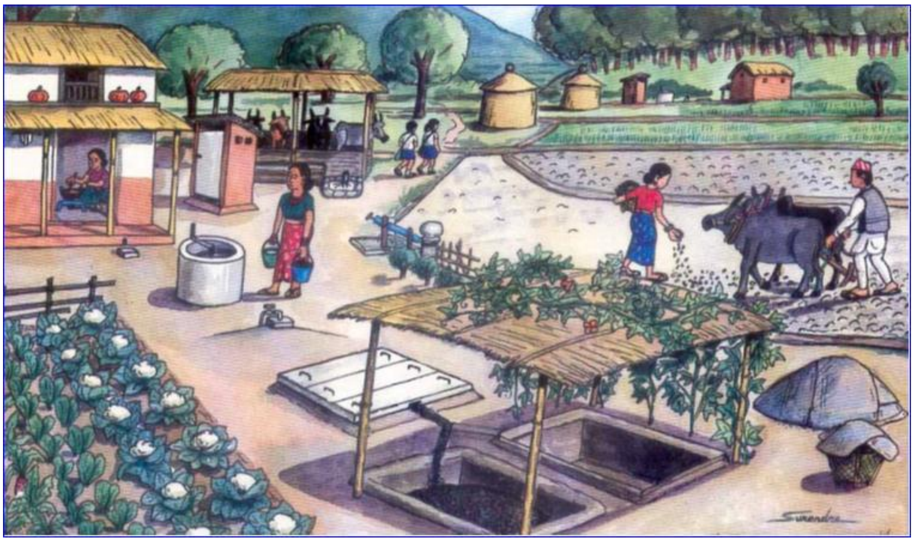
Reader for the
Compact course on

Domestic Biogas

Technology and mass dissemination
2014

at the University of Oldenburg
hosted by *Postgraduate Programme Renewable Energy*
www.ppre.de



Jan Lam / Felix ter Heegde / Steven von Eije
Version April 2014

Dear Reader!
This course reader was first issued as a short paper in 2005. Over the years it has grown as it has been updated with the experiences from the rapidly growing number of national biodigester programmes in Asia and Africa. The present course reader contains material originating from:
Asia Biogas Programmes: http://www.snvworld.org/en/sectors/renewable-energy/about-us/snv-energy/domestic-biogas/asia-biogas-programme

- Biogas Support Programme Nepal (BSP/N) (http://www.search4dev.nl/record/338833)
- Vietnam Biogas Programme (http://biogas.org.vn/english/Home.aspx)
- National Biodigester Programme Cambodia (http://www.search4dev.nl/record/338847) ,

And
Africa Biogas Partnership Programme (http://www.snvworld.org/en/sectors/renewable-energy/about-us/africa-biogas-partnership-programme).

It also contains material from partner organisations, particularly Hivos, The Netherlands (http://www.hivos.nl/) contributes to the carbon part.

Especