitive to a sudden change in physical and chemical conditions. For example, a sudden fall in the slurry temperature by even 2^{o}C may significantly affect their growth and gas production rate (Lagrange, 1979).

1.2.3 Biodigester designs

The biodigester is a physical structure, commonly known as the biogas plant. Since various chemical and microbiological reactions take place in the biodigester, it is also known as bio-reactor or anaerobic reactor. The main function of this structure is to provide an anaerobic condition within it. As a chamber, it should be air and water tight. It can be made of various construction materials and in different shapes and sizes.
Construction of this structure forms a major part of the investment costs for a biogas plant. Some of the commonly used designs are discussed below.

Floating Drum Digester

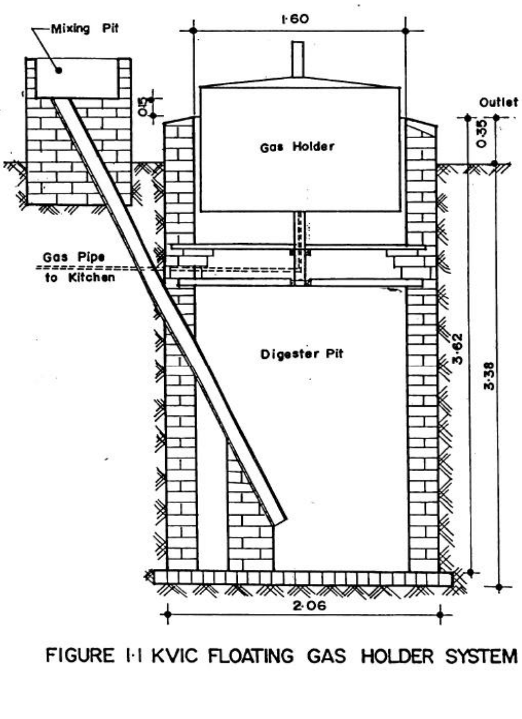


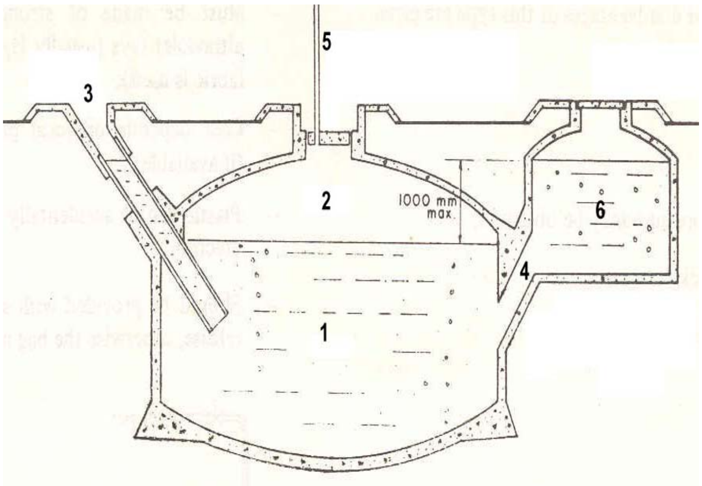
FIGURE 1·1 KVIC FLOATING GAS HOLDER SYSTEM

Experiments on biogas technology in India began in 1937. In 1956 the floating drum biogas plant, popularly known as *Gobar Gas plant*, was introduced. In 1962, this design was approved by the Khadi and Village Industries Commission (KVIC) of India and this design soon became popular in India. The design of KVIC plant is shown in Figure 1.1.
In this design, the digester chamber is made of brick masonry in cement mortar. A mild steel drum is placed on top of the digester to collect the biogas produced from the digester. Thus, there are two separate structures for gas production and collection.
With the introduction of fixed dome Chinese model plant, the floating drum plants became obsolete because of comparatively high investment and maintenance cost.

The advantage of the floating drum design is the constant gas pressure, which is equal to the gasholder's weight divided by its surface. This means that lamps, stoves and other appliances don't need any further adjustments ones they have been correctly set. Another advantage is that the level the gasholder has risen above the digester pit, is a clear indication of the available gas.
The high installation and maintenance costs have made this design obsolete for domestic use.

Fixed dome digester or Chinese model digester

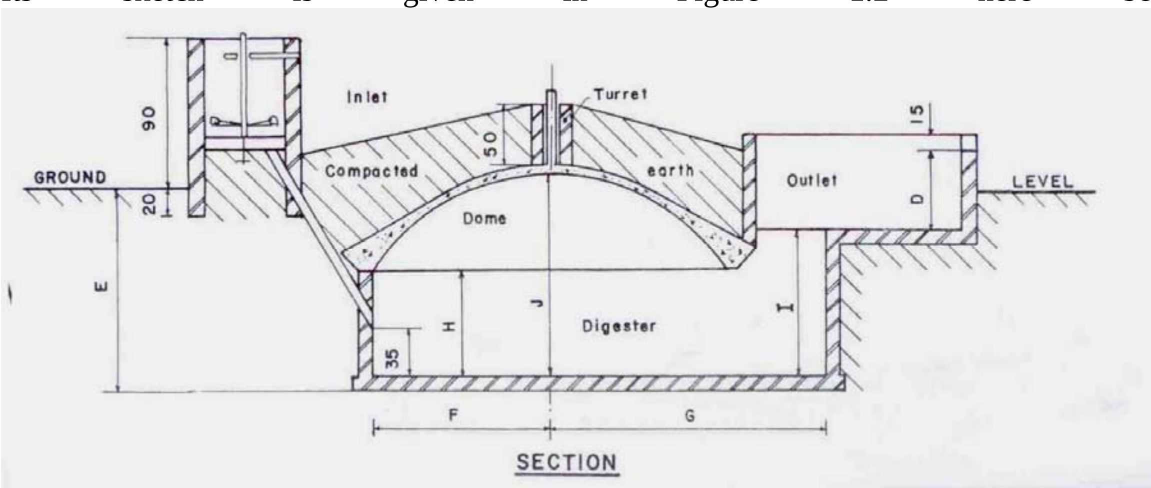
The fixed dome also known as Chinese model biogas plant was developed and built in China as early as 1936. It consists of an underground brick masonry compartment (fermentation chamber) with a dome on the top for gas storage. In this design, the fermentation chamber and gas holder are combined as one unit. This design eliminates the use of costlier mild steel gas holder which is susceptible to corrosion. The life of fixed dome type plant is longer (over 20 years) compared to the floating drum design.



1: digester part
2: gas holding part
3: inlet
4: manhole
5: gas pipe
6: outlet chamber also called compensation chamber

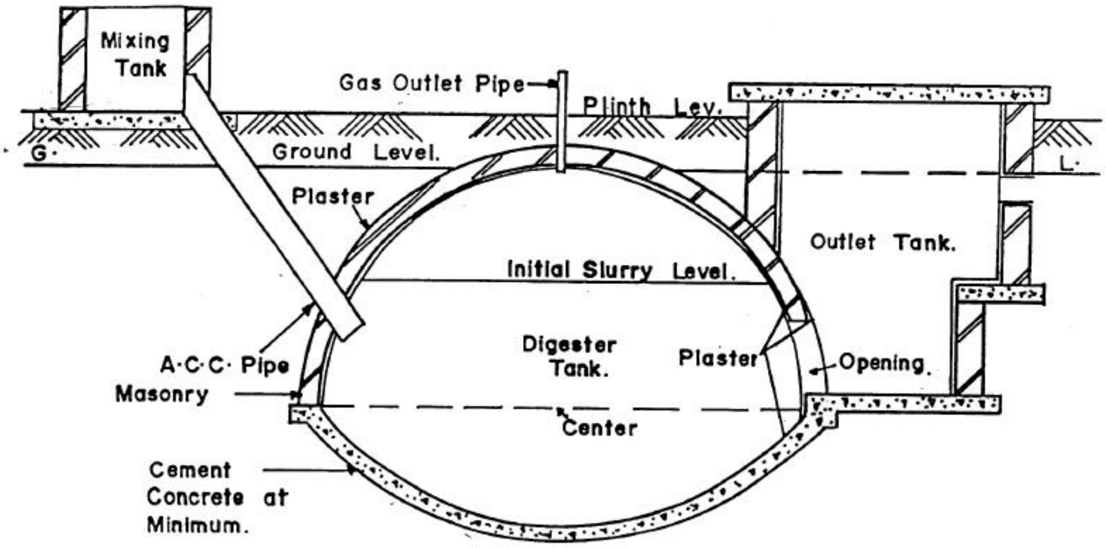
The original Chinese model is usually complete made out of concrete and constructed with the help of moulds.

Based on the principles of fixed dome model from China many different designs have been made. In Nepal a very successful design has been developed and constructed on a large scale since the last 20 years. The concrete dome is the main characteristic of the Nepal design. The digester's round wall and the outlet can be made out of bricks or stones. Therefore this model can be constructed throughout the country, also in the hilly areas where bricks are not commonly available. A noticeable change to the original Chinese design is the manhole. This has been moved from the top of the dome to the connection between digester and outlet.
Its sketch is given in Figure 1.2 here below.



Deenbandhu Model
In an effort to further bring down the investment cost, the Deenbandhu model was put forth in 1984 by the Action for Food Production (AFPRO), New Delhi, India. This model proved to be some percent cheaper than other fixed dome designs used at that time in India. It also proved to be about 45 percent cheaper than a floating drum plant of comparable size. Deenbandhu plants are made entirely of brick masonry work with a spherical shaped gas holder at the top and a concave bottom. A typical design of Deenbandhu plant is shown in Figure 1.3 (Singh. Myles and Dhussa, 1987).

The Deenbandhu model is now the most commonly used plant in India with more than 3 million plants constructed.



FIGURE–1·3 DEENBANDHU BIOGAS PLANT($3m^3$ gas production per day)

The above designs are developed particularly for household use in developing countries and with durability as an important criterion. In many countries models have been promoted which have low cost as the most important norm.

The most commonly used low cost plant is the Plastic Bag Digester
The plastic bag digester consists of a trench (trench length has to be considerably greater than the width and depth) lined with a plastic tube.
Because of the low investment cost this type of digester has been popular in south-east Asia, notably the south of Vietnam. The great weakness of this plant is its vulnerability, it is easily damaged by cattle and playing children. Also the UV rays in sunlight make that the plastic gets brittle. Another disadvantage is the large ground surface which is needed for the plant which, unlike for the dome design, cannot be used for other purposes after the construction.
An advantage is that this type of plant is easy to construct in areas with high water tables.

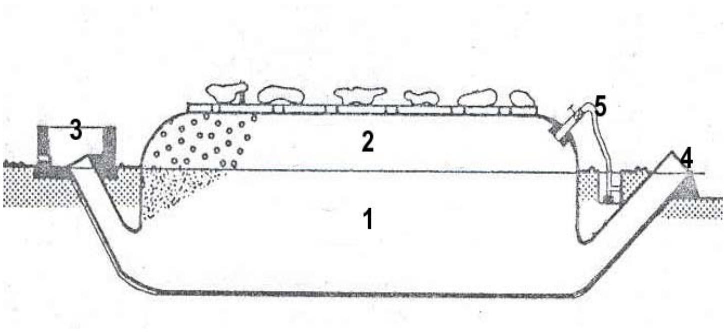


Fig. 1.4: Plastic Bag Digester

1: Digester part
2: Gas holding part
3: Dung inlet
4: Slurry outlet
5: Gas outlet pipe

On this drawing stones have been put on top of the bag to increase the gas pressure.
The following factors should be considered while deciding the types of biodigester for wide-scale dissemination:

Investment: An ideal plant should be as low-cost as possible in terms of the initial investment and in long term operation and maintenance cost.

Utilization of Local Materials: Use of easily available local materials should be emphasized in the construction of a biogas plant. This is an important consideration, particularly in the context of areas where transportation systems are often expensive. Furthermore, provision of service such as construction and repair work, can be hampered by the use of exotic materials.

Durability: Construction of a biogas plant requires certain degree of specialized skill which may not be easily available. A plant with a short life could also be cost effective but such a plant may not be reconstructed once its useful life ends. Especially in situation where people are yet to be motivated for the adoption of this technology and the necessary skill and materials are not readily available, it is necessary to construct plants that are more durable although this may require a higher initial investment. Furthermore is the existence of a service infrastructure an important consideration. If an adequate follow-up to a complaint on the functioning of a plant can not be guaranteed, it will be better to opt for a more reliable but usually also more costly design.

Suitable for the Type of Inputs: The design should be compatible with the type of inputs, popularly known as feeding materials, that would be used. If plant materials such as rice straw, maize straw or similar agricultural wastes are to be used then the batch feeding design or discontinuous system should be used instead of a design for continuous or semi-continuous feeding.

Other design selection and/or modification criteria are:
Soil conditions and water table. Unstable soil conditions, such as in black cotton soil, as well as high water tables require a structure that is able to cope with these conditions. Conical or sphere shaped floors are e.g. to be preferred in such conditions over flat bottoms.
Gas consumption pattern of the average household. If the daily gas use is most commonly ended early in the evening, a relatively larger gas storage capacity of the plant will be needed to hold the gas that is generated overnight.

1.2.4 Inputs and Their Characteristics

Any biodegradable organic material can be used as substrate for processing inside the biodigester. However, for economic and technical reasons, some materials are more preferable as input than others. If the inputs have to be purchased or transported over a large distance, the economic benefits of outputs, gas and slurry, will be affected adversely.

If easily available biodegradable wastes are used as substrate, then the benefits could be two fold: (a) economic value of biogas and its slurry; and (b) environmental cost avoided in dealing with the biodegradable waste in some other ways such as disposal in a landfill or in a lagoon.

One of the main attractions of biogas technology is its ability to generate biogas out of organic wastes that are abundant and freely available.

The potential gas production form some animal dung is given in
Table 2 here below:

Table 2
Gas Production Potential of Various Types of Dung

Type of Dung	**Gas Production per Kg Dung (m^3)**
Cattle (cows and buffaloes)	0.023 - 0.040
Pig	0.040 - 0.059
Poultry (Chickens)	0.065-0.116
Human	0.030- 0.050

In addition to the animal and human wastes, plant materials can also be used to produce biogas and biomanure. For example, one kg of pre-treated crop waste and water hyacinth has the potential of producing 0.037 and 0.045 m3 of biogas, respectively.

Since different organic materials have different bio-chemical characteristics, their potential for gas production also varies. Two or more of such materials can be used together provided that some basic requirements for gas production or for normal growth of methanogens are met.

Some characteristics of these inputs which have significant impact on the level of gas production are described below.

C/N Ratio:

The relationship between the amount of carbon and nitrogen present in organic materials is expressed in terms of the Carbon/Nitrogen (C/N) ratio. A C/N ratio ranging from 20 to 30 is considered optimum for anaerobic digestion. If the C/N ratio is very high, the nitrogen will be consumed rapidly by methanogens for meeting their protein requirements and will no longer react on the left over carbon content of the material. As a result, gas production will be low. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of ammonia (NH4), NH4 will increase the pH value of the content in the digester. A pH higher than 8.5 will start showing a toxic effect on methanogen population.

Animal waste, particularly cattle dung, has an average C/N ratio of about 24. Plant materials such as straw and sawdust contain a higher percentage of carbon. The human excreta have a C/N ratio as low as 8.

C/N ratio of some of the commonly used materials are presented in Table 3 (Karki and Dixit, 1984).

S.N.	Raw Materials	C/N Ratio
1.	Duck dung	8
2.	Human excreta	8
3.	Chicken dung	10
4.	Goat dung	12
5.	Pig dung	18
6.	Sheep dung	19
7.	Cow dung/ Buffalo dung	24
8.	Water hyacinth	25
9.	Elephant dung	43
10.	Straw (maize)	60
11.	Straw (rice)	70
12.	Straw (wheat)	90
13.	Saw dust	above 200

Materials with high C/N ratio could be mixed with those of low C/N ratio to bring the average ratio of the composite input to a desirable level. In China, as a means to balance C/N ratio, it is customary to load straw at the bottom of the digester upon which latrine waste will be discharged.

Dilution and Consistency of Inputs: Before feeding the digester, the excreta, especially fresh cattle dung, has to be mixed with water at the ratio of 1:1 on a unit volume basis (i.e. same volume of water for a given volume of dung) However, if the dung is in dry form, the quantity of water has to be increased accordingly to arrive at the desired consistency of the substrate (e.g. ratio could vary from 1:1.25 to even 1:2). The dilution should be made to maintain a total solid content from 7 to 10 percent. If the dung is too diluted, the solid particles will settle down into the digester and if it is too thick, the particles impede the flow of gas formed at the lower part of digester. There is also higher risk of scum formation at the top of the slurry layer. In both cases, gas production will be less than optimal. Furthermore, most biogas plants are designed for a total solids content of about 8%. A change of this ratio will have an impact on the HRT and the hydraulic functioning of the plant.

Volatile Solids: Volatile solids are the part of the total solids contents of the substrate that can be converted into biogas. Biomass that is completely dried and than heated to about 550^o C, will gasify. The weight of the dried biomass minus the weight of the remaining ash after gasification will be the weight of the volatile solids. The biogas production potential of different organic materials can also be calculated on the basis of their volatile solid content. The higher the volatile solid content in a unit volume of fresh dung, the higher the gas production. For example, a kg of volatile solids in cow dung would yield about 0.25 m3 biogas (Sathianathan. 1975).

1.2.5 Digestion

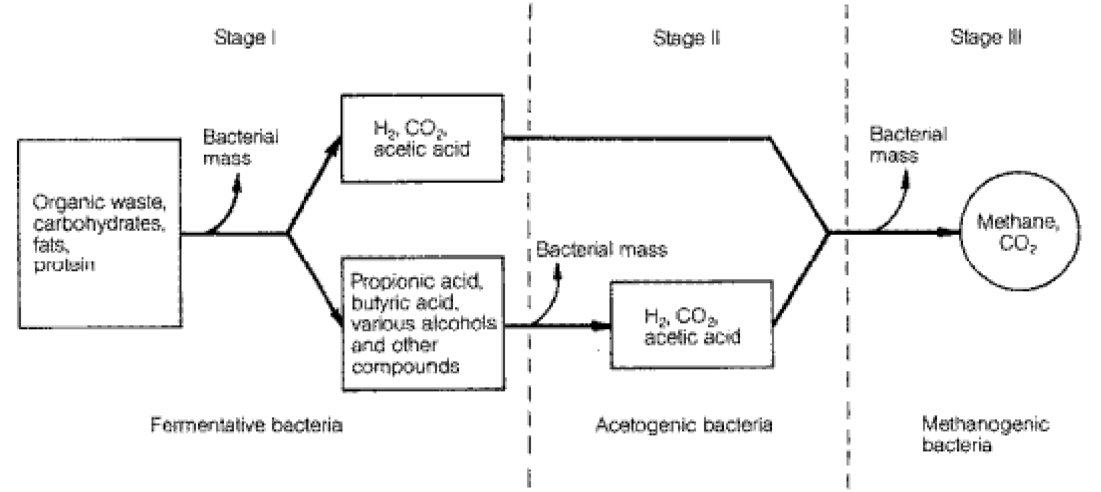
Digestion refers to various reactions and interactions that take place among the methanogens, nonmethanogens and substrates fed into the digester. This is a complex bio-chemical process involving different factors and stages of change. This process of digestion (methanization) is summarized below in its simple form.

The breaking down of inputs that are complex organic materials is achieved through three stages:

Stage 1 Hydrolysis: The waste materials of plant and animal origins consist mainly of carbohydrates, lipids, proteins and inorganic materials. Large molecular complex substances are solubilised into simpler ones with the help of extracellular enzyme? released by the bacteria. This stage is also known as the polymer breakdown stage. For example, the cellulose consisting of polymerized glucose is broken down to dimeric, and then to monomeric sugar molecules (glucose) by cellulolytic bacteria.

Stage 2 Acidification: The monomers such as glucose which is produced in Stage 1 is fermented under anaerobic condition into various acids with the help of enzymes produced by the acid forming bacteria. At this stage, the acid-forming bacteria break down molecules of six atoms of carbon (glucose) into molecules of less atoms of carbon (acids) which are in a more reduced state than glucose. The principal acids produced in this process are acetic acid, propionic acid, butyric acid and ethanol.

Stage 3 Methanization: The principle acids produced in Stage 2 are processed by methanogenic bacteria to produce methane. The reaction that takes place in the process of methane production is called Methanisation.



Obviously, there are many facilitating and inhibiting factors that play their role in the process. Some of these factors are discussed below.

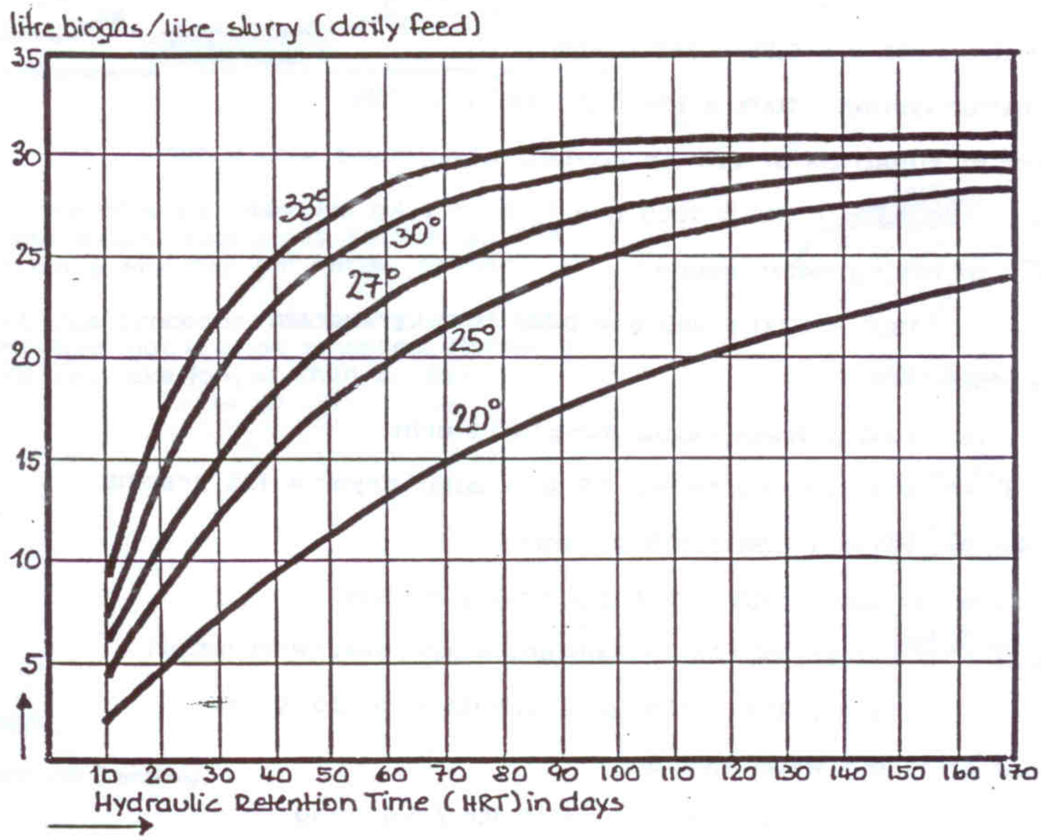
pH value : The optimum biogas production is achieved when the pH value of input mixture in the digester is between 6 and 7. The pH in a biogas digester is also a function of the retention time. In the initial period of fermentation, as large amounts of organic acids are produced by acid forming bacteria, the pH inside the digester can decrease to below 5. This can inhibit or even stop the digestion or fermentation process.

Methanogenic bacteria are very sensitive to pH and do not thrive below a value of 6.5. Later, as the digestion process continues, concentration of NH_4 increases due to digestion of nitrogen which can increase the pH value to above 8. When the methane production level is stabilized, the pH range remains buffered between 7.2 to 8.2.

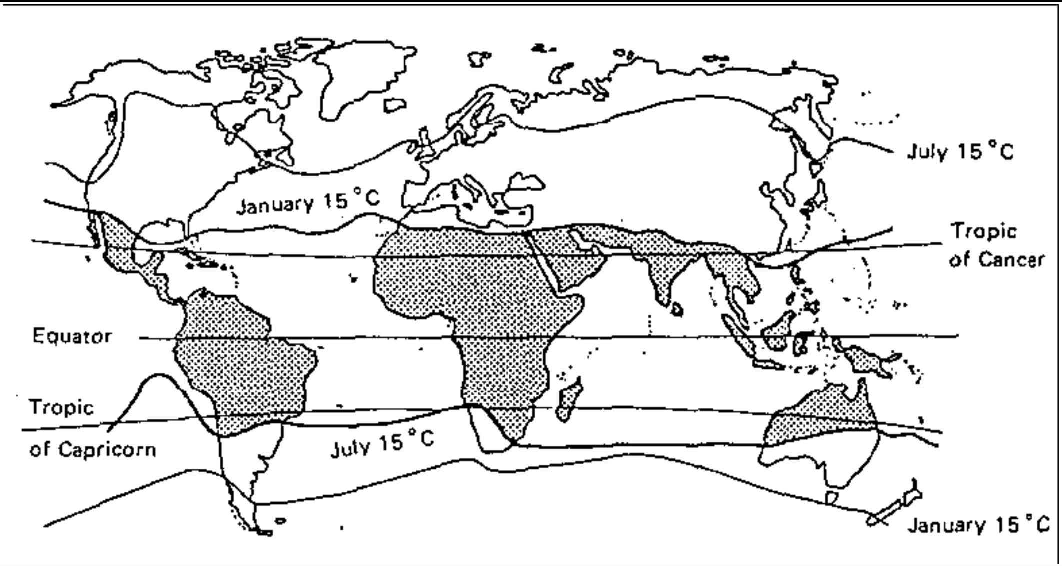
Temperature: The methanogens are inactive in extreme high and low temperatures. The optimum temperature is 35° C. When the ambient temperature goes down to 10° C, gas production virtually stops. Satisfactory gas production takes place in the so called mesophilic range, between 25º to 30° C. Proper insulation on top of the digester, i.e. by the placement of a haystack, helps to increase gas production in the cold season. When the ambient temperature is 30° C or less, the average temperature within the dome will than remain about 4º C above the ambient temperature (Lund, Andersen, Tony-Smith, 1996).

The process of bio-methanation is very sensitive to changes in temperature. The degree of sensitivity, in turn, is dependent on the temperature range. Brief fluctuations not exceeding ± 1°C/h may be regarded as still un-inhibitory with respect to the process of fermentation.
The temperature fluctuations between day and night are no great problem for plants built underground, since the temperature of the earth below a depth of one meter is practically constant.

The graph below indicates the gas production per kg of substrate in relation to the retention time. (source: L. Sasse)



The map below gives roughly the Global 15C isotherms for January and July, indicating the biogas conducive temperature zone. Notably in China technologies have been developed, like the integration of biodigesters in greenhouses, which allows for the use of biodigesters in colder regions.



Loading Rate: Loading rate is the amount of raw materials fed per unit volume of digester capacity per day. If the plant is overfed, acids will accumulate and methane production will be inhibited. Similarly but for different reasons, if the plant is underfed, the gas production will also be low.

Retention Time: Retention time (also known as Hydraulic retention Time, HRT) is the average period that a given quantity of input remains in the digester to be acted upon by the methanogens. The theoretical retention time is calculated by dividing the average slurry holding volume of the digester by the volume of daily added substrate added daily.
Depending on the vessel geometry, the means of mixing, etc., the effective retention time may vary widely for the individual substrate constituents. Selection of a suitable retention time thus depends not only on the process temperature, but also on the type of substrate used.

In general the optimum retention time can vary between 30 and 100 days. For a night soil biogas digesters the retention time is extended with another 10 days so that the pathogens present in human faeces are largely destroyed.

Toxicity: Mineral ions, heavy metals, antibiotics and the detergents are some of the toxic materials that inhibit the normal growth of microbes in the digester. Small quantity of mineral ions (e.g. sodium, potassium, calcium, magnesium, ammonium and sulphur) also stimulates the growth of bacteria, while very heavy concentration of these ions will have toxic effect. For example, presence of NH_4 from 50 to 200 mg/l stimulates the growth of microbes, whereas its concentration above 1,500 mg/1 results in toxicity.
Similarly, heavy metals such as copper, nickel, chromium, zinc, lead, etc. in small quantities are essential for the growth of bacteria but their higher concentration has toxic effects.
Detergents including soap, antibiotics, organic solvents, etc. inhibit the activities of methane producing bacteria and liberal addition of these substances in the digester should be avoided. Small domestic amounts, i.e. natural soap used to clean a toilet, do usually not cause major problems. Although there is a long list of the substances that produce toxicity on bacterial growth, the inhibiting levels of some of the major ones are given in Table 4.

Toxic Level of Various Inhibitors

S. N.	Inhibitors	Inhibiting concentration
1.	Sulphate (SO_4--)	5.000 ppm
2.	Sodium Chloride (NaCl)	40,000 ppm
3.	Nitrate (Calculated as N)	50 mg/l
4.	Copper (Cu++)	100 mg/1
5.	Chromium (Cr+++)	200 mg/1
6.	Nickel {Ni+++)	200 - 500 mg/1
7.	Sodium (Na+)	3,500 - 5,500 mg/1
8.	Potassium (K+)	2,500 - 4,500 mg/1
9.	Calcium (Ca++)	2,500 - 4.500 mg/1
10.	Magnesium (Mg++)	1,000 - 1,500 mg/1
11.	Manganese (Mn ++)	Above 1,500 mg/1

Source: The Biogas Technology in China, BRTC, China (1989)

1.2.6 Slurry

After extraction of biogas (energy), the slurry (also known as effluent) comes out of digester as by-product of the anaerobic digestion system. It is an almost pathogen-free stabilised manure that can be used to maintain soil fertility and enhance crop production. Slurry is found in different forms inside the digester as mentioned below:

– a light rather solid fraction, mainly fibrous material, which floats on the top forming the scum;
– a very liquid and watery fraction remaining in the middle layer of the digester;
– a viscous fraction below which is the real slurry or sludge; and
– heavy solids, mainly sand and soils that deposits at the bottom.

There is less separation in the slurry if the feed materials are homogenous. Appropriate ratio of urine, water and excrement and intensive mixing before feeding the digester leads to homogeneous slurry.

1.2.7 Construction, maintenance and operational problems

1.2.7.1 Construction

Space

In some countries the farmyards, especially in densely populated areas, are very confined and the construction of a biodigester can be difficult. Often in such cases the plant will be positioned underneath the pigsty or cattle stable. This means that these structures will have to be (partly) dismantled and reconstructed which leads to higher costs.

Ground water

For the construction of most plants a pit of 180-200 cm needs to be dug. In places with a high water table this can lead to problems as the pit has to remain dry during the construction of the base. There are techniques to lead ground water to a separate pit and to pump it away from there but, again, this leads to higher construction costs.

Soil conditions

In hard and/or rocky soil conditions the digging of the construction pit can lead to problems.

Agricultural season

During busy agricultural periods, like the rice planting season, there can be a shortage of labour to assist the mason with the plant construction.

1.2.7.2 Operational and maintenance problems

Water
The substrate of most digesters needs to be mixed with an equal amount of water. During the dry season in semi-arid places this can lead to an additional burden for the plant operator. Therefore it is not recommendable to build a digester if the nearest permanent water source is more than 30 minutes away.

Dung
In many places cattle are not kept in stables and are, at least for part the day, free roaming. As dung collection will not practiced with families who keep free roaming cattle, this new activity might be seen as an inconvenience.

Condense formation
Relative humidity inside the reactor is 100%. If the temperature of the gas drops, i.e. during the passage through an underground pipeline, the (absolute) humidity decreases and water condensates. This water may eventually obstruct the gas flow inside the gas pipeline. Therefore, it is necessary to drain condensed water. A special device, a water trap, for collecting the condensed water needs to be implanted at the lowest point in gas pipe line. This gadget needs to be placed with care especially so that the gas flow will not be hampered.

Scum-formation
Scum formation and/or floating layers on top of the substrate in the digester, can be a serious maintenance problem for biogas plants which are fed with a substrate that contains straw-like material. No problems have been reported with common use of dung. However when other especially lighter materials like husks etc are used, scum formation may take place readily. Also poultry (i.e. chicken) droppings and protein-containing wastes (like slaughtering wastes and wastewater) also have a bad reputation in this respect.
Scum formed inside the reactor and may eventually even clog the gas pipeline, and/or the outlet of the digester. Because a digester is a closed vessel, the scum inside the reactor, floating on the liquid surface is difficult to assess or reach from the outside.

Usually the first thing to notice with scum formation is a (gradual) decrease in net biogas production. When a relative big portion of gas is escaping from the outlet, a scum layer will be the problem. If the scum layer is relatively young you might be able to break and disperse by vigorously poking in your digester.

However, floating layers tend to dry out quickly and then will turn into a solid (floating) cake. The only solution is then to open up the digester from above and take out the scum with for example an extended bucket on a stick. Gas production and use can be resumed after a few days.

Prevention of (formation of) scum layers must be thought of in adjustment of the substrate or/and in pre-treatment of the substrate. For example (aerated) rotting and/or partial composting of substrate with a high lignin content may help break-up cellular structures and let the materials gain in moisture content.

Sediment formation
Collection of dung from stables with a non-paved floor and from farmyards can lead to pollution of the dung with gravel and soil. These heavy parts will accumulate at the bottom of the digester as sediment that needs to be removed when it takes up too much volume.

1.2.8 Use of Biogas

Of the outputs of a biogas plant, the gas is valued for its use as a source of energy and the slurry for its fertilizing properties (soil nutrients).

The energy content of biogas is most commonly transformed into heat energy for cooking and lighting. Other uses like fuel for combustion engines and for absorption fridges are less suitable for domestic biogas as they require large quantities of gas and/or purified gas at a constant pressure. Also, contrary to popular believe, it is also not feasible to compress biogas into a liquid form and store/transport it in gas cylinders.

Biogas applications

			ave. gas flow		const. gas press.	Gas purific.	
			LitresSTP/hour **		Yes / No	Yes / No	
No	Device	Specification	Min.	Max.		CO_2 (!)	H_2S (!!)
1	Household burner	1 burner	200	450	N	N	N
2	Industrial burner	1 burner	1000	3000	N	N	N
3	Lamp	500 CP	100	200	N	N	N
4	Refrigerator	100 l; 25°C;dT: 20 °C	30	75	Y	Y	Y
5	Light bulb	60 W equiv.	120	150	Y	N	N
6	Biogas/Diesel engine	Per Br.horse power	420	420	Y	N	Y
7	Biogas/Diesel-engine elect. energy	Per kilo-Watt-hour	700	700	Y	N	Y

**) ref.: L. Sasse, Biogas plants pa.55, Borda/GTZ, 1984

STP : Standard Temperature and Pressure

!) CO_2: carbon dioxide gas; non-corrosive, exhaust gas, heavier than air; elimination of CO_2 needs 180 gr. lime [Ca(OH)2.2H2O] per 100 l STP biogas (40/60) filter needed when a constant gas quality is needed i.e. refrigerators

!!) H_2S: Hydro sulphide gas, in high concentration toxic, upon burning producing sulphuric acid which is extremely corrosive;

Note: H_2S does not reach dangerous concentrations usually but will eventually damage burning equipment when it is not made out of INOX-steel or not filtered out of the gas

1.2.9 Cooking:

Cooking on biogas is the most commonly used application and the sturdiest one. It has a number of advantages over traditional cooking on the ground on a open fire, or wood stove, see the table 5 below.

The advantages of cooking on biogas have been summoned in table 5.

table 5 Advantages of use of (bio-)gas for cooking

1	Higher net efficiency: 5 times higher stove efficiency than traditional firewood stove
2	When firewood collection for traditional cooking is taken into account and the plant is laid out well, cooking on biogas is time-saving.
3	Does not produce smoke, less chance of eye irritations and respiration-problems (CARA)
4	Does not soothe the pans, less work to clean
5	Is faster
6	Flame can be regulated
7	Cooking can be done in up-right position
8	Cooking can easily be done inside the house
9	Use of pressure cooker, which again saves energy and time, becomes possible
10	More safe, less chance for children to get burned as is the case with open fire, or stoves etc.

1) The energy saving aspect and thus saving on cost for firewood is from the point of view of the farmer household an important aspect. Moreover it is on of the major considerations of a government to promote this technology because it reduces the burden on the environment. It saves trees and helps thereby to combat erosion and to store carbon (reduction of green house gasses).
2) The general impression is that cooking on biogas saves time because it eases the need to collect firewood. On the other hand extra time is needed to feed the installation daily and to carry out other maintenance like cleaning the burners or letting out condense water from the gas pipe. If the installation is badly located or if other circumstances are unfavourable (e.g. difficult to find water and/or feed material), the burden of collecting firewood is just replaced by another strenuous activity.
3) Cooking on biogas has also a significant health advantage over traditional cooking with an open fire. The major point is the fact that cooking is smokeless and that will diminish the number of eye infections and respiratory problems among in particular women usually in charge of cooking and small children being near their mothers. Also the danger that children burn themselves while cooking is less when using a biogas stove.

1.2.9.1 The combustion process during cooking

Table 6, Properties of biogas relevant for designing a stove or a lamp (Nijaguna, 2006)

Property	Value
Methane and carbon dioxide content	60 % and 40 % (v/v)
Calorific value	22 MJ/m^3
Specific gravity	0.940
Flame speed factor	11.1
Air requirement for combustion	5.7 m^3/m^3
Stoichiometry in Air	0.0947 by volume or 0.0581 by mass
Combustion speed	40 cm/sec.
Flammability in air	9-17 %

Understanding the combustion process provides a basis of performance criteria and emission standards used to regulate manufacturing and marketing of quality appliances in a country. Biogas burns in oxygen to give carbon dioxide and water and energy content in methane is released.

$$\underset{\text{(gas)}}{CH_4} + \underset{\text{(gas)}}{2O_2} \longrightarrow \underset{\text{(gas)}}{CO_2} + \underset{\text{(vapour)}}{2H_2O} + \underset{\text{(heat and light)}}{\text{Energy}}$$

One volume of methane requires two volume of oxygen to give one volume of carbon dioxide and two volumes of vapour. The energy release of pure methane is 36 MJ per m^3. The stoichiometric mixture of methane-air mixture is the optimum concentration of methane in air at which complete combustion occurs without unused air or fuel. About 9.6 volume of air per volume of combustion of methane is required to achieve complete oxidation.

Biogas is a clean fuel – non toxic in nature, odourless and smokeless. Chemically it contains 55 -70 percent methane, 35-40 percent carbon dioxide and less than 5 percent of other gases, such as ammonia, hydrogen, carbon monoxide, nitrogen, etc. On complete combustion of biogas, the amount of energy released is about 20-24 MJ/m^3.

Biogas-air mixture for complete combustion

Suppose biogas contains 60 percent methane and 21 percent oxygen is present in air, then

1/0.60 = 1.67 volumes of biogas will require 2/0.21 = 9.52 volumes of air, or

one volume of biogas requires 9.52/1.67 =5.70 volumes of air or

1/ (1+5.70) = 0.149 = 14.9 percent biogas in air (stoichiometric air requirement).

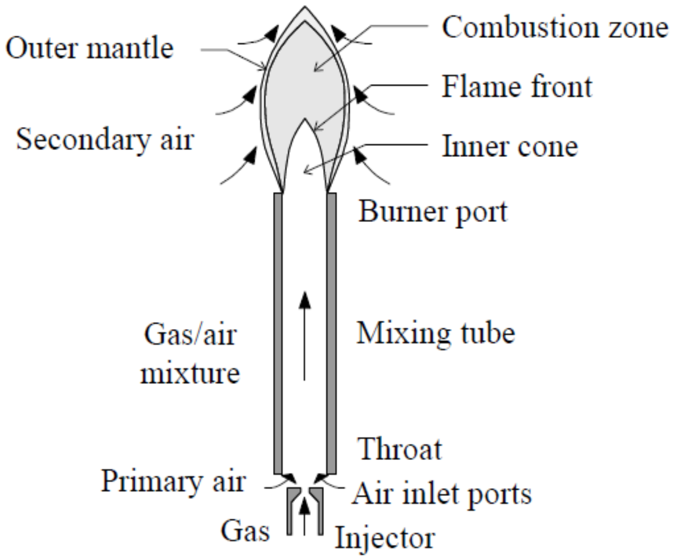
The biogas burns over a narrow range of mixtures from 9 percent to 17 percent of biogas in air. If the flame is ‘too rich’, i.e., has too much fuel, then it will burn badly and incompletely, giving carbon monoxide, which is poisonous and soot particles. Therefore, the designs of appliances should aim at to maximize the conversion of methane in order to minimize the release of unburned methane and products of incomplete combustion. Stoves usually run slightly lean with a small excess of air to avoid the danger of the flame becoming rich.

Biogas Flame

As shown in the figure on the next page, when biogas comes out of the injector, air is entrained and mixed with gas in the mixing tube. Then it reaches the burner ports. The unburned gas is heated up in an inner cone and starts burning at the flame front. The cone shape of the flame is a result of laminar flow in a cylindrical mixing tube. The mixture at the centre of the tube moves at a higher velocity than at the outside. In the main combustion zone, gas burns in the primary air and generates heat in the flame and combustion is completed at the outer mantle of the flame with aid of secondary air or the flame from the sides. With the vertical rise of combustion products, i.e., carbon dioxide and vapour, heat is transferred to the air close to the top of the flame. The hot air, which moves vertically away, draws in cooler secondary air to the base of the flame. The size of the inner cone depends on the primary aeration. A high proportion of primary air makes the flame much smaller and concentrated, giving higher flame temperature. If combustion is complete, which requires a temperature of >850 ^oC and residence time of >0.3 second, the flame is dark blue and almost invisible in daylight. If too little air is available, then the gas does not burn fully and part of the gas escapes unused. With too much supply of air, the flame cools off and as a result the consumption of biogas is increased and the cooking time is prolonged.

3.5 Effect of carbon dioxide and water vapours contained in biogas

The large quantity of carbon dioxide present in biogas poses a threat to stable combustion of biogas. CO_2 traps not only heat but it also interacts with the flame which could potentially cool the flame down enough that it becomes unstable and blows out. Similarly, the water vapours have a small but noticeable impact on flame temperature, flammability limits, lower heating value and air –fuel ratio of biogas.

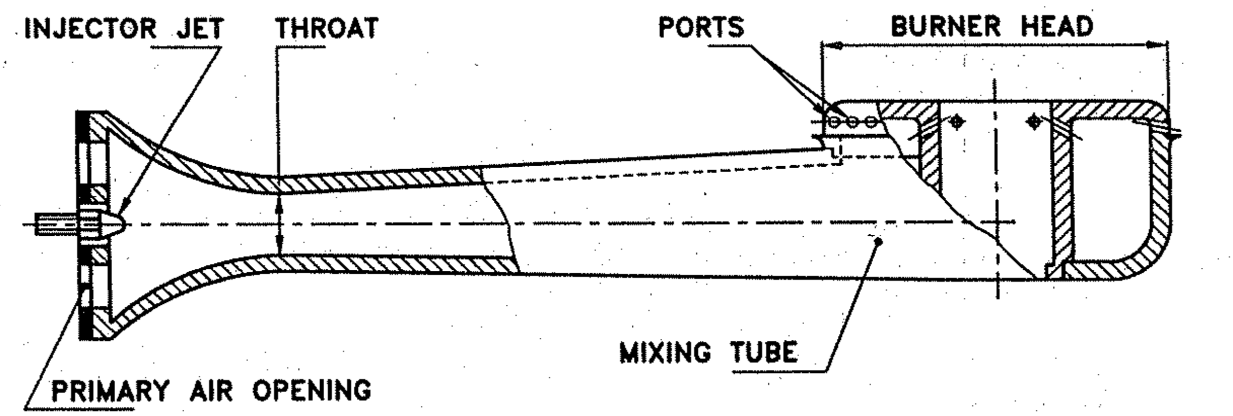


Biogas flame (Fulford, 1996)

1.2.9.2 Biogas Stoves

General features

A biogas stove is a relatively simple appliance for direct combustion of biogas. Its burner is premix and multi-holed burning ports type, operating at atmospheric low pressure. A typical biogas stove consists of gas supply tube, gas tap/valve, gas injector, primary air hole(s) or regulator, nozzle or throat, gas mixing tube/manifold, burner head, burner ports, pot supports and body frame. Assembly of a typical biogas burner is shown in the figure below.



Assembly of a typical biogas burner

Biogas reaches with certain speed at the stove, depending upon the gas pressure in the pipeline of a certain diameter from the biogas plant. With the help of an injector jet at the inlet of the stove, the speed is increased to produce a draft to suck primary air. The gas and air get mixed in the mixing tube and the diffused gas mixture goes into the burner head. The cone of the diffuse and the shape of the burner head are formed in such a way as to allow the gas pressure to equal everywhere before the mixture of gas and air leaves the burner through the ports (orifices) with a speed only slightly above the specific flame speed of biogas. For the complete combustion of biogas, more oxygen is drawn from the surrounding air, called secondary air.

Main designing parameters

The main parameters for designing a biogas stove are: efficiency and safety suiting to the kind of biogas plants being promoted, besides simplicity to mass manufacturing and cost effectiveness. For achieving a high efficiency, the important factors to be considered are:

- Gas composition,
- Gas pressure, and
- Flame speed (velocity).

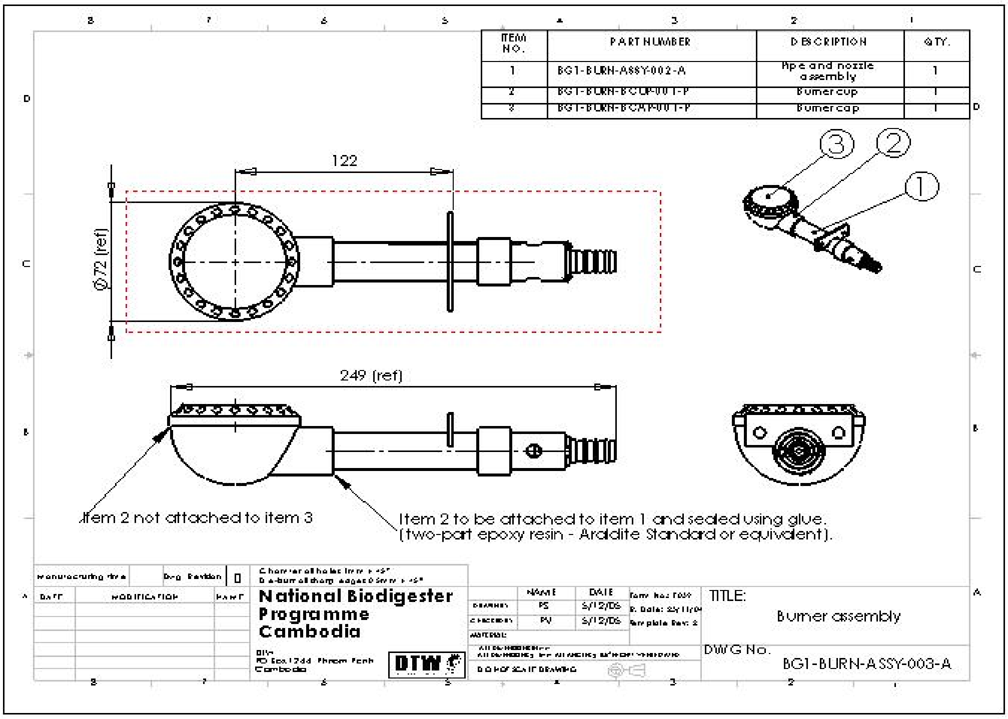
In general the stove should meet certain criteria mentioned below:

- Gas inlet pipe should be smooth to minimize the resistance to flow of gas and air.
- Spacing and size of air holes should match with the requirement of gas combustion.
- Volume of burner manifold should be large enough to allow complete mixing of gas with air.
- Size, shape and number of burner port holes should allow easy passage of the gas-air mixture, formation of stabilized flame and complete combustion of gas, without causing lifting up of flame, off the burner port or flashback of flame from burner port to mixing tube and injector.

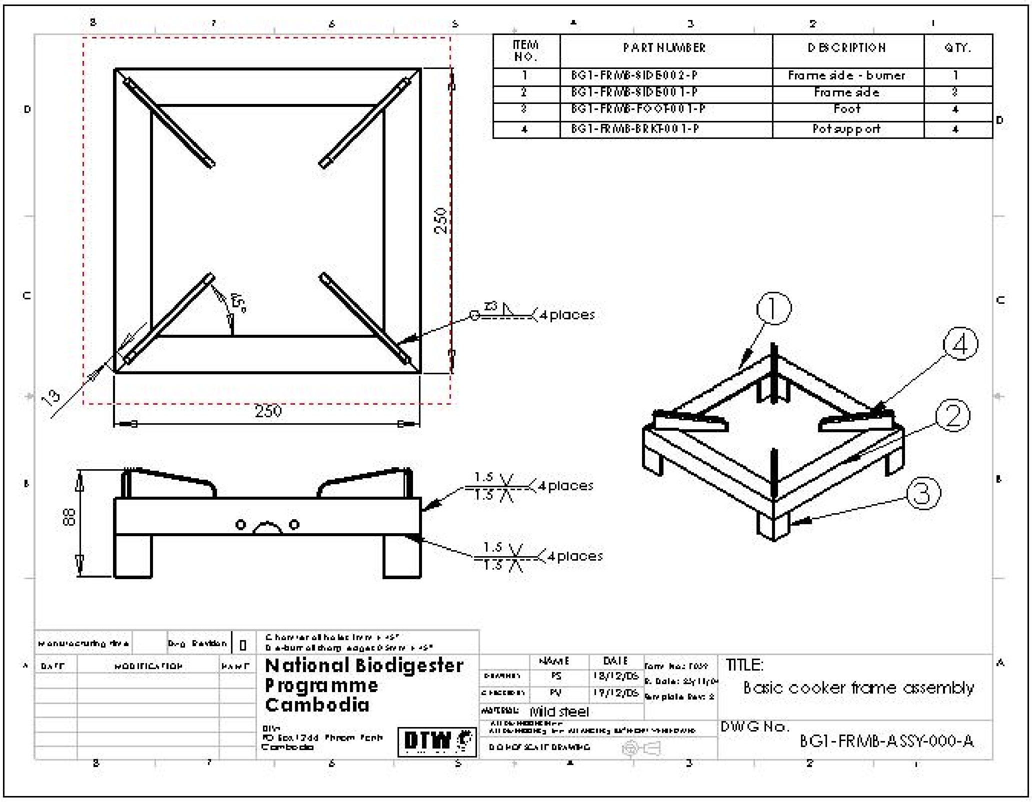
Biogas stoves have their own specific properties adapted to the caloric value of the gas and the oxygen requirement of optimal burning. Other stoves like butane or propane stoves cannot be used unless they are modified.

Biogas stoves are commonly available in hardware stores or specialised biogas companies in countries where the biodigester sector is well developed such as India, China, Nepal and Vietnam. These stoves are produced on a mass scale and very similar in their appearance compared to other gas stoves. Biogas stoves are officially standardised in China by the State General Administration of Quality Supervision and Inspection and Quarantine (GB/T 3606-2001 NSDBS, 2001) and in by the India Bureau of Indian Standards (BIS, 2002 Annex II). Both standards provide information on construction, operation, safety requirements and tests

In countries with a less developed biodigester infrastructure simple stoves can be made locally or they will have to be imported from one the countries mentioned above. The design of a reasonably efficient stove which can be made in workshops with modest equipment is given here below.



ITEM NO. | PART NUMBER | DESCRIPTION | QTY.
1 | BG1-BURN-ASSY-002-A | Pipe and nozzle assembly | 1
2 | BG1-BURN-BCUP-001-P | Burner cup | 1
3 | BG1-BURN-BCAP-001-P | Burner cap | 1
122
Ø72 (ref)
249 (ref)
Item 2 not attached to item 3
Item 2 to be attached to item 1 and sealed using glue.
(two-part epoxy resin - Araldite Standard or equivalent).
National Biodigester Programme Cambodia
TITLE: Burner assembly
DWG No. BG1-BURN-ASSY-003-A



ITEM NO. | PART NUMBER | DESCRIPTION | QTY.
1 | BG1-FRMB-SIDE002-P | Frame side - burner | 1
2 | BG1-FRMB-SIDE001-P | Frame side | 3
3 | BG1-FRMB-FOOT001-P | Foot | 4
4 | BG1-FRMB-BRKT001-P | Pot support | 4
250
250
13
4 places
88
1.5
4 places
National Biodigester Programme Cambodia
Mild steel
TITLE: Basic cooker frame assembly
DWG No. BG1-FRMB-ASSY-000-A

1.2.10 Lighting

Efficiency of biogas lamps

In villages without electricity, lighting is a basic need as well as a status symbol. Therefore provision of biogas lamps will often be an imported part of a biogas programme and a strong motivation for a farming family to install a plant. However, biogas lamps are not very energy-efficient. This means that they, besides light, also generate a lot of heat.

The bright light of a biogas lamp is the result of incandescence, i.e. the intense heat-induced luminosity of special metals, so-called "rare earth" like thorium, cerium, lanthanum, etc. at temperatures of 1000-2000°C. If they hang directly below the roof, they can cause a fire hazard. It is important that the gas and air in a biogas lamp are thoroughly mixed before they reach the gas mantle, and that the air space around the mantle is adequately warm.

The mantle of a biogas lamp resembles a small net bag. A binding thread made of ceramic fiber thread is provided for tying it onto the ceramic head. When heated at a temperature of more than 1000 ^{o} C, the mantle glows brightly in the visible spectrum while emitting little infrared radiation. Fabric of the mantle, when flamed for the first time, burns away, leaving a residue of metal oxide. Therefore the mantle shrinks and becomes very fragile after its first use. In general the mantles do not last long because of insect damage and high gas pressure, regular maintenance and mantle change is needed.

Since thorium is radioactive material it should be handled with utmost care. The particles from thorium gas mantles could fall out over time and get into the air where they could be inhaled. Also of concern is the release of thorium bearing dust if the mantle shatters due to mechanical impact. Alternative materials which could be used are yttrium or zirconium, although they are either more expensive or less efficient.

The key factor which determines the luminous efficiency is the type and size of mantle, besides the inlet gas pressure, the fuel-air mixture, etc. The hottest inner core of the flame, should match exactly with the form of the mantle.

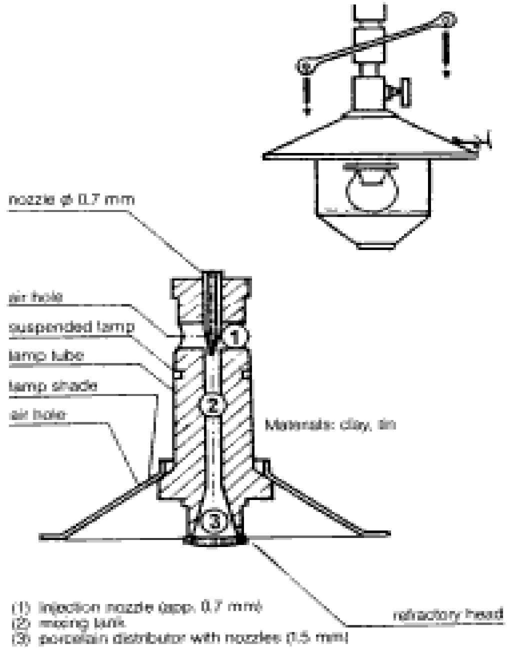
Another critical parameter that determines the luminance is the intake gas pressure (Nijguna, 2006). At a gas pressure of less than 75 mm of water column, the shining efficiency was found poor and at 150 mm water column, the shining efficiency was excellent. This means that biogas lamps cannot be used for plastic bag digesters or for plants where the gas is stored in plastic bags.

Light output

The light output (luminous flux) is measured in lumen (lm). At 400-500 lm, the maximum light-flux values that can be achieved with biogas lamps are comparable to those of a normal 60-75 W light bulb. Their luminous efficiency ranges from 1.2 to 2 lm/W. By comparison, the overall efficiency of a light bulb comes to 3-5 lm/W, and that of a fluorescent lamp ranges form 10 to 15 lm/W. One lamp consumes about 120-150 liter biogas per hour.

Optimal tuning

The performance of a biogas lamp is dependent on optimal tuning of the incandescent body (gas mantle) and the shape of the flame at the nozzle, i.e. the incandescent body must be surrounded by the inner (=hottest) core of the flame at the minimum gas consumption rate. If the incandescent body is too large, it will show dark spots; if the flame is too large, gas consumption will be too high for the light-flux yield. The lampshade reflects the light downward, and the glass prevents the loss of heat.



Schematic structure of a biogas lamp

Using biogas for lighting the following aspects should be considered:

1) The amount of light of a biogas lamp under normal operational conditions is comparable with a 60-75 W electric bulb with gas consumption, varying between 0,10-0,15 m^3/hour.
2) Gas mantles are easily worn out. Fluctuations in pressure and composition of the biogas result in frequent adjustment of the burner and breaking of the mantle.
3) Experience of lamps running on biogas in India and Nepal has shown that expectations of users are often too high.
4) Use of gas lamp often works in competition with the use of the stove burner.

Despite all the mentioned limitations of a biogas lamp, for users the availability of light can be very important. Therefore the above mentioned points need attention in the communication towards end-users to avoid disappointment later.

2. Utilisation of biodigester effluent (slurry) as feed and fertiliser

By-products of agriculture, mainly animal wastes and crop residues, are the primary inputs for biogas plants. The digested slurry as one of the outputs of a biogas plant can be returned to the agricultural system. Proper application of the slurry as organic fertilizer increases agricultural production because of its high content of soil nutrients, growth hormones and enzymes. Dried slurry can also safely replace a part of animal and fish feed concentrates. Furthermore, slurry treatment also increases the feed value of fodder with low protein content. When the digested slurry is placed into the food chain of crops and animals, it leads to a sustainable increase in farm income.

This close relation between biogas and agriculture can be taken as an indicator of the environmental friendly nature of the technology as shown in the chart below.

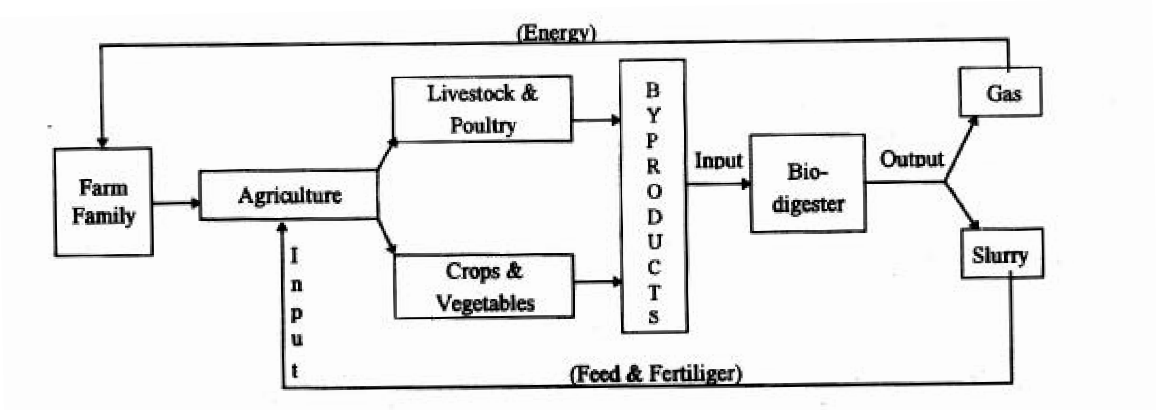


Chart: Relationship between Biogas and Agriculture in a Farming Family

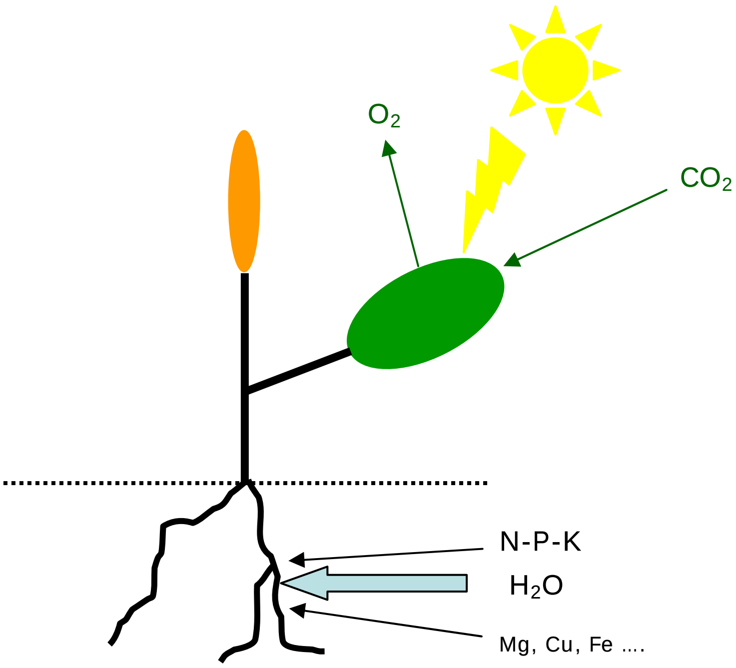
2.1 Limitations of Chemical Fertilizer Use

The chemical fertilizer use only replenishes only a small part of the soil nutrients removed every year. With the poor management (loss of manure due to insufficient gathering and nutrients during the composting process) and application of Farm Yard Manure (FYM), soils are not replenished fully with the nutrients mined every year in terms of agricultural production. Thus, the productivity of soils is declining due to this continuous over-mining.(APROSC/JMA, 1995).

Organic matter plays an important role because of its beneficial effects in supplying plant nutrients, improving soil aggregation, increasing water holding capacity of soils, stabilizing its humid content and increasing its water holding capacity. Organic soil amendments support biological activities and also control root pathogens. Biodigester slurry has proved to be a high quality organic manure Compared to FYM, digested slurry will have (slightly) more nutrients, because in FYM, the nutrients are lost to some extent by volatilization (nitrogen) due to exposure to sun (heat) as well as by leaching.

The farmer needs to use chemical fertilizer to increase his crop production. However, if only mineral fertilizers are continuously applied to the soil without adding organic manure, productivity of land will decline. On the other hand, if only organic manure is added to the soil, desired increase in crop yield can not be achieved. Fertility trials carried out in Nepal and elsewhere have revealed that optimum results can be achieved through the combined application of both chemical and organic fertilizers.

In countries where biogas technology is well developed, for instance in China, there are evidences which support the fact that productivity of agricultural land can be increased to a remarkable extent with the use of slurry produced from biogas plant. In Nepal too, when properly managed, the biogas slurry plays a major role in supplementing the use of imported and expensive chemical fertilizers.



The figure above illustrates a plant growing process. While chemical fertilisers can provide the primary macro elements N,P and K, the secondary elements Ca, Mg and S as well as the trace elements B, Cu, Fe, Cl, Mn, Mo, and Zn have to be provided through organic fertilisers.

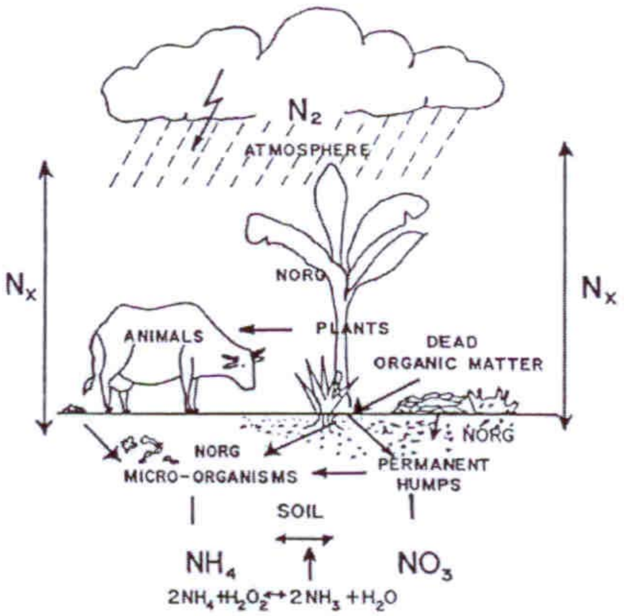
2.2 Characteristics of Digested Slurry

Only approximately 10 percent of the total nitrogen content in fresh dung is readily available for plant growth. A major portion of it has first to be biologically transformed in the soil and is only then gradually released for plant use. When fresh cow dung dries, approximately 30 to 50 percent of the nitrogen escapes within 10 days. While nitrogen escaping from digested slurry within the same period amounts to only 10 to 15 percent Therefore, the value of slurry as fertilizer, if used directly in the field as it comes out of the plant, is higher than when it is used after being stored and dried (Moulik, 1990).

The short term fertilizer value of dung is doubled after being anaerobically digested while the long term fertilizing effects are cut by half. Under tropical conditions (i.e. where biogas plants are most effective) the short term value is of greater importance because rapid biological activities degrade even the slow degrading manure fraction in relatively short time.
Cattle dung contains about one percent total nitrogen. Nitrogen is considered particularly important because of its vital role in plant nutrition and growth. The nitrogen cycle in nature is depicted in the chart on the next page. (Sasse, 1991).

During anaerobic digestion, 25 to 30 percent organic matter is decomposed and hence the nitrogen percentage is raised to 1.3. Although no new nitrogen is formed during anaerobic digestion, 15 to 18 percent nitrogen is converted into ammonia (NH_4) whereas nitrogen in aerobically digested organic wastes (activated sludge, compost) is mostly in oxidized form (nitrate and nitrite). Increasing evidence suggests that for many land and water plants, ammonium is more valuable as a nitrogen source than oxidized nitrogen in the soil. Ammonium is less likely to leach away and hence more apt to become fixed to exchange particles like clay and humus (Satliianathan, 1975).

Experiments in China have shown that compared to fresh dung, the ammoniac nitrogen in the digested slurry increases by 260 percent whereas it decreases by 17.5% in FYM.
As a result of anaerobic fermentation, about 30 to 40 percent of organic carbon present in the dung is decomposed as carbon dioxide and methane. The rest is retained as such and contains plant nutrients. When fully digested, the slurry from a biogas plant is odourless and does not attract insects or flies.



The Nitrogen-Cycle in Nature

The organic fraction of slurry may contain up to 30-40 percent of lignin, undigested cellulose and lipid material, on a dry weight basis. The remainder consists of substances (mineral, salts, etc.) originally present in the raw materials but not subject to bacterial decomposition. The amount of bacterial cell mass is low (less than 20 percent of the substrate is converted to cells). Therefore, there is less risk of creating odour and insect breading problems.

Some of the major key features of biogas slurry can be summarized as follows:

- Biogas manure is ready in shortest possible time.
- There is minimum loss of nitrogen in biodigester slurry due to anaerobic conditions in the plant.
- If night soil and cattle urine are added, availability of nitrogen and phosphorus in the biodigester slurry is increased.

2.3 Utilization of Digested Slurry

It has been observed that the use of digested slurry as manure improves soil fertility and increases crop yield. Data from field experiments suggest that the slurry should be applied at the rate of 10 tons/ha in irrigated areas and 5 tons/ha in dry farming. The slurry can be used in conjunction with normal dose of chemical fertilizers. Such practice will help achieve better returns from fertilizers, minimize the loss of fertilizers from the soil and provide balanced nutrition to crops. Different methods of slurry applications are described this section.

2.3.1 Application of Slurry in Liquid Form

The digested slurry can be directly applied in the field using a bucket or a pale. An alternative to this is to discharge the slurry into an irrigation canal. However, these methods of direct application have some limitations. Firstly, not all farmers have irrigation facility throughout the year. Secondly, in the cascade system of irrigation in which water is supplied from one field to another, slurry is not uniformly distributed in the fields. Finally, since the digested slurry is in a liquid form, it is difficult to transport it to farms located far from the biogas plants.

The sludge and slurry could be applied to the crop or to the soil both as basal and top dressings. Whenever it is sprayed or applied to standing crop, it should be diluted with water at least at the ratio of 1:1. If it is not diluted, the high concentration of available ammonia and the soluble phosphorus contained in the slurry will produce toxic effect on plant growth "burning the leaves".

2.3.2 Application of Slurry in Dried Form

The high water content of the slurry causes difficulties in transporting it to the farms. Even if it is applied wet in the field, tilling is difficult. Due to such difficulties, the farmers usually dry the slurry before transporting it into the fields. When fresh slurry is dried, the available nitrogen, particularly ammonium, is lost by volatilization. Therefore, the time factor has to be considered while applying the slurry and in this regard, immediate use can be a way of optimizing the results.

2.3.3 Utilization of Slurry for Compost Making

The above mentioned difficulties can be overcome by composting the slurry. If the slurry is composted by mixing it with various dry organic materials such as dry leaves, straw, etc., the following advantages can be realised:

- The dry waste materials around the farm and homestead can be utilized.
- One part of the slurry will be sufficient to compost about four parts of the plant materials.
- Thus, increased amount of compost will be available in the farm.
- Water contained in the slurry will be absorbed by dry materials. Thus, the manure will be moist and pulverized. The pulverized manure can be easily transported to the fields.

A schematic diagram for use of slurry in making compost is shown in the chard on the next page. The ideal arrangement would be to dig three similar pits which may be filled in turn. The size of these pits should be such that by the time the third one is filled, the first one is dry enough to transport the compost to the field.
The availability of nutrients in composted manure, FYM and the digested slurry are presented in the table below.

Nutrients Available in Composted Manure, FVM and Digested Slurry

Nutrients	Composted manure		FYM		Digested Slurry	
	Range	Average	Range	Average	Range	Average
Nitrogen (N)	0.5 to 1.5	1	0.5 to 1.0	0.8	1.4 to 1.8	1.6
P205	0.4 to 0.8	0.6	0.5 to 0.8	0.7	1.1 to 2.0	1.55
K20	0.5 to 1.9	1.2	0.5 to 0.8	0.7	0.8 to 1.2	1.0

Furthermore, the complete digestion of cattle dung in a biogas plant destroys weed seeds and organisms that can cause plant diseases.

2.4 Size of Compost Pit

It is advisable to construct at least two compost pits beside the biogas plant so that each of them can be emptied alternatively. The total pit volume should be equal to the volume of the biogas digester.

2.5 Quality Assessment of Compost and Digested Slurry

To derive maximum benefit from organic manure application, the compost should be well decomposed and be of good quality. Use of un-decomposed organic manure should be avoided as it will do more harm than good. Un-decomposed materials when applied to the soil attract insects and take a longer time (i.e. more time than the life cycle of the crop) before the plant nutrients present in them are converted in the form that can be assimilated by the plants.

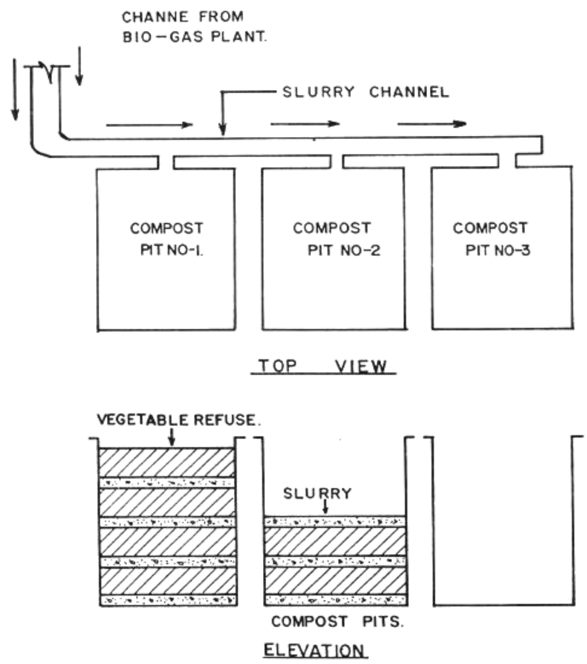


CHART-43 USE OF SLURRY IN MAKING COMPOST

2.6 Field Experiment

Field experiments carried out in China have produced the following results (Biogas Technology in China, 1983):

- Compared to the control, application of digested slurry increased the late rice, barley and early rice yields by 44.3 percent, 79.8 percent and 31 percent, respectively.
- Compared to FYM, application of digested slurry increased the rice, maize and wheat yields by 6.5 percent, 8.9 percent and 15.2 percent, respectively.
- Compared to FYM, application of digested slurry along with ammonium bicarbonate (chemical fertilizer) increased the rice and maize yields by 12.1 percent and 37.6 percent, respectively.

The Chinese results indicate that biogas slurry is of superior quality than FYM. Crop productivity can be significantly increased if the slurry is used in conjunction with appropriate nature and dose of chemical fertilizer.

The national biodigester programme in Vietnam has reported the following findings:

- Use of bioslurry to replace chemical fertilizer in tea farming improves quality of tea product, and helps to increase yield by 11%, net saving being 148 euro/ha/harvest (about 5-6 harvest/year)
- Use of bioslurry to replace NPK in vegetable farming helps to increase the yield by 20% and reduce the incidences pest insects considerably
- Use of bioslurry as pig-feed helps in saving food cost to an amount approximately 9-11euro/pig/feeding cycle of two months. However, feeding of bioslurry for piglet is not recommended.
- Use of bioslurry as feed for fish nurseries saves 67% fish-food cost equalling to 375euro/ha/harvest (about three harvests/year)
- Use of bioslurry as feed for adult fish saves 40% fish-food cost, eliminates head floating and increases the yield by 12%, equalling to the saving of 1000euro/ha/harvest (about 2 harvests/year)

Effect of bioslurry use in terms of economic aspect, quality of product and food safety can be realized by the savings of 50 Euro/ha for winter rice, 44 Euro/ha for spring rice and 12.5 Euro/ha for spring peanut).

2.7 Effluent as a Supplement in Ration of Animal and Fish

Digested slurry has been used to supplement feed for cattle, pigs, poultry and fish in experimental basis. The encouraging results obtained from experiments are yet to be commonly practiced by the users. The following subsections describe various experiments carried out in this area.

2.7.1 Digested Slurry as a Feed to Animals

Results from the Maya Farms in the Philippines showed that in addition to the plant nutrients, considerable quantity of Vitamin Bi2 (over 3,000 mg of Bi: per kg of dry sludge) are synthesiscd in the process of anaerobic digestion. The experiment has revealed that the digested slurry from biogas plant provides 10 to 15 percent of the total feed requirement of swine and cattle, and 50 percent for ducks (Gunnerson and Stuckey, 1986). Dried sludge could be substituted in cattle feed with satisfactory weight gains and savings of 50 percent in the feed concentrate used (Alviar. et al.. 1990). The growth and development of Salmonella chloreasuis and Coli bacillus were inhibited under anaerobic fermentation.

The low availability of good quality forage is the result of low productivity of rangeland as well as limited access to it. Only 37 percent of rangelands arc accessible for forage collection (HMG/AsDB/ FINNIDA 1988). Therefore, addition of dried sludge in cattle feed would improve the nutrient value of the available poor fodder.

An experiment was carried out at BRTC, Chengdu. China in 1990 to study the effects of anaerobically digested slurry on pigs when used as food supplement. Effluent (digested slurry) was added at the rate of 0.37 to 1.12 litres of kg of feed in the normal mixed feed rations.

The pigs were fed with this ration until their body weight reached 90 kg. The piglets in this experiment grew faster and showed better food conversion than the control group. Negative effects on the flavour or hygienic quality of the meat were not noticed (Tong, 1995). Subject to further trials, digested slurry might be safe as animal feed.

2.7.2 Digested Slurry as a Feed to Fish

A comparative study on fish culture fed only with digested chicken slurry was carried out by National Bureau of Environmental Protection (NBEP). Nanjing. China in 1989. The results showed that the net fish yields of the ponds fed only with digested slurry and chicken manure were 12,120 kg/ha and 3,412.5 kg/ha, respectively. The net profit of the former has increased by 3.5 times compared to that of the latter. This is an effective way to raise the utilization rate of waste resources and to promote further development of biogas as an integrated system in the rural areas (Jiayu, Zhengfang and Qiuha, 1989).

An experiment was carried out in Fisheries Research Complex of the Punjab Agricultural University, Ludhiana, India to study the effects of biogas slurry on survival and growth of common carp. The study concluded that growth rates of fish in terms of weight were 3.54 times higher in biogas slurry treated tanks than in the control. Biogas slurry proved to be a better input for fish pond than raw cow dung since the growth rate of common carp in raw cow dung treated tanks were only 1.18 to 1.24 times higher than in the control. There was 100 percent survival of fish in ponds fed with digested biogas slurry as compared to only 93 percent survival rate in ponds fed with raw cow dung.

2.8 Other Uses

Many extensive experiments performed in China have proved that the digested slurry, when used as fertilizer, has strong effects on plant tolerance to diseases such as potato wilt (Pseudomonas salanacearum), late blight, cauliflower mosaic, etc. and thus can be used as bio-chemical pesticide.

A series of experiments and analyses conducted in China in a period of three years show that the cold-resistant properties of early season rice seedling are effectively enhanced by soaking seeds with digested slurry.

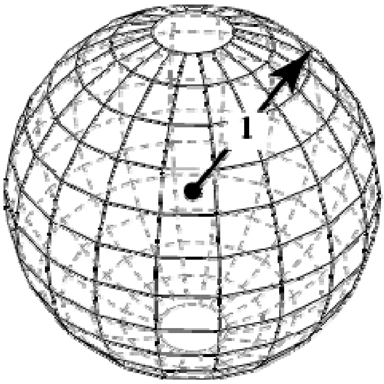
The survival rate increased by 8 to 13 percent and the quality of seedlings raised by soaking seeds with digested slurry is much higher than that of the control group during the recovering period after low temperature stress. The seedlings germinated faster, grew well and resisted diseases (Biogas Technology In China, 1989).

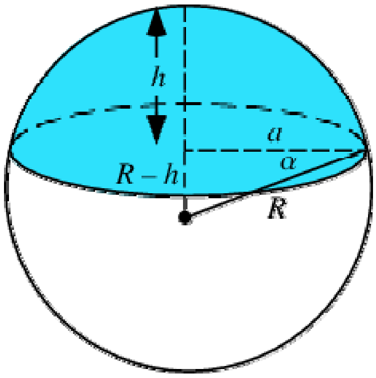
Foliar application of diluted slurry increases rate of wheat plant growth, resists to lodging and increases size of grains and length of the ear. Foliar application in grapes have been found to increase yield, length of fruit-year, sugar content, fruit size, colour, and resistance to mildew diseases. In cucumbers, it has been observed to increase resistance to wilt diseases. In peach, it develops better fruit colour and early maturation.

Digested slurry can effectively control the spreading and occurrence of cotton's weathered disease. It decreases the rate of the disease with an efficiency rate of 50 percent for one year and 70 percent for more than two years along with increase in production.

3. Plant size calculations

The general steps followed to calculate the capacity of plant for spherical (dome shaped) biodigester is given hereafter as an example:

<table>
<tr>
<td>The volume of sphere is: $V = \frac{4}{3}\pi R_1^3$


So half sphere volume $V_1 = \frac{4\pi R_1^3}{6}$,
After simplifying, $V_1 = 2.09\,R_1^3$</td>
<td>$V_2 = \frac{1}{3}\pi h^2 (3R_2 - h)$, segment of sphere


$R_2^2 = R_1^2 + R_1^2 \Rightarrow R_2 = R_1\sqrt{2} = 1.414R_1$
$h = R_2 - R_1 = R_1\sqrt{2} - R_1 = R_1(\sqrt{2} - 1)$
$h = 0.414R_1$
$V_2 = \frac{\pi \times (0.414 \times R_1)^2}{3}(3 \times 1.414R_1 - 0.414R_1) = 0.687R_1^3$</td>
</tr>
<tr>
<td colspan="2">$V = 2.09R_1^3 + 0.687R_1^3$, this is the simplified equation of total digester volume.</td>
</tr>
</table>

Design criteria:

1. Dead volume of gas storage (top of dome) should be 0.2 – 0.3m^3
2. Gas storage capacity should be >50% of the total daily gas production
3. Volume of outlet = Volume of active gas storage
4. Length of outlet should = 1.5 of breadth of outlet

Example, sizing digester volume of $4m^3$.

Step 1: Calculation of R_1 and R_2

- $4m^3 = 2.09R_1^3 + 0.687R_1^3$, from this equation by trial and error compute R_1, and it is found to be
- R_1 = 1.13 m, and
- R_2 = 1.6 m
- h = 0.47 m

Step 2. Calculation of Volume of Upper Sphere and Volume of Bottom Sphere

- $V_1 = 2.09\,R_1^3 = 3.016\,m^3$
- $V_2 = 0.687R_1^3 = 0.99\,m^3$
- V = 4.006 m^3.

Step 3: Computation of Volume of Gas-storage

- From experience, the gas storage volume needs to be 25% of the total plant volume, so
- The volume of gas storage (Vg) $V_{gas} = 25\%\,V = 1.0015m^3$
- Height of gas storage tank in m is computed by $V_{gas} = \frac{1}{3}\pi h^2\left(3R_1 - h\right)$, so
- $V_{gas} = \frac{1}{3} \times 3.14 \times h^2 \times \left(3 \times 1.14 - h\right) = 1.047h^2\left(3.42 - h\right) = 3.581h^2 - 1.047h^3 = 1.0015\,m^3$
- $1.047h^3 - 3.581h^2 + 1.0015 = 0$
- $h_{gasstorage} = 0.58\,m$

Step 4: Active Slurry Volume

$V_{active\_slurry} = V_{total} - V_{gas} = 4.006 - 1.0015 = 3.0045$

Step 5:

- HRT in days = 40

Step 6: Computation of Daily Feeding

- $\text{Daily feeding} = \frac{V_{active\_slurry}}{HRT} = \frac{3.0045}{40} \times 1000 = 75\,\text{liters}$
- With ratio 1:1, the daily dung requirement in kg is: $\frac{75}{2} = 37.5kg$

Step 7: Computation of Maximum Gas Production

- $\text{Daily maximum gas production}\left(m^3\right) = \text{Daily feeding, kg} \times \text{Gas produce per kg dung, liters / kg}$
- $37.5 \times 40\,\text{liters / kg} = 1.5m^3$

Step 8: Computation of effective gas volume, V_{eff_gas}

- Effective gas volume in m^3 = 50% of total daily gas production = $0.5 \times 1.5 = 0.75m^3$.
- $V_{eff\_gas} = 0.75m^3$

Step 9: Computation of maximum gas volume

- $\text{Maximum gas volume}, V_{max\_gas} = \text{Volume of storage}, V_{gas} + \text{Effective gas volume}, V_{eff\_gas}$
- $V_{max\_gas} = 1.0015 + 0.75 = 1.75m^3$

<u>Step 10:</u> Computation the Height of max storage in m

- $V_{max\_gas} = \frac{\pi h^2}{3}(3R_1 - h) = 1.75m^3$
- $V_{max\_gas} = \frac{1}{3} \times 3.14 \times h^2 \times (3 \times 1.14 - h) = 1.047h^2(3.42 - h) = 3.581h^2 - 1.047h^3 = 1.75\,m^3$
- $1.047h^3 - 3.581h^2 + 1.75 = 0$
- $h_{max\_gas} = 0.79m$

<u>Step 11:</u> Computation the height of manhole

- $Manhole\ Height, h_{manhole} = Inner\ radius\ of\ top\ dome, R_1 - Height\ of\ \max imum\ gas\ storage, h_{\max\_gas}$
- $h_{manhole} = 1.14 - 0.79 = 0.35m$

<u>Step 11</u>: Computation of Pressure height, p in m

- $p = h_{\max\_gas} - h_{gasstorage}$
- $p = 0.79 - 0.58 = 0.21m$

<u>Step 12</u>: Computation of dead volume, V_{dead} in m^3

- $V_{dead} = V_{gas} - V_{eff\_storage} = 1.0015 - 0.75 = 0.25m^3$
- $1.047h^3 - 3.581h^2 + 0.25 = 0$
- $h_{dead} = 0.27m$

<u>Step 13:</u> Computation the volume of Outlet, V_{out} in m^3

- $V_{out} = V_{eff\_gas} = 0.75m^3$

<u>Step 14:</u> H of Outlet, J

- $J = h_{gas\_srage} + 0.1m = 0.58 + 0.1 = 0.68m$

<u>Step 15:</u> Computation area of outlet, A_{out}

- $A_{out} = \frac{V_{out}}{J} = \frac{0.75}{0.68} = 1.1m^2$

<u>Step 16:</u> Computation of width B_{out} and length L_{out} of outlet tank

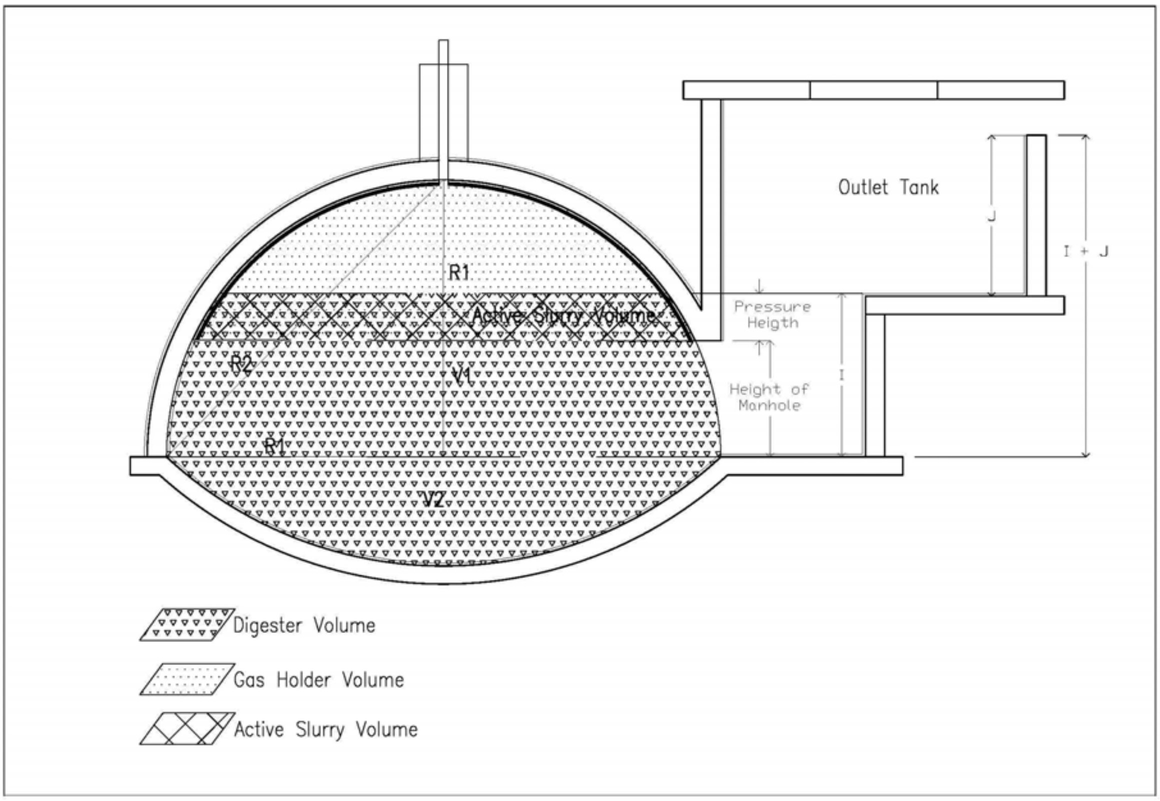
- $L_{out} = 1.5B_{out}$
- $A_{out} = L_{out} \times B_{out} = 1.5B_{out} \times B_{out} = 1.5B_{out}^2 = 1.1m^2$
- $B_{out} = 0.86m$
- $L_{out} = 1.5 \times 0.86 = 1.29m$

<u>Step 17:</u> Computation the height of first step outlet tank, I, m

- $\text{Height of first step outlet tan k}, I = \text{Height of manhole}, h_{m\_hole} + \text{Pr essure height}, p$
- $I = 0.35 + 0.21 = 0.56m$

<u>Step 18</u>: Computation total height of outlet tank, $I + J$

- $I + J = 0.56 + 0.68 = 1.24m$



4. Building viable domestic biogas programmes; *Success factors in sector development*

0 Summary

For the past two decades, SNV-the Netherlands Development Organisation has been involved in preparation and implementation of large-scale domestic biogas dissemination programmes.

Although the (apparent) success of these programmes can be ascribed to a range of factors, this chapter examines the influence of SNV's rather unique approach on the achievements.

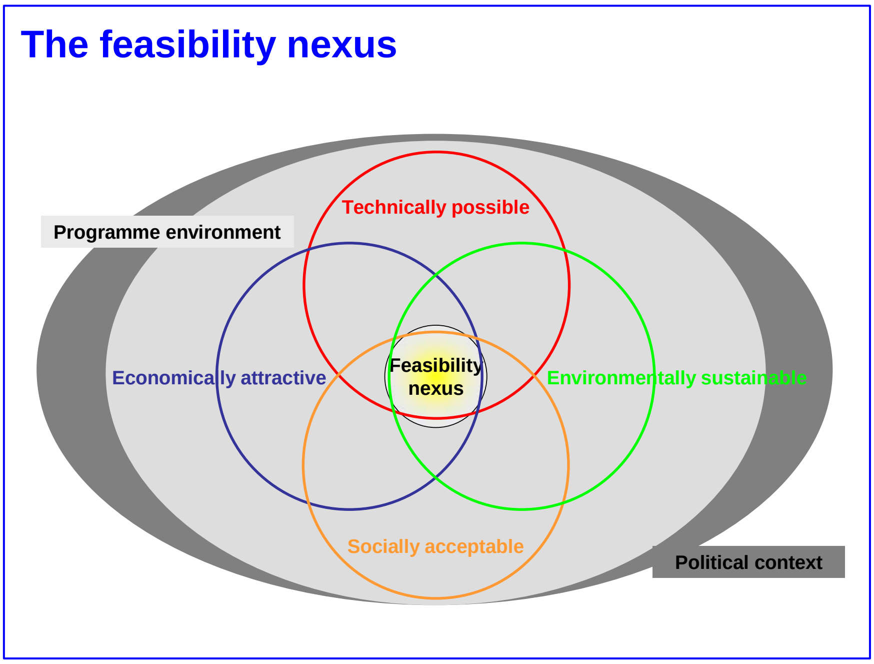
Taking the key question "What is the secret of the successful biogas programmes, and what is SNV doing to achieve this?" as its point of departure, five features are identiefied, and their challenges, of the approach:

- Thorough, participatory and context-specific preparation;
- A sustainable sector as the ultimate long-term objective;
- Interlinking impact and capacity development targets;
- Promoting a market-oriented approach;
- Attributing sector-functions to multiple stakeholders.

Hereunder, these five –interrelated- characteristic features of SNV's biogas approach are presented, together with their associated challenges. For each feature a description is provided of SNV's specific role as well as some examples.

4.1 Thorough, participatory and context-specific preparation

("P5: Proper Preparation Prevents Poor Performance")



Although Nepal, Vietnam, Cambodia, Bangladesh, Pakistan and Lao PDR are all Asian countries, they show significant differences in their technical, economic, social / cultural, environmental and political make-up. A national biogas programmes needs to fit this country-specific environment and as a result, programmes differ significantly between countries; whereas the private sector drives the biogas programme in Nepal, the programme in Vietnam is very much governed by the provincial governments.

The quest for the best fit, expressed in the feasibility nexus, is in the focus during all the steps of the preparatory process. To assess the feasibility, SNV uses comprehensive checklists and questionnaires.

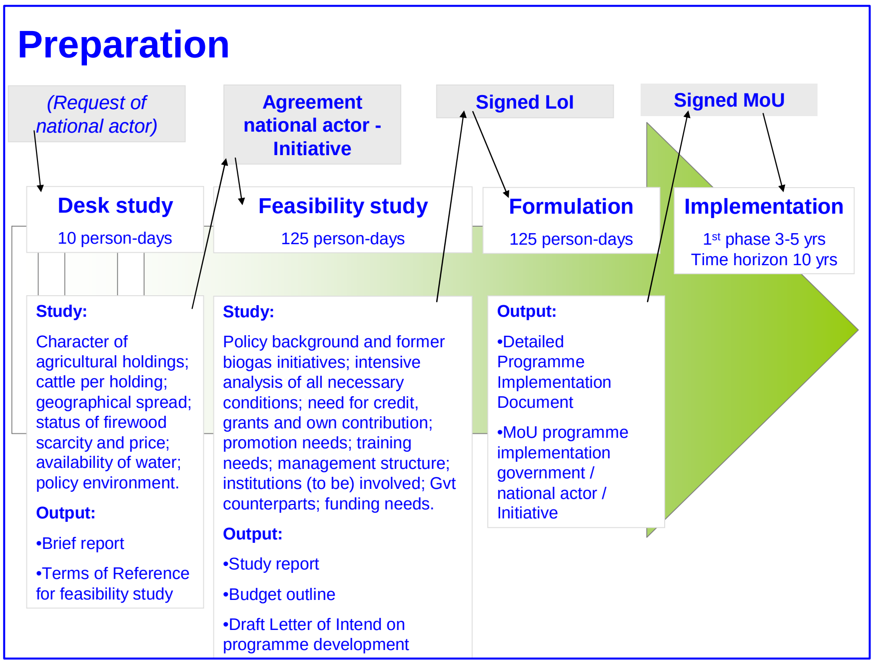
Thorough studies are required to determine the market potential for domestic biogas, the proper technical design, the most appropriate institutional set-up and the required implementation modalities. To instil ownership from the very beginning, such preparation needs to place take in a participatory manner, in close consultation with relevant stakeholders from the government, civil society and private sector.

The *challenge* of this feature is that the thorough preparation makes starting-up a biogas programme time-consuming and costly. Quicker and cheaper deals are always tempting, but have a considerable risk that the programme will eventually not be owned by the relevant stakeholders.

SNV applies an elaborate preparation trajectory: during the desk study, first answers are provided regarding the technical potential for domestic biogas. If the conditions for large-scale dissemination of domestic biogas are met, SNV will undertake fact finding missions and feasibility studies in order to make a well founded "go/no go" decision for intervention.

This second step, the feasibility study, assesses environmental, social and economic aspects in detail. These missions and studies include comprehensive context and multi-stakeholder analyses; look at the potential demand for biogas plants and the constraints faced by the current and possible future suppliers of services. Analyses also look at possible inclusion of women and disadvantaged groups. The resulting reports thus provide information on the commercial scope of the programme, indicates high-potential areas within the country, and a first sketch of the programme and its environment, identifying potential key stakeholders.

In case of a “go” decision, a detailed proposal for a national programme including output targets, estimated expenditures and proposed financing is formulated in cooperation with the different (potential) stakeholders. Crucial during the formulation phase is to arrive at an accepted institutional set-up for the programme. Typically, the resulting Programme Implementation Document describes the 1st phase of implementation –a period of 3 to 5 years- within an overall planning horizon of 10 years.



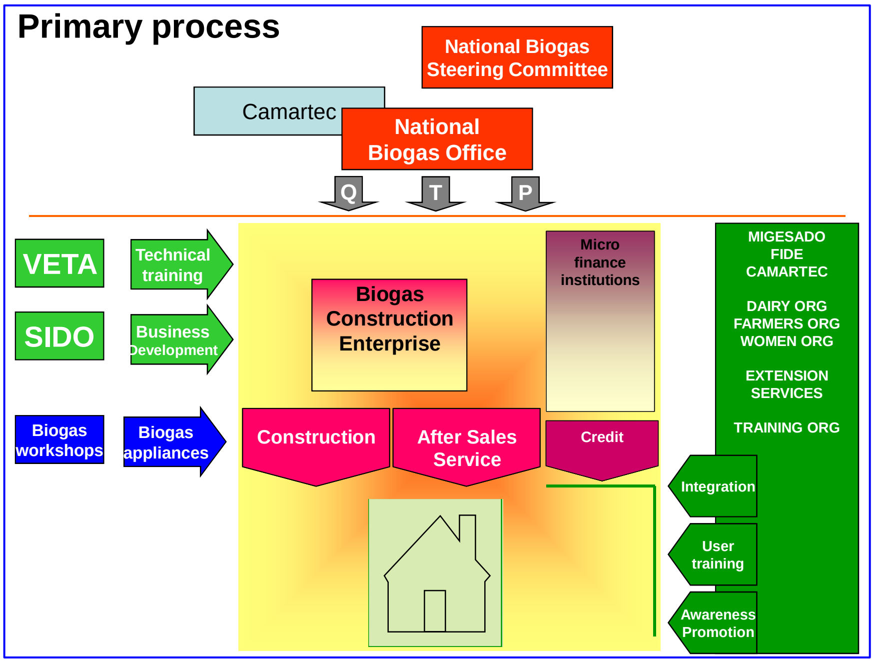
Actual implementation will only take place after financial arrangements (increasingly including a carbon component) and organizational issues have been settled. Between desk study and start of the implementation easily 1 to 2 years can pass.

Example 1:

The Technology Research Institute of Science Technology and Environment Agency (STEA/TRI) in Lao PDR requested SNV to assist in the set-up of a biogas programme. A number of studies were undertaken to analyse the possible market potential of domestic biogas. It was concluded that on the short term this potential would be not very big, but that in certain areas, for example in Vientiane Capital, a modest demand could be already tapped. Also a participatory assessment of the possible institutional set-up for a small programme was undertaken, concluding that STEA/TRI would not be the appropriate implementing partner as they do not employ staff-members at district level that would be able to interact with the livestock farmers in the rural areas. The Department of Livestock and Fisheries (DLF) under the Ministry of Agriculture and Forestry (MAF) was recommended as the most appropriate implementing partner. However, STEA/TRI could be one of the other actors within the project undertaking activities in the field of technical training, applied R&D and perhaps also quality control. The total lapse time for the preparation of the national pilot programme in Lao PDR amounted to one and a half years.

4.2 Sustainable sector as the ultimate, long-term objective

("Haste makes waste")



The ultimate objective of all activities undertaken in the framework of national programmes is to arrive at a commercially viable biogas sector; a sector that can be sustained by capable stakeholders and financed without any Official Development Assistance (ODA)[1]. In essence, then, sector development should translate into *Biogas companies marketing their services to smallholder households on a commercial basis, whereby customers have access to credit facilities to finance the investment*. For this to happen, the primary process -the transaction between supplier and client- should follow as close as possible the rigours of the market.

In many countries, the biogas sector is weakly developed or all-together absent at the start of the intervention. Sector development is a complex job and can not be achieved overnight. A long-term effort of between 7 to 20 years may be required to create the required 'critical mass'.

The *challenge* of this feature is that donors are often not able and/or willing to continue support for a long period, as their policy cycle is seldom longer than five years, often resulting in frequent shifts in priorities and objectives. For national governments in developing countries, priorities usually are manifold and domestic biogas is just one of the many sub-sectors that would be in need of support. As a result of such "short-sightedness", many development efforts get started, but suffer an early abortion without getting a fair chance to become mature.

SNV is advocating the importance of a sustainable sector as a long-term objective and plays an active role in mobilising the required resources for subsequent phases of biogas programmes. Success and tangible impact are the crucial ingredients required to convince governments and donors to continue providing financial support to national programmes.

In addition, SNV increasingly embarks on the –often cumbersome- development of a carbon component to the biogas programmes to improve the financial feasibility of large-scale programmes, thereby reducing the financial dependency on public funding.

[1] ODA does not refer to carbon funds to be mobilized for the financing of national programmes on domestic biogas

Example 2:
In Nepal, sector development has been on the agenda of BSP since its start in 1992. It took not less than two years to open the market for other constructors and lenders than GGC respectively ADB/N. The establishment of the apex body, the AEPC, required a preparation of four years as well as diplomatic pressure by donors making such apex body conditional to their funding. The association of biogas companies (NBPA) was established in 1994, but till date this association has not yet fully achieved its envisioned role. Investment subsidies have been reduced, the GoN has been increasing its contribution to the programme and a start was made with self-financing through CDM project development. No doubt, the biogas sector in Nepal has made significant developments. This progress was only possible with the continuous financial support provided by DGIS since 1992, the German Development Bank (KfW) and the Government of Nepal since 1997. SNV played a very active role in advocating this support to the programme.

4.3 Interlinked targets on impact and capacity development

("It takes two to tango")

In the programmes, impact targets are linked to capacity development targets. Targets on impact relate to the number of households getting access to biogas plants, while capacity building targets relate to results in the areas of organisational strengthening and institutional development. Needs for capacity building become clear when targets on impact are not reached in a qualified manner. All actors in the biogas programme are potential clients for capacity development services, whereby the focus may shift dependent on performance at a certain time. Hence, impact-level is the main driver for capacity development.

The *challenge* of this feature is that many development interventions just look after one set of targets; impact or capacity development. Targeting impact without capacity development looks attractive as it can generate tangible results on the short-term, but often fails to sustain these results. Targeting capacity development without impact focus builds on the assumption that actors – after being capacitated - will automatically deliver to (prospective) customers. This assumption often does not materialise, also because the analysis of the required capacity development is determined by an actor and/or donor, but not tested in the market.

SNV regards impact and capacity development as Siamese twins, strongly promoting the link between both. This concept was successfully applied during the set-up (formulation of objectives and activities; estimate of required budgets) and implementation (monitoring, quality control, reviews) of the national programmes in Nepal, Vietnam, Cambodia, Bangladesh, Lao PDR and Rwanda. Impact targets, like the number of households having installed a biogas plant, are directly linked to the development of the capacity of parties at the supply side, like the number of companies providing quality services on construction and after sales service. And the content of capacity building is directly linked with observed gaps in service quality (examples include: quality control for Biogas Technicians, training support for participating vocational training institutes, business training for biogas companies, ICT and administration training for participating government officials).

Example 3:
At the start of the second phase, construction progress in a number of provinces of the Vietnam Biogas Programme showed only modest progress whereas research indicated ample potential. Further analysis indicated that many Biogas Construction Teams –a kind of "proto-companies"- depended heavily on the provincial authorities regarding their marketing, rather then reacting directly on the market developments. To improve the performance of the Biogas Construction Teams, the Vietnam Biogas Programme developed a comprehensive "commercialization component" to the programme, aiming to improve business and marketing skills of the construction teams.

3.4 Promoting the market-oriented approach

("The customer is always right")

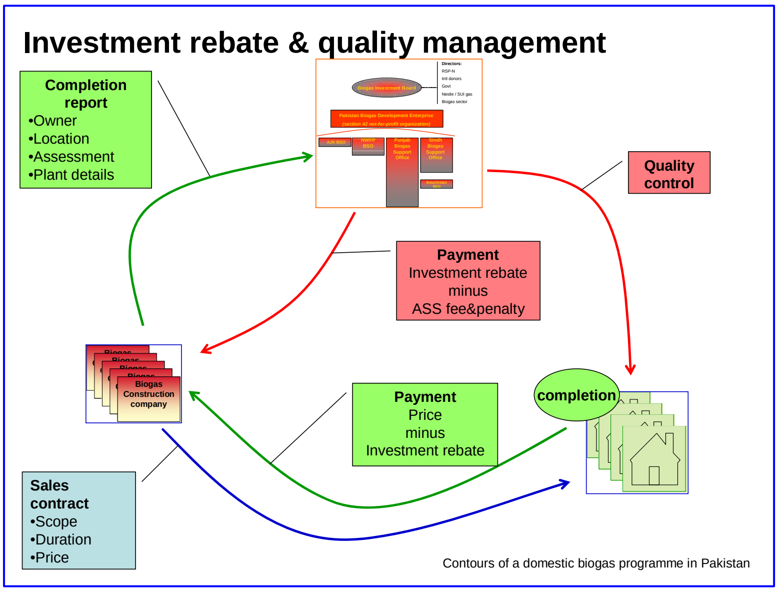
When biogas services fail to live-up to the expectations of the owner, it is the user who will suffer in the first place. In addition, there will be an immediate negative effect on the progress of the programme as neighbouring potential users will delay or even cancel their investment decision. As a result, the market for biogas plants will perish. Crucial in the promotion of biogas technology, hence, is a strict enforcement of carefully designed quality standards.

These standards shall not be limited to the design, construction materials or method and after sales service of biogas plants, but also include the quality of information provided to the potential users prior to their investment decision. If this decision is taken on the basis of wrong (too high) expectations, these expectations will never be met after installation of the plant; product dissatisfaction by the user will prevail, even if the plant is kept in operation.

Ensuring user-satisfaction requires actors at the supply side (constructors and lenders) to be fully accountable to the (prospective) customers and behave customer-friendly in order to increase their business. Product credibility as perceived by the customers in rural areas is not easy to achieve, but fundamental to the creation of the feedback loop: "service-quality – user satisfaction – promotion – sector development".

It is this loop that drives large-scale dissemination of an innovative technology as domestic biogas. By linking service quality to investment-rebate, biogas programmes create leverage on quality whereby a "carrot and stick" approach supports development towards a mature sector.

The *challenge* of this feature is striking the right balance between market-driven and programme enforced quality management. Although, eventually, the market will drive towards products with the highest user-satisfaction, actors operating in a *marginal market* may not have (the luxury of) a long-term perspective, may lack the drive of competition or may face market domination by large singe-actors; all factors hampering the sector to mature. On the other



hand, (too) strong programme enforced quality management may undermine the accountability of actors at the supply side towards prospective customers. This will increase the (financial) burden on the programme, slowing down development towards a sustainable sector.

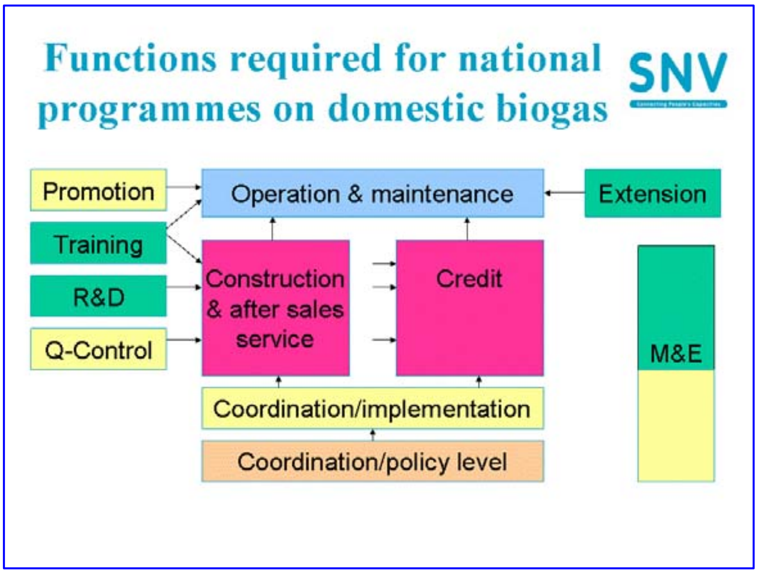
SNV has developed and tested for the Biogas Support Partnership in Nepal several systems on quality management and on quality enforcement from the perspective of the customers and for the protection of the investment made by the customers. For example, standards for the construction of biogas plants are put on paper, agreed with the companies and controlled on the basis of samples. Well performing companies are awarded and provided with a high quality grade that they can use for the marketing of their product, while non-performing companies are penalised and, when persisting, expelled from the programme. SNV is transferring its vast knowledge on quality management to new biogas programmes in other countries.

> *Example 4:*
> Before the initiation of BSP, the Gobar Gas Company (GGC) in Nepal was the sole organisation for the construction & after sales service of biogas plants. On paper, GGC had developed an outstanding policy on after sales service including guarantee. In practice, however, this policy was not implemented and there was no other party enforcing the GGC to implement. In addition, the GoN was frequently changing promotional subsidies on investment or interest. The broken promises seriously undermined the credibility of the technology, resulting in a stagnant or even declining market.

4.5 Multiple functions, multiple actors

("Let the cobbler stick to his last")

National biogas programmes require a wide range of functions to be executed in a comprehensive and coordinated manner. Examples of such functions are promotion and marketing, financing, construction & after sales, operation & maintenance, quality control, training & extension, research & development, monitoring & evaluation, and programme management.

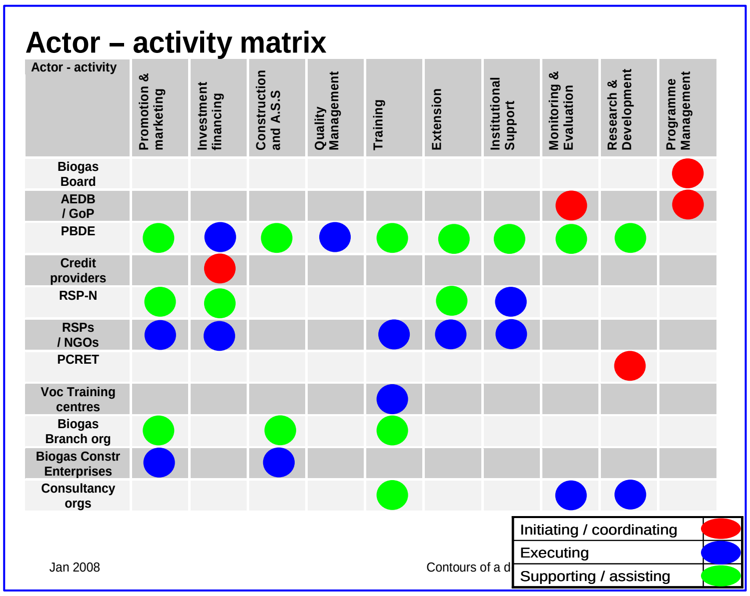


Whereas the function of operation & maintenance can only be executed by the customers, other functions should as much as possible be undertaken by multiple rather than single stakeholders to avoid monopolies, dependencies and conflicts of interest. This allows competition at the supply side from which ultimately the users will benefit.

Another consideration directing towards this multi-actor approach is that successful programmes would quickly grow too large and complex to be run efficiently by a single actor.

National and local governments, the private sector and NGOs can only fruitfully work together in the programme on the basis of proper role divisions, suitable institutional arrangements and good governance. Governments should not engage in construction or credit facilities, but could be involved in facilitation, promotion, regulation, financing and lobby for donor funding. Similarly, credit providers should not involve in construction (but can play an important role in promotion).

Proper institutional arrangements are required; multiple stakeholders, like construction companies and banks/MFIs, can only compete at a level playing field. Such arrangements should first of all be in place between user and supplier in the form of sales contract, guarantee card, credit agreement, etc, but also between the implementing agency and the primary suppliers (companies and banks/MFIs). Parallel programmes with different implementation modalities need to be avoided as these will distort the market. Good governance (transparency, accountability), by all actors, is paramount for all transactions to be concluded in the programme.



The *challenge* of this feature is that stakeholders often do not want to limit their activities to one or a few functions only. They rather like to operate on the basis of a "single actor project approach", as such approach will provide them with the maximum amount of resources and freedom to manoeuvre, and the minimum discipline by the market.

SNV promotes involving a maximum of existing organisational and institutional capacities already and to strengthen these capacities through local capacity building organisations rather than to establish new organisations or institutes. As an outsider and backed-up by its recognised capability in the field of domestic biogas, SNV often plays an effective role in bringing stakeholders together and in reaching consensus between these stakeholders on the way forward. Capacity development is the core business of SNV and directly relates to the development of a sustainable sector.

Example 5:
The biogas programme in Vietnam aims to construct of 140,000 biogas plants between 2006 and 2011. The resulting training requirement for provincial administrators and technicians, as well as biogas constructors, is substantial.

Vocational schools throughout the country have been capacitated by the programme to provide these trainings. The shift clearly reduces the workload of the project but, more importantly, introduces biogas technology as a part of the regular curriculum in schools. In this way, biogas training courses can be offered on commercial bases to masons and local programme staff, securing a sound basis of biogas knowledge that lasts beyond the project.

4.6 Concluding observations

Building viable domestic biogas programmes evolves around three important aspects; programmatic, technical and financial sustainability.

Aiming for *programmatic sustainability*, SNV follows an integrated approach to optimise institutional arrangements and to strengthen the capacities of all actors in the sector. Focal in this approach is the role of the private sector in the primary process of the programme.

As said, SNV aims to involve a maximum of organisational and institutional capacities already available in the country and to strengthen these capacities through local capacity building organisations *("What you don't phase in, you don't have to phase out").*

Hence, SNV does not implement activities directly and limits its permanent deployment of manpower to maximum two biogas advisors per programme.

Technical sustainability is pursued and by introducing rigorous a quality management components to the programme while ensuring supply-side actors remain fully accountable to their customers.

Quality management should not limit itself to direct "technical" aspects only, but include the promotional message, user satisfaction and after sales service. Linking investment rebate with quality provides programmes with the necessary leverage on service quality.

The *financial sustainability* of national biogas programmes is more complex to achieve, requiring first of all national governments to contribute to the costs. Carbon benefits need to become a sustainable source of income for biogas sectors[2]. It is envisioned that both institutional and financial sustainability for the biogas sectors in Nepal and Vietnam is achieved by 2012, while the other countries in Asia (Cambodia, Bangladesh and Lao PDR) may need an additional period of five years (by 2017).

The "human factor".

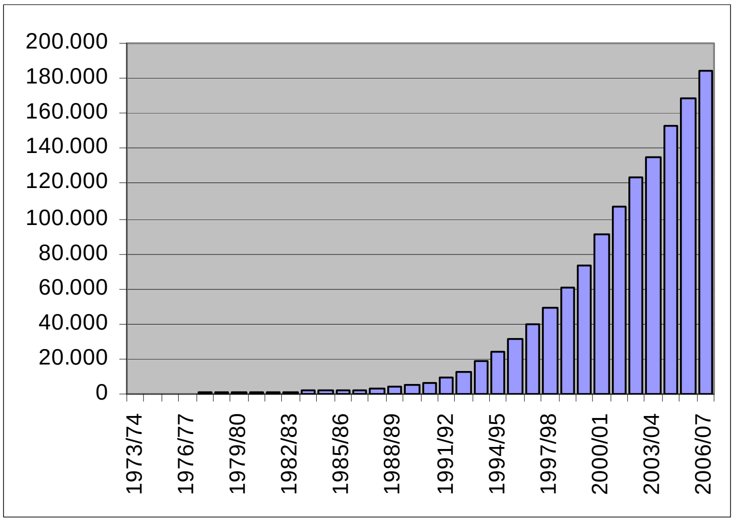
Regarding manpower, there just might be another hidden aspect in SNV's approach. Within SNV's Biogas Practice Team, many advisors have been with the organisation for rather long time. As a result, the team managed to build up institutional memory across countries and regions about what works and doesn't work in specific contexts, and in this way developed a product over time. As team members typically are involved in specific programmes over a longer period they are able to develop a relation with key external stakeholders (donor agencies, knowledge centres, government) based on trust. Equally important, the team managed to keep the (biogas) product high on the internal SNV agenda throughout all the strategy changes from the nineties onwards. The importance of a core team of well led and coordinated, dedicated, knowledgeable, professional staff can hardly be overestimated.

A related *challenge* is to combine a steady course of action based on lessons learned with "out of the box" thinking, using new opportunities, learning from successes elsewhere.

[2] As a carbon component to biogas programmes would typically require performance verification, carbon components could improve the programmatic and technical sustainability of biogas programmes as well.

The Biogas Support Programme in Nepal

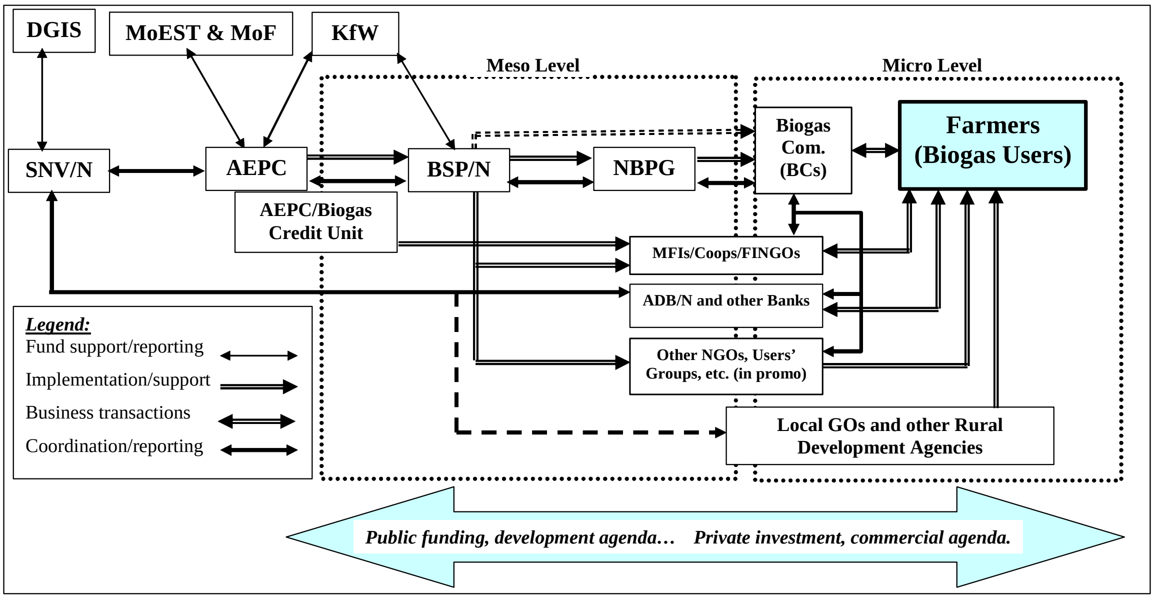
With financial support from the Netherlands Directorate-General for International Cooperation (DGIS), the Biogas Support Programme (BSP) in Nepal was started in 1992. At the time of its initiation, there was basically only one, state-owned, company, the Gobar Gas Company (GGC), producing and servicing biogas plants and only one state-owned bank, the Agricultural Development Bank (ADBL), providing loans to biogas farmers. Due to various constraints, the production of biogas plants never exceeded 1,500 units per year, despite a tremendous technical potential of 1.5 million units throughout the country.



Much has been changed since then, as by the end of 2007, over 180,000 units have been installed throughout the country (see graph: cumulative number of biogas plants installed in Nepal over the period 1973/74 up to 2006/07).

Also the biogas sector has made significant developments, as:

- More than 60 qualified private companies by the end of 2007 install biogas plants throughout the country;
- Appliances are manufactured by some 15 qualified local workshops;
- In 1994, the biogas companies established a branch organisation called the Nepal Biogas Promotion Association (NBPA) to promote the interest of these companies which forms a rather sustainable backbone of the sector;
- In addition to the ADB/N, more than 120 MFIs deliver loans to biogas farmers;
- About 30 local and international NGOs promote biogas in their working areas;
- In 1996, the GoN established an apex body under the Ministry of Science & Technology, the Alternative Energy Promotion Centre (AEPC), to support biogas and other alternative energy applications in Nepal at policy level. A Biogas Coordination Committee under the AEPC representing all major stakeholders plays a coordinating role;
- At the start of phase IV of BSP in 2003, the SNV programme office was transformed to an autonomous, indigenous institute called Biogas Sector Partnership-Nepal (BSP-N). This institute was established to further take over responsibilities for the implementation of the programme, with SNV limiting itself to the provision of advisory services to the major players in the sector. The figure below provides an overview of the institutional set-up of the programme.



5. Biodigester Programme Set-up

5.1 Programme objectives

The Netherlands Development Organisation (SNV) is assisting at the moment 5 Asian countries and 2 African countries in the set-up and running of national biogas programmes.

The main objective of all programmes is quite similar:
The mass dissemination of domestic biodigesters as an indigenous, sustainable energy source through the development of a commercial, market oriented biodigester sector.

Also the specific objectives are, depending on the stage of development of the programme, similar:

- To increase the number of family sized, quality biodigesters with x number over the programme period.
- To ensure the continued operation of all plants constructed under the programme.
- To maximise the benefits of the operated biodigesters, in particular the optimum use of biodigester slurry.
- Institutional strengthening and capacity development of organisations working within the sector.

5.2 Feasibility studies

After first contacts have been made between a national organisation (ministry or national NGO) interested in biogas and the SNV biogas unit, a pre-feasibility (desk study) will be carried out. If the outcome of this study is positive a feasibility study will be conducted in the concerned country by a study team comprised of local consultants and a SNV biogas unit team member.

The following conditions are considered essential for the launch of a large scale dissemination programme and therefore examined during the study:

Technical Conditions:

- Daily ambient temperature above 20^{o} C throughout the year. The biological process in a domestic biogas digester is temperature dependent. The optimum digester temperature is 35^{o}C, below 15^{o}C the process comes practically to a stand-still.
- Availability of at least 20kg cattle and/or pig dung per day at a large number of farms. Cattle should be at least kept in a stable during the night. 10kg of dung yields enough gas to operate a normal sized kitchen stove for 1 hour, to make an investment remunerative a minimum of 2 stove hours per day are required.
- Availability of water. If cattle dung is fed into a plant, it needs to be mixed with water on a 1:1 ratio

Economic Conditions:

- Use of organic fertiliser is traditionally practised and integrated farming systems are common. Often it is not the saved firewood but increased crop production from the use of bio-slurry that generates additional income.
- Traditional cooking fuels like firewood and charcoal are difficult (time consuming) to gather or expensive. If firewood is cheap and easy to come by, it will be difficult to motivate farmers to make the necessary investment.
- Farmers should have access to (micro) credit on reasonable terms, and have the possibility to invest, e.g. by having the title deeds of their farms as collateral. Even with the use of subsidies, farmers still have to make a considerable investment.

Social Conditions:

- Role of women in domestic decision making. Women are the main direct beneficiaries of the biogas plant, they spend less time on fuel collection, cooking and cleaning of cooking utensils when biodigesters are installed. Furthermore, as there is far less indoor air pollution, they will suffer less from eye and respiratory ailments. Therefore women should be accessible for extension services and have a say in the decision making process at household level.
- Role of women in livestock keeping and dung handling. As women will be the users of the gas, they will be most motivated to keep the plant in good operational order. There should be no cultural barriers for them neither to operate the plant nor to participate in local training programmes.

Institutional Conditions:

- Political will from the Government to support a national biogas programme. Preferably a Governmental institution should act as a national coordinating body for the programme and governmental extension services should be involved in promotion and on farm training. An important document here can be the National Poverty Reduction Strategy paper.
- The existence of farmer unions, like dairy cooperations, is not essential but will be very helpful.
- If a programme has gained sufficient volume, financing through the Clean Development Mechanism (CDM) becomes an option.

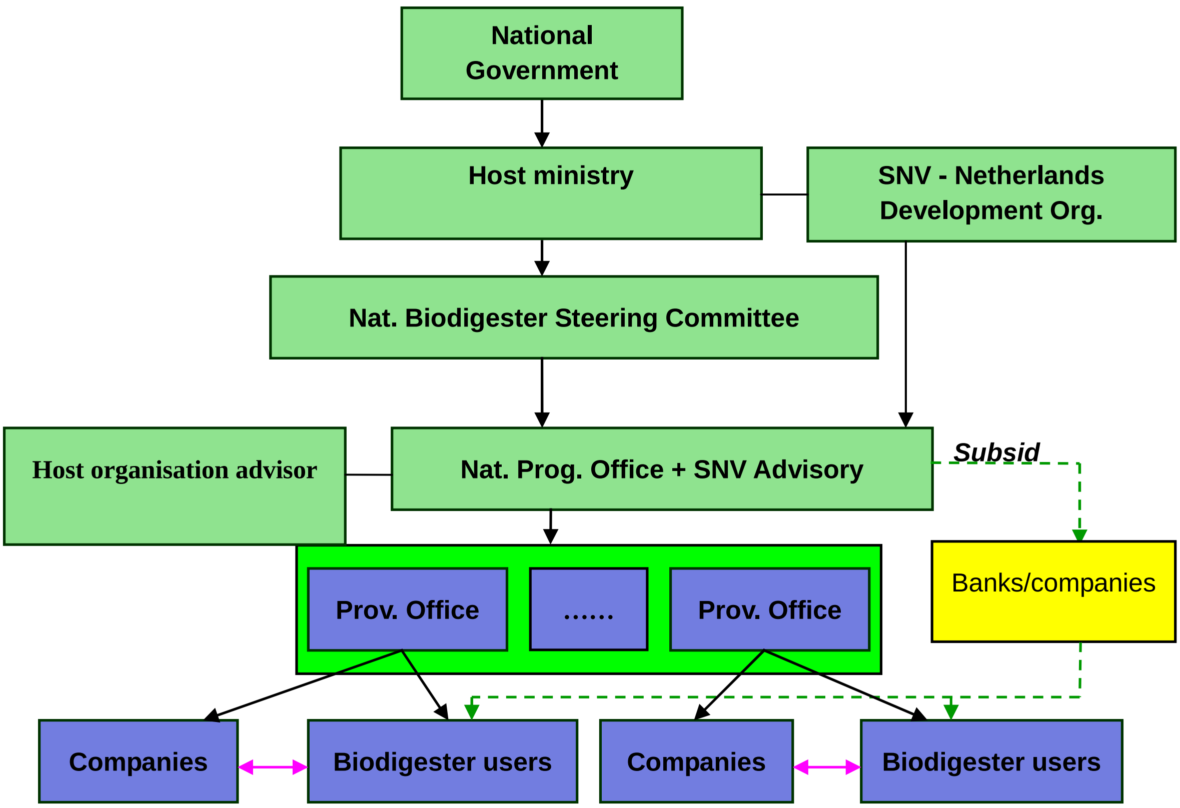
Furthermore the study team will conduct a consultation process to come to recommendations on the most effective programme structure.

5.3 Programme structure

During the feasibility study a national partner organisation will be identified as host organisation. This must be an organisation with a well established rural infrastructure and a direct link to the potential biodigester farmers. In most cases these are ministries of agriculture, rural development and infrastructure.

A semi-autonomous operating national programme office plans, coordinates, monitors on a national level and disburses subsidies. On a provincial level the programmes are often executed by the provincial offices of the host organisation. They cover the promotional, training and technical monitoring work. The actual construction is done by individual masons in young programmes and by established biogas companies in more mature programmes.

The overall programme will be guided and monitored by a national programme steering committee. The chart below shows a typical set-up.



Programme activities

5.4.1 Promotion

An essential part of any marketing strategy for biodigesters is and will remain the quality of the product and the services. As the investment for a biodigester is high, low quality plants with a short lifespan cannot be accepted. Furthermore a well functioning plant is the best possible promotion and the satisfied user the best possible promoter for biodigester technology. Therefore, control of quality regarding plant sizing, construction, user training on operation and maintenance and after-sales services will be of utmost importance, especially during the pilot phase of the programme.

The working model followed for biodigester promotion and marketing consist of 6 phase, briefly described here below.

Phase 1: Promotion
Target group: all potential users
Aim: to create awareness on the advantages of biodigester technology and to raise interest in biodigester technology
Means: mass communication, after-sales service, and subsidy

Phase 2:Information/education
Target group: potential users with differentiation in economical class and sex
Aim: to raise active interest of potential users in a way that they can evaluate the advantages and disadvantages for the possible adoption of biodigesters for their particular situation
Means: group approach communication with use of extension workers, company-to-farmer communication

Phase 3: Personal persuasion
Target group: potential users who have shown active interest in biodigesters
Aim: to give the final 'push' for adoption
Means: personal communication from extension worker to potential user and farmer-to-farmer, company-to-farmer communication

Phase 4: Decision/adoption
The period between awareness and adoption is influenced by economical and social/cultural factors and by the individual characteristics of the adopter.

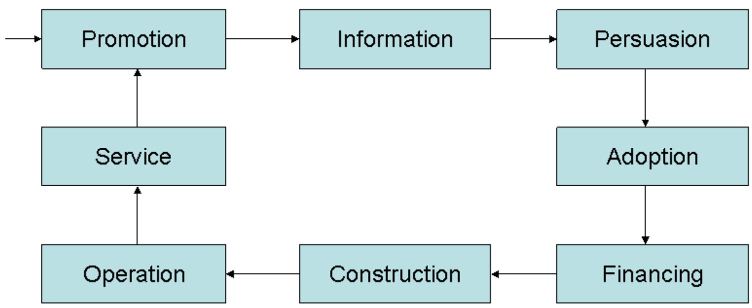
Phase 5: Training
Target group: users (men and women)
Aim: to provide the necessary knowledge and skills for the proper O&M to use the plant efficiently and effectively
Means: training on the spot or elsewhere

Phase 6: After-sales service
Target group: users (men and women)
Aim: to have good functioning plants in operation with satisfied and positive users, leading to farmer-to-farmer motivation

Means: fast and reliable service after user complaint and regular (at least yearly) visits with emphasis on O&M

In the above model promotion (Phase 1) raises general to awareness; information and education (Phase 2) to evaluation; personal persuasion (Phase 3) to decision; adoption (Phase 4) to use; training (Phase 5) to effective use; and after-sales service (Phase 6) will keep the plants in good function which is a precondition for the promotion of biodigesters (Phase 1).

A chart showing the complete cycle, including the financing and construction, is give here below.



Promotion of biogas towards potential users leads to awareness; reliable information to evaluation; and (personal) persuasion to adoption. After adoption, financing is required before construction can take place. Proper operation and after sale service are critical to keep the biogas plants well functioning which is a pre-condition for credible promotion towards other potential users

5.4.2 Extension

Where promotion relates to activities to be undertaken before the construction of a biodigester, extension is focussed on activities - apart from after sales service - needed after installation. Proper training of especially female users on operation and maintenance does not only benefit the users but also the biodigester masons in reducing their workload in after sales.

Use of biodigester effluent has to be an integral part of the plant's overall use. The programme must conduct research on how the effluent use can optimise the benefits of the digester. Extension materials have to be developed and distributed while agricultural extension staff needs to be trained on the most beneficial effluent use.

Connection of a toilet to the biodigester is most advisable to improve the hygienic conditions of the households. In case the farmer would reject the connection of a toilet presently for cultural reasons, the possibility for connection can be left open by providing a second inlet pipe during the construction.

5.4.3 Training

The following training courses and targets are most common:

Masons:
Training of masons must have a high priority because the masons will be the back-bone of the programme. Besides the technical part of the training (construction, maintenance and repair) the masons must also be trained on promotion (how to attract new clients), plant sizing, user extension (how to explain to the user operation and maintenance tasks, including trouble shooting and small repairs) and feed-back from users. The training is usually divided in 2 parts, a 10 day training at a centrally located Biodigester Technical Training Centre and 40 days (the time required to complete at least 2 plants) at field level.

Mason refresher training:
Trained masons who are active in the biodigester construction will receive refresher training. Preferably every mason should get such training after one year of the completion of his mason training. If the quality of a mason's work is not good enough, additional training can be made compulsory.

Supervisors training:
The biodigester companies have the final responsibility of the construction of the biodigester plants while provincial programme staff will perform quality control work on sample basis on behalf of the programme. Therefore both organisations will have supervisors who can inspect the plants on quality and, if necessary, instruct the masons on improvements to be made. The supervisors will be trained at a Biodigester Technical Training Centre on inspection and quality control.

Supervisor refresher training:
Like with the mason refresher training, supervisors will also be invited to attend a refresher course 1 year after completion of their supervisor training. During this training the participants will acquire a more in-depth understanding of biodigester technology while also attention will be focussed on the programmatic aspects.

Staff of provincial programme offices:
The provincial programme staff will be responsible for the planning, implementation and reporting of the programme on provincial level. For the staff of the offices, appointed by the host organisation, workshop/training will be organised to introduce them to the programme and to train them in the proceedings and regulations.

Managers training:
Provincial staff and company managers will be trained in marketing, promotion and quality management.

Study tours:
Study tours in the region should be organised to for people working in the sector to learn from experiences elsewhere.

MFIs, Bank, (I)NGOs and Line agencies extension and promotion training:

Extension staff of financial institutions, (I)NGOs, as well as extension staff of line agencies (agriculture, forestry, health, women affairs, …) are expected to play a very important role in the promotion and use of biodigesters. Staff of these organisations should be trained on the basics of biodigesters, the roles of the different actors, quality standards and how to promote and extend biodigesters to potential users.

Pre-construction user training:
During this training potential users will be explained what the advantages and disadvantages of biodigesters are. A strong focus should be on the input requirement for feeding and the financial consequences. Also it will be explained what the procedures are if people want to acquire a plant under the programme.

Post-construction user training:
The functioning of a biodigester and its overall efficiency is for a large part determined by the user's operation and maintenance of the plant. Apart from the instructions from masons and supervisors, groups of (mainly) female users will be trained on how the plant works, what output can be expected, how to use the effluent and what maintenance activities are required.

Training of trainers:
The trainers of the user trainings will be trained on how to extend the users on the operation and maintenance of the plants and on cooking practices and conditions for maximum effectiveness.

Training activities will be, when ever opportune, contracted to appropriate institutes like polytechnics, NGOs and consulting firms.

5.4.4 Quality control and enforcement

Companies and mason teams who wish to corporate with a national programme and benefit from the subsidy scheme, will be required to seek recognition from the national programme office. Such recognition should be subject to a series of strict conditions such as:

- approval of standard design and sizes of biodigesters;
- trained, certified and registered masons for the construction of biodigesters;
- construction of biodigesters on the basis of detailed quality standards;
- provision of national programme approved quality biodigester appliances (pipes, valve, stove, water trap, lamp);
- provision of proper user training and provision of a user instruction manual;
- provision of one year guarantee on appliances and two years guarantee on the civil structure of the biodigester, including an annual maintenance visit during the guarantee period;
- timely visit of a technician to the biodigester in case of a complaint from the user;
- proper administration.

These conditions must be put down in an agreement between the national programme and the biodigester companies and mason teams.

Quality control on plants in operation and under construction is a key aspect of quality enforcement and the long-term success of the programme. The controls will be conducted by supervisors of the provincial programme supervisors and company supervisors with regular assistance from the national programme office engineers.

Of the inspected plants an inspection form must be filled out and the resulted date must be entered in a data base to monitor the results over time. Masons and/or companies with less than satisfactory performance will be facilitated in upgrading their skills. If the poor performance is persisting they will be eliminated from the programme.

5.4.5 R&D and standardisation

Applied technical research into areas as product innovation, standardisation, testing of new design and developments, monitoring and measuring plant performance determinants of demand for biodigesters, etc. will be necessary for a programme to improve, update and adapt to changing circumstances. Examples of more specific applied research activities to be carried out are the following:

- Effluent R&D will consist of exchange with and study visits to other biodigester programmes in Asia as well as applied research within the country itself on the optimal use of effluent as fertiliser. Also research will be done on the best possible way to conduct effluent extension work and on the development of extension material;
- development and testing of alterations on the biodigester plant design, in order to make them more efficient, better adapted to the local farmer and/or lower in cost;
- development and testing of appliances that can be manufactured locally, this includes gas tap, stove, lamp and water trap;
- solving technical problems related to the construction, operation, maintenance of biodigester plants and appliances;
- standardisation of biodigester plant and appliances designs as well as construction and manufacturing methods;
- studies to assess the impact of biodigester use on households; determining savings on traditional fuels like wood and kerosene, on chemical fertiliser and the impact on crop production.

In principle research and development activities will be contracted to research institutes and consulting firms on the basis on ToRs elaborated by the national programme office and programme proposals by the above mentioned parties.

5.4.6 Monitoring and evaluation

In addition to technical R&D, monitoring of the programme activities and evaluation will be conducted. Some of the activities are:

- CDM baseline study to determine the effect of the programme on CO_2 equivalent emissions by improved manure management and replacement of fuelwood;
- user surveys to study field experiences especially in relation to the impact on women;
- surveys on the experiences with effluent use;
- surveys to analyse the willingness and ability to pay to determine the effective demand;
- surveys why farmers do not install a biodigester;
- evaluation of the performance of financial institutes in the credit provision for biodigesters;
- evaluation of the quality of the after sales service;
- evaluation of trainings like user's pre and post-construction training and extension activities.

Monitoring and evaluation activities will be contracted to research institutes and consulting firms on basis of ToRs elaborated by the national programme office.

5.4.7 Institutional support

A programme should seek the involvement of existing Government offices, (I)NGO's, financial institutions and private enterprises. If there will be a structural and long-term involvement of these parties support, both financial support as well as advice can be provided by the programme to enhance the capacity of the involved parties. This support will be based on proposals with clear objectives submitted by the concerned party.

5.4.8 Management and technical assistance

On a national level the management, coordination, reporting and financial administration is the task of a National Biodigester Programme Office. This office should remain as small as possible with all implementing activities contracted out. The supervision is usually done by a National Steering Committee, chaired by an appointee of the host organisation.

SNV-Cambodia provides technical assistance to the programme in the form of one or more Biodigester Advisor(s). Other advisors (CDM, business development, financial affairs, …) will be deployed on a temporary basis if the need arises.

6.0 Financial and Economical analysis of a typical biogas plant

6.1 Financial analysis

Financial Internal Rate of Return (FIRR) analysis is the most commonly used tool that helps to decide whether a user benefits from installation of a biogas plant and, if so, by how much. The basic underlying assumption of FIRR analysis is that people will adopt a new technology only if they expect to have a positive impact in their financial situation. In a FIRR analysis for domestic biogas plants, all costs and benefits are to be viewed from the point of view of the users.

Benefits and costs of biogas plant will vary depending upon the use of inputs and outputs by the particular user. The financial analysis of different sized fixed dome biogas could be done with the following major assumptions:

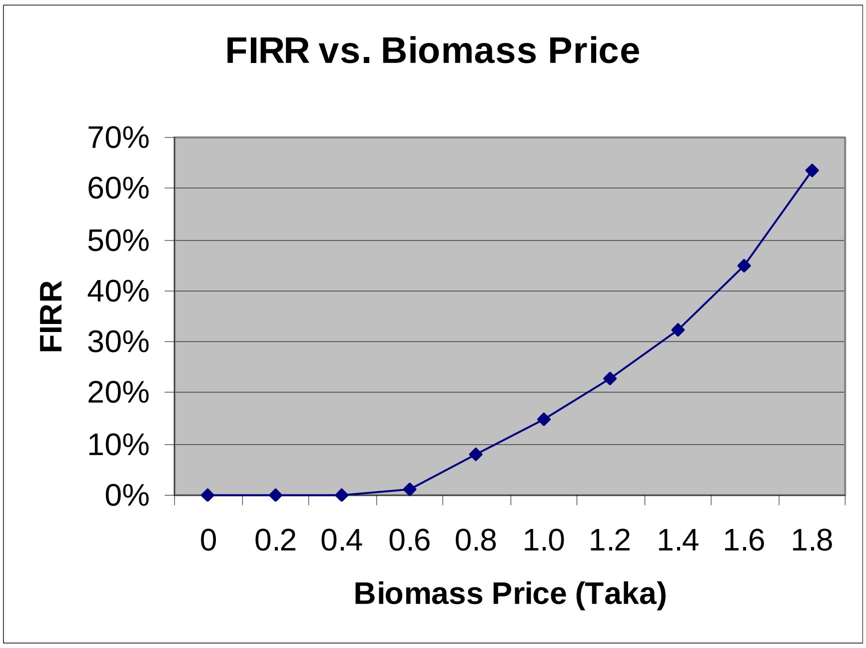
- Though a fixed dome type of biogas plant lasts for more than 20 years depending on the quality of construction materials and workmanship, the economic life span period of biogas plant is taken as 10 years mainly because any cost and benefit accrued after 10 years will have insignificant value when discounted to the present worth.
- Cost of construction of different sizes of biogas plant should be based upon the responses from the users and different costs for the same sizes should be summed up to calculate the average cost per plant
- Operation and maintenance cost is taken as per the actual amount spent by the users.

Annual income from plant is mainly based on saving on conventional fuel sources. Saving on chemical fertilizer because of the use of bio-slurry is more difficult to quantify especially when the programme is still in an early stage. The saving of time because of the installation of biogas plant is also difficult to be considered as it is hard to find evidence to justify that the time is used in other income generating activities.

Below an example of a FIRR calculation for a plant in Bangladesh with a daily gas production of 2.8m3is give, 1Euro = 95 Taka:

Costs	Taka				
Investment Costs	25000				
Ann Maint. Costs	500	2%	of investment costs		
Subsidy	7000				
Net Cost	18000				
Down Payment	2500	10%	of investment costs		
Loan Amount	15500	17%	Ann. Int.	4	yrs term
Ann Loan Payment	-5650.2633				
Ann.Savings	Unit	Taka/unit	Total Taka		
Biomass (kg)	3500	1.00	3500		
Kerosene (lt)	0	25.0	0		
Nutrients	Not firm				
Labour Time					

Year	1	2	3	4	5	6	7	8	9	10
Expenditures	8650	6150	6150	6150	250	250	250	250	250	250
Savings	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500
Net Savings	-5150	-2650	-2650	-2650	3250	3250	3250	3250	3250	3250
FIRR	15%									



The salvage value of a biodigester is not included in the benefit stream of financial analysis because after 10 years of operation, the plant or its parts will not be re-saleable.
In such calculation, quantity of conventional fuels saved is taken into consideration not the value of total gas produced as equivalent to the cost of fuels.
A subsidy is part of most biodigester programmes. A subsidy is justifiable when the society as a whole benefits from the investment of an individual. The function of the subsidy is:

- To lower the financial threshold, especially for poorer farmers;
- To enforce strict quality standards for digesters build under the programme;
- To make plant installation more appealing for the farmer (promotion).

Usually subsidies are on a flat rate basis, one amount regardless of the plant volume. This simplifies the financial administration, reduces the risk of subsidy fraud and relatively favours the smaller plants and therewith the poorer farmers.

6.2 Economical analysis

In the analysis Economical Internal Rate of Return (EIRR) of a biodigester, intangible benefits like environmental impacts (protection of forest, land-productivity improvement, reduction in carbon emissions etc); reduction in smoke-borne diseases and improvement in general health;

improvement in economic condition due to employment opportunities and proper use of saved time; increased yield of crop with the use of nutrient-rich bio-slurry are valued.
The monitary quantifying all benefits and adjusting their market prices to reflect social preferences are a major limitation of the economic analysis. The situation requires some level of generalization, simplifications, and even some restrictive assumption.

The example of an EIRR calculation here below is of the same plant used for the FIRR calculation:

Cost/Benefit Breakdown	Financial	EF*	Economic			
Costs	(Taka)	(%)	(Taka)			
cement	4200	0.6	2520			
materials	8445	0.75	6333.8			
labour	5550	0.75	4162.5			
appliances	2595	0.9	2335.5			
fees & charges	4210	1	4210			
Total Capital Costs	25000		19561.8			
Ann. Maintenance Costs	500		391.2			
Benefits				unit/yr	unit	Taka/unit
biomass savings	3500	1	3500	3500	kg	1
kerosene savings	0	1.1	0	0	liters	25
nutrients		1	1971			
labour time	547.5	0.75	410.625	365	hours	1.5
tons CO2-eq reduced		1	1600	5	tons	320
toilet attachments		0	0			
smoke reduction		1	400			
employment		0	0			
Total Annual Benefits	4047.5		7881.625			

EF= Economic Factor or Shadow Value

Exchange Rate	Euro 1 = 95 Taka
Notes:	EIRR for benefits from just biomass savings = 18%
set labor EF=0.75	EIRR with the value of saved domestic labour added = 22%
set nutrients EF=1	EIRR with the value of nutrients saved added to all of the above = 41%
set smoke EF=1	EIRR with the value of smoke reduction added to all of the above = 45%
set carbon EF=1	EIRR with the value of reduced carbon added to all of the above = 62%

Year	1	2	3	4	5	6	7	8	9	10
Costs	19952.985	391.24	391.24	391.24	391.24	391.24	391.24	391.24	391.24	391.24
Benefits	7881.625	7881.63	7881.63	7881.63	7881.63	7881.63	7881.63	7881.63	7881.63	7881.63
Net Benefits	-12071.36	7490.39	7490.39	7490.39	7490.39	7490.39	7490.39	7490.39	7490.39	7490.39
EIRR	62%									

7. Domestic biogas projects and carbon revenue;

A strategy towards sustainability?

Abstract.

Domestic biogas installations can reduce greenhouse gas (GHG) emissions in three ways: by changing the manure management modality; by substituting fossil fuels and non-renewable biomass for cooking (and to a smaller extent for lighting) with biogas, and; by substituting chemical fertilizer with bio-slurry. The actual reduction of greenhouse gas emissions by domestic biogas installations depends on the local situation, the size of the installation and the way the installation is operated, whereas the “claimable” GHG emission reduction depends on the used methodology.

Emission reduction units, measured in tons CO_2 equivalents, can be traded on the formal CDM market or the voluntary market. For both markets methodologies applicable for domestic biogas are available. Following an approved CDM methodology will likely produce emission reduction units (CERs) that are more attractive to potential buyers as compared with the emission reductions produced under a voluntary scheme (VERs). CDM procedures, however, are significantly more complicated, lengthy and expensive than voluntary schemes. On the other hand, the absorption capacity of voluntary schemes may be limited, introducing a financial risk for larger projects. For both markets the uncertainties beyond the current commitment period hamper a longer-term financial planning that includes carbon revenue. The voluntary Gold Standard biodigester methodology seems –to some extent- an exception as its methodology and monitoring requirements meet –or even exceed- formal standards but allows the project more flexibility in choosing baseline GHG reduction components and project size.

It seems that for smaller domestic biogas projects, or projects that are just starting up, the voluntary market offers interesting propositions. For larger projects, however, the formal market –or possibly the Gold Standard scheme- may provide better sustainability.

To date, there is no example of a domestic biogas project that been run through the entire carbon project cycle; the applicable methodologies all harbour their own uncertainties and formulation, management and monitoring of carbon-included projects require a significant effort.

However, the global market for CERs as well as VERs looks promising and expertise on the combination of domestic biogas and GHG emission reduction is increasing. At the same time, the demand for renewable energy technology, including domestic biogas, is likely to grow. As carbon revenue can improve the financial, technical and programmatic sustainability of large-scale domestic biogas projects, the option deserves serious attention of project developers.

0 Introduction

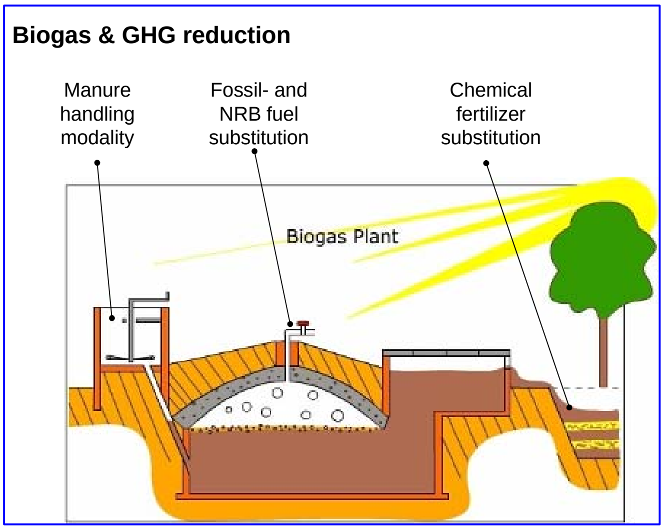
Domestic biogas plants are installations used for fermentation of –mainly- animal manure with the objective to generate biogas and bio-slurry that can be used by individual households for cooking or lighting and agricultural production respectively.

Carbon revenue is the general term for revenue obtained from projects that reduce greenhouse gas emissions as compared to the situation in which the project would not take place. The amount of greenhouse gas reduction that can be claimed, thus, is the difference between the "baseline-situation" and the "project situation". Typically, carbon revenue comes available to the project as an additional revenue stream "up on delivery", i.e. after the real reduction has been independently established.

This paper seeks to explore the opportunities for large-scale domestic biogas projects to improve programmatic, financial and technical sustainability through the inclusion of a greenhouse emission reduction component.

7.1 Greenhouse gas emission reduction by domestic biogas installations.

Domestic biogas installations –potentially- reduce greenhouse gas (GHG) emissions in three ways: by changing the manure management modality; by substituting fossil fuels and non-renewable biomass for cooking (and to a smaller extent for lighting) with biogas, and; by substituting chemical fertilizer with bio-slurry.



7.1.1 Manure management.

The traditional manure management modality may include storage or discharge of animal dung under (semi-)anaerobic conditions, e.g. by deep pit storage or discharge of raw manure in sewage channels or lagoons[3]. The anaerobic condition will cause the manure to (partly) ferment, in which case methane (CH_4), a potent[4] greenhouse gas, is emitted in the environment.

[3] N.B. not all traditional manure management modalities are "anaerobic". For instance animal dung dropped in the fields by free roaming cattle has a very limited GHG emission.

[4] The greenhouse potential of a gas is indicated by its "Global Warming Potential (GWP) relative to carbon-dioxide. The

In a domestic biogas installation, the manure is immediately discharged in the installation. In the plant the fermentation of the manure takes place under controlled conditions, whereby the generated methane gas is captured and used for cooking. Technically, this process is referred to as "methane capture and destruction", whereby the potent CH_4 is converted in carbon-dioxide (CO_2) and water. Although CO_2 and H_2O are greenhouse gasses in their own right[5], they are far less potent than CH_4 and, more importantly, can be considered "renewable" as the CO_2 is absorbed by the very growth of vegetation from which it originates.

7.1.2 Substitution of fossil fuel and non-renewable biomass.

The domestic fuel mix of rural households in developing countries typically includes significant amounts of fossil fuel (kerosene, coal, LPG) and biomass (fuelwood, charcoal, dung cakes). The combustion of these traditional energy sources creates carbon-dioxide (and to a lesser extent Nitrous-oxide[6] (N_2O), another GHG).

Fossil fuels, by definition, are non-renewable sources of energy. Hence, the full amount of GHG emission resulting from combustion of these energy sources results in a net increase of GHG in the atmosphere. For biomass, however, the situation is less straight-forward. When biomass is obtained from renewable sources (agricultural waste, dung-cakes) the produced carbon-dioxide is assumed to be absorbed by the vegetation from which they originate. Therefore, carbon-dioxide emissions from renewable biomass do not contribute to the net GHG concentration in the atmosphere. Biomass obtained from non-renewable sources (referred to as "Non Renewable Biomass, NRB), however, do contribute to global warming. NRB includes e.g. fuelwood and charcoal whose harvest results in a reduction of forested area and therefore in a reduction of the carbon sink function of this area.

To the extent that biogas replaces fossil fuels or non-renewable biomass, this substitution then results in a reduction of greenhouse gas emissions.

7.1.3 Chemical fertilizer substitution.

Many developing countries face a net outflow of soil nutrients[7]. Most farmers apply chemical fertilizer to maintain the fertility of their soil. Although chemical fertilizer use in developing countries often is erratic and scattered, typically many farmers do use fair amounts of chemical fertilizer. Production as well as application of chemical fertilizer has a GHG aspect, mainly as a result of the high energy requirement for chemical fertilizer production and the Nitrous oxide (N_2O) emissions.

The "by-product" of a biogas installation is "bio-slurry". Bio-slurry is the digested dung that is discharged from the installation after the fermentation process. The fermentation process does not reduce the nutrient value (NPK-value) of the feeding material. In fact, when applied correctly, the fertilizing value of bio-slurry even surpasses that of raw manure[8]. Therefore, bio-

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GWP of CH_4 is 21, indicating that the global warming potential of CH_4 is 21 times more than CO_2

[5] Although H_2O has a significant greenhouse warming potential, it is not included in the GHG list of the UNFCCC.

[6] Nitrous-oxide has a GWP of 300.

[7] Soil nutrients are generally referred to as NPK, Nitrogen, Phosphorus and Kalium, the main soil nutrients

[8] In digested manure, a larger share of the organic nitrogen is converted to mineral nitrogen (NH_4); the nutrient will be easier

slurry is a good organic fertilizer that can replace or reduce the application of chemical fertilizer[9].

To the extent to which bio-slurry is actually replacing chemical fertilizer, GHG emissions are reduced. From an accountability point of view, this component of GHG emission reduction by domestic biogas installations may proof very cumbersome to substantiate.

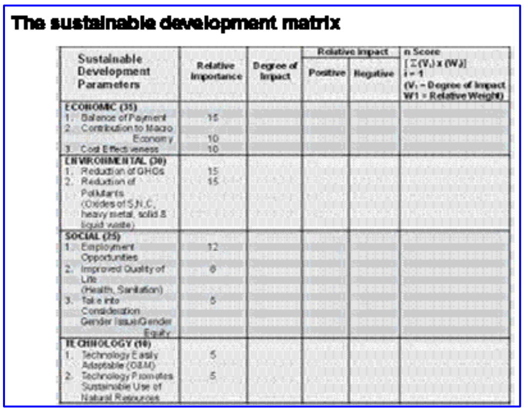
7.1.4 GHG emission reduction potential of domestic biogas installations.

The actual reduction of greenhouse gas emissions by domestic biogas installations depends on the local situation, the size of the installation and the way the installation is operated, whereas the “claimable” GHG emission reduction depends on the used methodology (see 2.1 and 2.2). However, results of our own –tentative- calculations and claimed reductions by other domestic biogas projects would indicate a range of 1.7[10] to 7[11] tons CO2eq per installation per year. It has to be noted that the currently approved CDM – biogas projects are working under methodologies that are since withdrawn.

7.2 Reducing global GHG emissions.

In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted to combat global warming. Subsequently, in 1997, the Kyoto Protocol (KP) was adopted to commit developed countries (annex 1 parties) to reduce their greenhouse gas emissions. This binding Kyoto Protocol eventually came into force in February 2007, following the ratification of Russia. The KP requires annex 1 countries to reduce their GHG emission to ~ 95% of their pre 1990-levels over the period from 2008 to 2012[12]. The required GHG reduction, also know as the assigned amount units (AAUs), is measured in tons of Carbon-dioxide equivalent[13].

As global warming is a world-wide phenomenon, the geographical location of greenhouse gas emission reductions is irrelevant. Hence, the KP defined three “flexibility mechanisms” to achieve its emission targets economically:



The sustainable development matrix

Sustainable Development Parameters	Relative Importance	Degree of Impact	Relative impact: Positive	Relative impact: Negative	n Score [Σ (V$_i$) x (W$_i$)] i = 1 (V$_i$ – Degree of Impact W1 = Relative Weight)
ECONOMIC (35)					
1. Balance of Payment	15				
2. Contribution to Macro Economy	10				
3. Cost Effectiveness	10				
ENVIRONMENTAL (30)					
1. Reduction of GHGs	15				
2. Reduction of Pollutants (Oxides of S,N,C, heavy metal, solid & liquid waste)	15				
SOCIAL (25)					
1. Employment Opportunities	12				
2. Improved Quality of Life (Health, Sanitation)	8				
3. Take into Consideration Gender Issue/Gender Equity	5				
TECHNOLOGY (10)					
1. Technology Easily Adaptable (O&M)	5				
2. Technology Promotes Sustainable Use of Natural Resources	5				

– The Emission Trading (ET) allows for annex 1 parties (industrialized countries) to acquire (buy, trade) emission reduction units from other annex 1 parties.
– Joint Implementation (JI)allows annex 1 parties to implement GHG emission reducing projects in other annex 1 parties and count the resulting emission reduction for meeting their own KP target.
– The Clean Development Mechanism (CDM)

and quicker available for the vegetation.

[9] In addition to the macro-nutrients (NPK), bio-slurry contains micro-nutrients that are lacking in chemical fertilizer.

[10] Tentative calculations for Nepal, based on proposed methodology 1E (Saroj Rai).

[11] Current claim by Cambodia Biogas Programme for HIVOS voluntary market.

[12] The 2008 to 2012 period is normally referred to as the “first commitment period”.

[13] One AAU equals one 1 ton CO_2eq reduction commitment.

allows annex 1 parties to implement GHG emission reducing projects in non-annex 1 parties (developing countries) in return for Certified Emission Reductions (CERs)[14] whereby host parties are assisted in achieving sustainable development (through "technology transfer") and the ultimate goal of the Convention is supported.

By capping global GHG emissions and allowing trade in GHG reduction units, the UNFCCC, with its Kyoto Protocol, introduced a commercial market for greenhouse gas reduction. In the spirit of this commercial market, but also to circumvent the complicated and lengthy formal procedures, non-UNFCCC initiatives were launched as well. These initiatives, like "Trees for Travel", are normally referred to as the "Voluntary Market". Voluntary projects are outside the Kyoto system. Their emission reductions cannot be traded in official emission trading systems. Most offset projects to date are developed in the voluntary market and have not followed a particular standard. Small projects will find the voluntary offset market increasingly attractive because projects are often cheaper to develop and implement than under the CDM. They are attractive to companies who use offset as part of their corporate social responsibility strategy but which up to now are not legally obliged to lower their emissions. To distinguish between UNFCCC and voluntary emission reductions, emission reductions traded at the voluntary market are referred to as Verified Emission Reductions (VERs), similarly equaling one ton of carbon dioxide equivalent.

Carbon trade taking place on a commercial market by definition implies that the value of CERs or VERs depends not only on the real costs of reducing GHG emissions in annex 1 countries, but also on supply and demand of emission reduction units. Currently, depending on the quality of the CERs, values range between € 5 to € 15 per tCO_2eq. Values on the regular market tend to be slightly higher than the value of VERs. Over the past 5 years, CERs and VERs market value has shown a gradual increase.

7.2.1 The Clean Development Mechanism.

Although, as explained above, there are two markets for emission reduction trade, the formal Clean Development Mechanism very much stands model for initiatives on the voluntary market. Therefore, the CDM is here explained in a little more detail.

Emission trading under the CDM

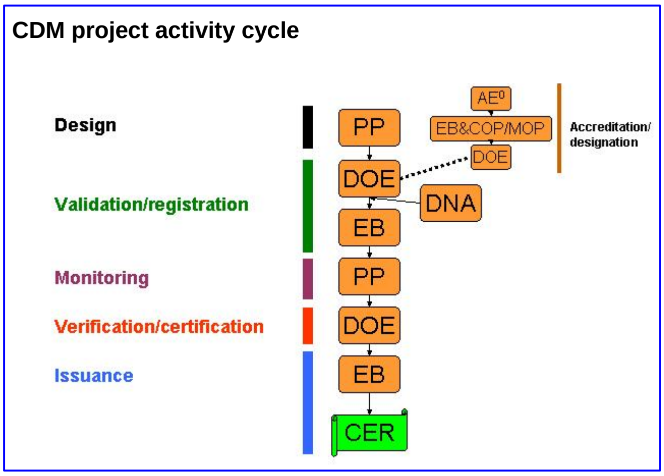
For CDM projects, a first distinction can be made in regular projects, following regular methodologies, and Small Scale CDM (SSC) projects following "simplified methodologies". For domestic biogas so far only SSC methodologies have been developed. An overview of methodologies relevant for domestic biogas is provided in chapter 2.1 and 2.2 hereunder and in the table in annex 1.

[14] One CER equals one 1 ton CO_2eq reduction.

7.2.2. The CDM project cycle.

Without going into too much detail in the CDM project cycle, some "typicalities" are relevant and will feature as well in the voluntary market.

A "project proponent" (PP) designs the project. For the CDM component, standard forms and methodologies are available. Normally, an outline of the project is prepared in the Project Identification Note (PIN) and if the project has merit, a formal Project Design Document (PDD) is formulated. The PIN and the PDD can either be designed by the PP itself, the PP can obtain consultancy services during this process, or can "sub-contract" the entire formulation to a specialized consultant, even on a "no-cure no-pay" basis.



The Designated National Authority, on behalf of the host country, has to issue a "letter of no objection" (LONO). The DNA checks either the PIN or –more often- the PDD mainly on the sustainable development component, but individual countries may screen a PDD in more detail.

With the LONO, the PDD can be submitted for validation. A Designated Operational Entity (DOE) will perform a "technical check" on the document, establishing whether legal and administrative procedures are duly followed, correct methodologies are used and the forecast emission reduction is realistic. As a ball-park figure, costs for validation can be estimated at € 10,000.

Only validated PDDs can be submitted to the Executive Board of the CDM for registration. Depending on the expected annual emission period, a registration fee is due. Projects below 15,000 tCO_2eq per year are fee exempted, US$ 0.10 and US$20 per CER will be due for issued CERs up to 15,000 tCO_2eq and over 15,000 tCO_2eq respectively, with a maximum of US$ 350,000. After registration one has a proper CDM project. And only after registration, a project can trade CERs

In the mean time the project-proper has started off, producing –as a by product- CERs. The PP will be responsible to monitor the project, according to the monitoring plan that is part of the PDD, making sure the forecast CERs are indeed generated.

On set intervals, say annually, a project would like to sell those CERs. For that, the PP will contract a DOE to verify the amount of CERs generated over that period. The DOE will produce a verification report, stating the amount of CERs that can be claimed. Again as a ball-park figure, verification may cost some € 20,000.

The EB, based on the verification report of the DOE, will then issue the CERs to the project. Only now the Project Proponent will be able to sell its CERs. For this, the PP may –possibly in an earlier stage- enter into an Emission Reduction Purchase Agreement (ERPA) with an interested / interesting buyer.

Important features of the procedure include:

- The market value of CERs increases with reducing risks. Hence, CERs have a significantly higher value once a project is officially registered, compared with a project that can only show a PIN or PDD.
- CER payment will only be “up on delivery”, lead time between verification and issuance can easily be 6 months, and running through the first full cycle will take longer[15].
- Accountability is key; validation and verification is done by independent, accredited firms. Contracting these firms is costly.
- Once a project enters into an ERPA, it commits to a performance obligation. Depending on the contract, not being able to deliver may result in the project being fined.

7.2.3 Methodologies.

When is comes to measuring emission reductions, two situations have to be taken into account: emissions without the intervention of the project (baseline) and emission after the intervention (project). The difference –as measured through monitoring- between the two defines the emission reduction that can be claimed by the project. For measuring the baseline and monitoring emissions, different methodologies have been developed.

Under the CDM, only small scale methodologies have so far been developed for domestic biogas. Although these simplified methodologies are advantageous in terms of monitoring requirements, they put a limit to the number of individual biogas installations that can be brought under one project. The following small scale methodologies are currently available (or under consideration):

AMS I.C. Thermal energy for the user with or without electricity.

This category comprises renewable energy technologies that supply individual households or users with thermal energy that displaces fossil fuels. Examples include solar thermal water heaters and dryers, solar cookers, energy derived from renewable biomass for water heating, space heating, or drying, and other technologies that provide thermal energy that displace fossil fuel[16]. Biomass-based co-generating systems that produce heat and electricity are included in this category.

AMS I.C. limits the project size is by the total thermal generation capacity, which shall not exceed 45 MW_{th}. For a typical domestic biogas project[17], this would mean that up to 22,500 installations[18] could be bundled in one small scale project. For domestic biogas, this methodology allows to claim GHG emission reductions resulting from substitution of fossil fuels (see 1.1). AMS I.C does not foresee in the use of non-renewable biomass in the baseline situation

[15] Increasingly, however, buyers are willing to pay “up-front” for future CER or VER delivery.

[16] Note that biogas installations or biogas stoves are not specifically mentioned; they would be “implied” as “other technologies that provide thermal energy that displace fossil fuel”. This implication could also be derived from methodology AMS III.R.

[17] Assuming the thermal performance of a biogas stove is about 2 kW. This is, however, still to be subject to debate.

[18] The Hubei PDD even proposes to include 30,000 installations. The Hubei PDD has not been validated yet.

(AMS) I.E. Switch from non-renewable biomass for thermal applications by the user.
This category comprises small thermal appliances that displace the use of non-renewable biomass by introducing new renewable energy end-user technologies. Examples of these end user technologies include biogas stoves and solar cookers

This category comprises of small appliances involving the switch from non-renewable biomass to renewable sources of energy. These technologies include biogas stoves, use of solar cookers and measures that involve the switch to renewable biomass.

(AMS) I.E. is an “indicative methodology”. Although the methodology was approved by the COP/MOP in Bali, it is still pending approval of the EB (23st of January 2008). Indications are that the EB will still propose significant changes to this methodology. The draft paper does not mention yet the limit of the project size.

For domestic biogas, this methodology allows to claim GHG emission reductions resulting from substitution of non-renewable biomass only (see 1.1). The methodology specifies how the fraction of non-renewable biomass can be established.

AMS III.R Methane recovery in agricultural services at household / small farm level.
This project category comprises recovery and destruction of methane from manure and wastes from agricultural activities that would be decaying anaerobically emitting methane to the atmosphere in the absence of the project activity.

The category is limited to measures at individual households or small farms (e.g. installation of a domestic biogas digester). Methane recovery systems that achieve an annual emission reduction of less than or equal to 5 tons of CO_2eq per system are included in this category. Aggregated annual emission reductions (i.e. including the emission reductions resulting from methodology AMS I.C.) of all systems included shall be less or equal to 60 kt CO_2eq.

This project category is only applicable in combination with methodology AMS I.C. It is not clear whether, in time, this methodology will be allowed to be used in combination with AMS I.E. as well.

For domestic biogas, this methodology allows to claim GHG emission reductions resulting from changing the manure handling modality (see 1.2)

Programme of Activities.
Individual project activities can be brought under a Programme of Activities (PoA). Such PoA then can be registered as a single CDM project activity, provided that approved baseline and monitoring methodologies are used that, inter alia, define the appropriate boundary, avoid double counting and account for leakage, and ensure that the emission reductions are real, measurable and verifiable and additional to any that would occur in the absence of the project activity.

A Programme of Activities has a maximum duration of 23 years.

This procedure allows combining domestic biogas projects, demarcated by time or geographical location (e.g. subsequent projects or projects in different provinces / countries), in one “Programme of Activities” whereby:

- Only a single registration is required;
- Adding new domestic biogas projects under the same programme is simplified, making the individual project size less critical;
- Some of the requirements, like an Environmental Impact Study, can be arranged at programme level. Verification, however, will still take place at project level.

7.3 The voluntary market.

Projects selling emission reductions on the voluntary market are not limited by UNFCC approved methodologies. Many buyers propose their own baseline, project and monitoring methodology. Examples in the domestic biogas sector include the VER-Normaal project in Vietnam and the VER-Hivos project in Cambodia (under preparation). VER-units, hence, are less standardized. Typically, but not necessarily, these voluntary schemes handle only a rather small project size[19].

Buyers on the voluntary market may, however, also look for quality assurance: the Gold Standard (GS) for voluntary offset projects tackles this need and is so far the only independent standard for quality in this market.

7.3.1 GS Programme, baseline and monitoring methodology for small scale biodigester.

This methodology is applicable to programmes of activities involving the implementation of biodigesters in households within the project’s boundaries. The project activity is implemented by a project coordinator who acts as the project participant. The individual households will not act as project participants. The consumption of biogas from the biodigesters replaces the consumption of fossil fuel and/or biomass.
The GS biodigester methodology is not a “small scale” methodology, the number of bundled biogas installations under one project, hence, is not limited.

The GS biodigester methodology includes GHG emission reductions resulting from a change in manure handling management and fossil fuel and NRB substitution (CO_2 and CH_4 only, N_2O is excluded). The methodology specifies how the fraction of non-renewable biomass can be established.

The high standards that the GS prescribes will have ramifications on formulation, monitoring and verification of the project. The flip-side of the extra effort required will be that the VER-value is likely to be higher.

7.3.2 Normaal – Vietnam

The Dutch rural rock band Normaal released a new CD album called “Hier Normaal” for which a number of promotional tours were made. The transport and electricity use during these tours generated 250 ton CO2 eq. Because the music stars are aware of the threats of global warming, they wanted to compensate for the green house gasses emitted during these performances.

[19] Vietnam 25 biogas installations, Cambodia 10,000 biogas installations.

To compensate these emissions, the emission reduction rights of a number biodigesters were purchased in 2007 in Vietnam for a period of 5 years. Conservatively, a biodigester in Vietnam reduces 2 ton CO2 eq per year: 1 ton via fuel substitution and 1 ton for manure management. So in 5 years time, 10 tons are compensated. Therefore a total number of 25 biodigesters are exclusively constructed for Normaal, against a price of 10 Euro per ton CO2 eq. The plants will not be used for any other carbon trade scheme for the coming 5 years.

There was no authority involved to approve this agreement. As means of verification the band receives a photograph of each digester and the GPS coordinates via the programme.

7.3.3 Hivos Climate Fund - Cambodia

In 2006 the National Biodigester Programme of Cambodia (NBP) conducted a CDM baseline study to determine the potential GHG mitigation after the dissemination of biodigesters. The study focussed on GHG emissions from different types of animal waste management systems (dry storage, slurry, and lagoon storage) and on emissions from burning fossil fuel and non-renewable biomass. Ex-ante GHG emission reduction resulted in 4.4 ton of CO_2eq, following the IPCC guidelines, excluding N_2O and a 77% NRB component.

NBP negotiated hereafter with project developers / CER brokers on the start of a CDM project. Because of the high costs involved and uncertainty whether projected results could be reached, it was decided not to pursue CER sales.

The Hivos Climate fund offers a series of projects in developing countries that reduce GHG emissions to those in The Netherlands who want to compensate their emissions. These can be individuals, organisations and companies. NBP and Hivos are in the process to come to an agreement where by Hivos will buy the emission reductions for 10,000 plants over a 5 year period. The advantages for NBP are that little time and funds have to be invested in the preparation work -the CDM baseline study is largely sufficient- while the regular monitoring practices of the programme suffice for the VER monitoring.

Under this agreement N_2O is excluded in the calculation while all biomass is considered non-renewable. This because there is a significant difference between biomass production and consumption in Cambodia and therefore all biomass consumption reduction contributes to narrowing this gap. The price offered by the Hivos Climate Fund is competitive compared to what is commonly paid for CERs.

7.4 Notes to the methodologies.

Methodologies and relevant documentation is written in Carbonese. Carbonese does not necessarily translate easily in English; understanding the full technical, operational, administrative and legal implications of articles may-at times- be beyond the capacity of the interested layman/women. Hereunder some general notes on the methodologies.

7.4.1 Pioneering.

To date, no domestic biogas project has been validated and registered under currently valid CDM methodologies[20]. To the author's knowledge, this is true for the GS-biodigester methodology as well. Although relevant methodologies get clearer and experience in going through the entire registration / verification process is mounting, embarking upon establishing a GHG emission reduction component in domestic biogas project will still require a fair amount of pioneering work, with all related risks.

7.4.2 Inclusion of chemical fertilizer substitution.

As argued earlier, monitoring of the substitution of chemical fertilizer by bio-slurry may proof cumbersome. Anyhow, there is currently no small scale or voluntary methodology available that allows the inclusion of chemical fertilizer.

7.4.3 Inclusion of the manure handling component.

The benefits of including the manure handling component in the carbon reduction methodology may vary significantly from country to country, depending on the type of livestock, the local practice of livestock keeping, manure storage and application. Preliminary calculations indicate that countries with a large share of free roaming cattle (some African countries, Pakistan, Nepal) may have little to gain from this methodology while countries with a large and confined pig population, like Vietnam, China and Cambodia, can benefit a great deal.

7.4.4 Inclusion of non-renewable biomass in the baseline.

Many of (potential) biogas households traditionally use a significant amount of biomass to provide in their cooking energy requirement. The CDM methodology I.C. (apparently) does not allow inclusion of biomass in the baseline at all. With the CDM I.E. and the GS methodology for small scale biodigesters, non-renewable biomass consumption can be brought into account (this still means that dung cakes or agricultural waste are excluded all together).

For fuelwood or charcoal, to be allowed in the baseline, the fraction of non-renewable fuelwood in the total amount of fuelwood has to be established. Both the CDM methodology I.E. (under consideration) and the GS methodology for small scale biodigesters include a methodology to establish this fraction. Please note that the definitions used for non-renewable biomass are strict and the determination of the NRB-fraction may be subject to a lot of discussion[21].

[20] The Nepal biogas programme got registered under a methodology that later was withdrawn

[21] However, the Hivos methodology proposed for the Cambodia biogas project agrees with all fuelwood used for domestic cooking being non-renewable

7.4.5 Suppressed and satisfied demand.

For the domestic fuel consumption, the methodologies AMS I.C.[22] and "GS biodigester" offer the project proponent the option to choose defining the baseline consumption as the "satisfied demand situation". This option assumes that in the actual baseline situation, households do not have access to the required domestic energy against "comparable but better off" households; they suffer "suppressed demand". If one chooses to do so, not only the energy level, but also the technology from the satisfied demand situation can be taken as the baseline. This seems to offer two important advantages:

- A fossil fuel and corresponding technology, e.g. LPG and LPG stoves (Senegal) or coal and coal stoves (Hubei, China), can be taken as the baseline, thus avoiding the (cumbersome) establishment of the NRB-fraction in the baseline biomass consumption.
- Replacing biomass for fossil fuel implicitly enters the full amount of energy consumption back in the baseline; for households with a large share of renewable biomass -like dung cake (Pakistan) or agricultural waste (Ethiopia)- in their baseline, this will significantly increase their potential greenhouse gas reduction.

7.4.6 Safeguarding additonality.

The key notion in GHG emission reduction projects is –basically- that the claimed or forecast reduction would not take place in absence of the project. It is therefore critical that project documents clearly mention that the project anticipates additional carbon-revenue.

7.4.7 Bringing separate projects under one "Programme of Activities".

To my knowledge, there is no registered PoA yet. From the documentation, the administrative requirements for registration of a PoA seem significant but "doable" (in the sense that the requirements seem to be in the same order of magnitude as necessary for registration of a separate project).

Advantages, if any, from registering a PoA, may include:

- After the first registration, the PoA plus one project, adding a new country / project only requires validation; registration follows automatically. As long as projects answer to the PoA's eligibility criteria, they do not necessarily have to follow the exact same methodologies.
- Standardization –to some extent- of CDM administration, monitoring and verification procedures.
- Expanding national biogas projects may add new projects, either time-wise or geographically, under the PoA.
- For smaller countries / projects, the PoA may offer a cost-effective way of obtaining carbon revenue.
- Possibly a centralized approach enables steeper learning curve in building-up expertise in formulation, administration and managing of the domestic biogas / carbon projects?

[22] Application of para 46 of Modalities and Procedures: "the baseline may include a scenario where the future anthropogenic emissions by source are projected to rise above current levels, due to the specific circumstances of the Host Party" (surpassed demand, application might be debatable). Possibly also applicable for (AMS) I.E. (?)

- Possibly a better negotiation position in selling CERs, due to both larger amounts of credits available, higher professionalism / expertise level on the carbon trade and centralization of this project component?
- Possibly economies of scale could work out in other fields as well, like subcontracting (parts of) formulation, validation and verification.

There are risks as well:
- If only one project under the PoA does not play by the rules this could have repercussions for the programme as a whole.
- There may be a political constraint for a PoA with more than one national domestic biogas programmes when respective governments do not like to depend on a regional programme

7.4.8 Voluntary or CDM.

In general:
- In terms of formulation and monitoring requirements, CDM methodologies and the GS-biodigester methodology differ little. The procedure for registration, verification and issuance, however, might be shorter / simpler for the GS-biodigester methodology.
- Following an approved CDM methodology will likely produce CERs that are more attractive to potential buyers as compared with the VERs produced under a voluntary scheme. Hence, CER-values may have a higher and more predictable value than VERs[23].
- Over a longer period, the absorption capacity of voluntary schemes may proof too small, introducing a significant financial risk for larger projects that depend on carbon revenue for their feasibility.
- CDM procedures are significantly more complicated, lengthy and expensive than voluntary schemes.
- The value of the CERs is dependent on the commitment period. For the current commitment period, 2008 – 2012, regulations are set and CER values are –within some margin- established. CER values for the period after 2012 are uncertain; projects will have to take a considerable discount for CERs produced after the current commitment period if an up-front payment is requested. VER values might be less affected by the CDM commitment period.
- The voluntary GS biodigester methodology might be an exception regarding the above mentioned points.

Therefore, it seems that:
- Smaller biogas projects or projects that are just starting-up would be well served with a voluntary carbon revenue scheme.
- Larger projects, particularly if their feasibility depends on a reliable in-stream of carbon revenue, seem better of with a formal carbon revenue scheme (CDM or possibly GS-biodigester).
- For some countries (Vietnam, Pakistan) or programmes (Asian Biogas Programme or the African Biogas Initiative) the “Programme of Activities” option may harbour some advantages. This implies, however, that projects follow formal CDM methodologies.

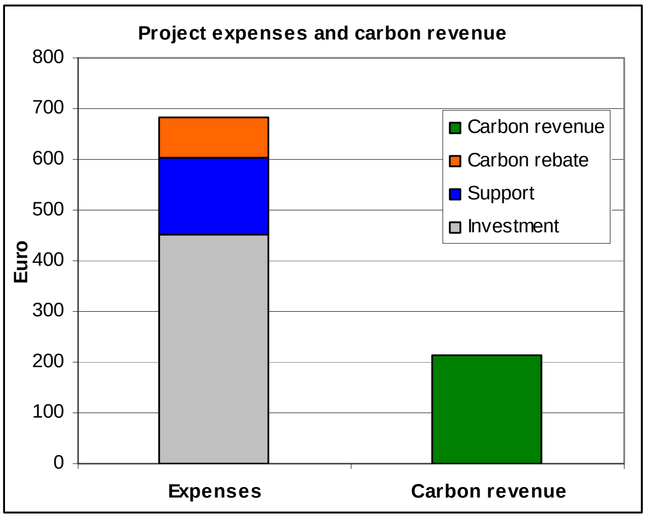
[23] This is, however, not a rule; (rumors on) exceptions have been reported.

7.5 The value of carbon revenue for biogas projects.

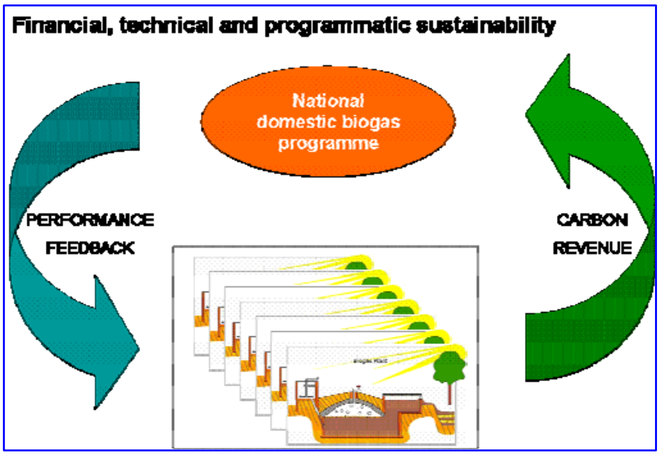
As mentioned in chapter 1.4, domestic biogas plants potentially reduce GHG emissions with 1.7 to 7 tons CO_2eq per plant per year. To assess the value of carbon revenue, an example derived from the PID study for a national biogas programme in Pakistan is presented[24]. This budget is based on a starting national biogas programme, aiming to construct 30,000 installations over a period of 4 years.

For this example, total budgeted installation costs would arrive at € 681[25], broken down as follows:

- Household investment, including financing costs € 453.
- Support costs, including programme activities and carbon revenue related expenses, but excluding costs for international technical assistance: € 151.
- Investment subsidy, or more appropriately for a carbon project, "carbon rebate": € 77.



Preliminary calculations indicate a potential GHG emission reduction of 5.1 tons CO_2eq per plant per year. Taking a CER/VER value of € 7 and further assuming a crediting period of 10 years and a CER/VER annual price increase of 2%, the total discounted (discount rate 10%) value of the carbon revenue would amount to € 213.



As this example shows, carbon revenue, even at discounted rates, on the long run, could provide approximately 30% of the entire programme costs [26], and would (nearly) suffice to cover the support costs, including carbon rebate, of such programme. The conclusion seems justified that –potentially- carbon revenue can play an important role in the financial sustainability of national biogas programmes.

In addition to financial sustainability, carbon revenue can also play an important role in the technical sustainability of large scale domestic biogas programmes. As carbon revenue is

[24] The Pakistan budget breakdown is reasonably representative for a national biogas programme in the Asia Biogas Programme context.

[25] International technical assistance costs are excluded from this example.

[26] As explained earlier, actual inflow of carbon revenue will be delayed by the verification and issuance procedures

performance related, credits will only be made available on actual amounts of GHG emissions reduced, the carbon-component will provide an in-built quality management incentive.

Furthermore, the carbon revenue is seen by Governments and the donor community as an important tool to make biodigester programmes (more) durable. This boosts the commitments of these parties to the programmes.

7.6 Conclusions.

In conclusion:

- There are an increasing number of carbon-reduction methodologies applicable for domestic biogas programmes, both for the formal CDM market and the voluntary market, available;
- Expertise, and to a lesser extent experience, on establishing a carbon component in domestic biogas is steadily mounting;
- There seems to be a good demand for both CERs and VERs and;
- Carbon revenue potentially can improve the financial, technical and programmatic sustainability of large scale biogas programmes.

At the same time:

- The applicable methodologies harbour uncertainties and risks;
- Formulation of carbon projects is complicated;
- Management and monitoring of carbon projects requires a significant, focussed effort, both financially and in terms of expertise;
- There is still no example of a biogas project that has been run through the entire carbon project cycle; in fact, there is no biogas programme registered under currently valid methodologies, and;
- The market for CERs –and to a lesser extent VERs- is only established for the current commitment period, the post-2012 situation is as yet uncertain.

However, as carbon revenue can improve the financial, technical and programmatic sustainability of large-scale domestic biogas projects, the option deserves serious attention of project developers.

Methodology	Manure mgt. modality	Fuel substitution				Monitoring requirement		Project size limitation	Notes
		Fossil fuel	Biomass	NRB-fraction	Satisfied / suppressed demand	Baseline	Project		
AMS I.C. Thermal energy for the user with or without electricity.	Excluded	Included	Excluded	n/a	Application of para 46 (?)	– Baseline fuel use – For "suppressed" demand: fuel use by "comparable but better-off" hh – Ex-post, census or sample	– Recording # of plants annually in operation – Estimating average annual hrs of operation – Project fuel use – Ex-post census or sample	Max energy production 45 MW_{th}, PDDs with up to 30,000 biogas installations proposed	Applicability may be debated
(AMS) I.E. Switch from non-renewable biomass for thermal applications by the user.	Excluded	Excluded	Included	Meth. included	Not clear yet, but with current text unlikely	– Baseline fuel use (ex-post) – Or thermal energy in project activity – Ex-ante? Or ex-post	– Recording # of plants annually in operation – Project fuel use, or energy generation – For NRB: biomass saved by project used outside the project. – "Monitoring should confirm the substitution of NRB of each location" – Ex-post census or sample	Small scale, but project size not yet mentioned	Methodology under consideration
AMS III.R Methane recovery in agricultural services at household / small farm level.	Included, in combination with AMS 1.C. Not (yet) mentioned in AMS I.E.	n/a	n/a	n/a	n/a	– Baseline animal population, waste production, manure handling modality – Ex-post census or sample	– Recording # of plants annually in operation – Estimating average annual hrs of operation – Projects avg animal population, waste production, plant feeding – Proper soil application of bio-slurry – IPCC data available – Ex-post, census or survey	CH_4 recovery up to 5 t CO_2eq per plant per year, Project limited to CH_4 reduction up to 60 kt CO_2eq per year.	
Gold Standard Programme, baseline and monitoring methodology for small scale biodigester.	Included	Included	Included	Meth. included	Included, with ample explanation	– Baseline fuel use – For "satisfied" demand: fuel use by "comparable but better-off" hh (ex -ante?) – Baseline animal population, waste production, manure handling modality – Ex-pos census or sample	– Recording # of plants annually – Project fuel use – Project manure input in installation – Ex-post calculation of statistical correction – Data storage in electronic database – Ex-post census or sample	Digester capacity up to 20 m^3 Not small scale, no limitations.	
Normaal -Vietnam	Included	Included	Included	n/a	Excluded / not mentioned	– Baseline fuel use – Baseline animal population, waste production, manure handling modality – Ex-ante sample	– Photographs of the installations – Annual report on operational status	25 installations	
Hivos CF -Cambodia	?	Included	Included	n/a	Excluded / not mentioned	– Baseline fuel use – Baseline animal population, waste production, manure handling modality – Ex-ante survey	– Recording of # of plants (cont) – Project quality management schedule	10,000 installations	Under preparation

8. Who is out there?

This chapter provides with a selection of some 30 website addresses of various institutes working in the field of domestic biogas and renewable energy in developing countries. This list encompasses mainly global oriented actors that may serve as starting point for a more complete inventory of your specific interest. It should be noted however that webbased information is dominated by public funded programmes and initiatives, whereas in reality a lot of unrecorded activities take place through private construction and (local) enterprises.

On many websites reference is made to the Millennium Development Goals (MDGs), the developing agenda that aims to half global poverty between 2000 and 2015. At the UN World Summit on Sustainable Development held in Johannesburg in 2002, it was concluded that access to reliable and affordable modern energy services is a prerequisite for achieving the MDGs. From an environmental point of view, the growing concern about climate change and how to reduce green house gas emissions stimulated interest in carbon neutral energy solutions. From these points of view renewable energy programmes gain increasing interest, drawing NGOs, micro credit institutes, banks, green investors and players in the carbon market also into the realm of domestic biogas.

In view of the information requirements by the participants of this course, three categories are made:

(K) “knowledge resources”, providing background information for research and writings;
(P) “practitioner networks” relate to biogas/RE programme implementation and activities
(F) “finance opportunities” on financial resources available for biogas and renewable energy projects.

Last update December 2009.

	Name	**Description**	**Website**	**K**	**P**	**F**
	HEDON	Global network household energy	http://www.hedon.info	×	×	
	Practical Action	NGO on household energy	http://practicalaction.org/?id=energy	×	×	
	GNESD	Global network on energy for sustainable development	www.gnesd.org	×	×	
	GTZ HERA	NGO on household energy	http://www.gtz.de/en/themen/umwelt-infrastruktur/energie/×294×.htm	×	×	
	YES	International network of young energy specialists	www.yes-dc.org	×	×	
	ETC energy	NGO in energy programmes	www.etcint.org/energy	×	×	
	BORDA	NGO on water treatment DEWATS	http://www.borda.de	×	×	
	UNDP	UNDP sustainable energy	http://www.undp.org/energy/	×	×	
	UNAPCAEM	UN Asian Pacific centre for agriculture	http://www.unapcaem.org/	×	×	
	FAO	UN Food and agricultural organisation	http://www.fao.org/	×	×	

	SNV	NGO working on biogas, with weblinks to national biogas programmes	http://www.snvworld.org/en/ourwork/Pages/energy.aspx	×	×	
	GATE	Information on domestic biogas	http://www.gate-international.org/energy.htm	×		
	UNFCCC	Framework Convention on Climate Change	http://unfccc.int	×		
	Renewable Energy World	Website and magazine	http://www.renewableenergyworld.com	×		
	LEISA	Network of magazines on sustainable agriculture	www.leisa.info	×		
	BRTC	Biogas Research and Training Center Chengdu (BRTC),	http://www.biogas.gov.cn/Z_Show.asp?ArticleID=629	×		
	Biogas for Better Life	Biogas Africa	http://www.biogasafrica.org		×	×
	IEA	International Energy Agency global statistics	www.iea.org	×		
	WB	World Bank; Asia Sustainable and Alternative Energy Program	www.worldbank.org/astae		×	×
	ADB	Asian Development Bank Energy Programme	http://www.adb.org/Clean-Energy/default.asp		×	×
	E4All	Energy for All Partnership	http://www.energyforall.info		×	×
	EU	European Union	http://ec.europa.eu/energy/index_en.htm			×
	GVEP	Global Village Energy Partnership	www.gvep.org		×	×
	Energia	Energy and gender lobby network	www.energia.org		×	
	WSSD	Base of political commitment to energy services	http://www.johannesburgsummit.org/		×	
	Sparknet	African network on household energy	www.sparknet.info		×	
	AREED	The United Nations Environment Programme's Rural Energy Enterprise Development	www.areed.org		×	
	FMO	Bank for poverty reduction/RE	www.fmo.nl			×
	KfW	Bank for poverty reduction/ biogas	www.kfw.de			×
	PCIA	Partnership for clean indoor air	http://www.pciaonline.org/	×		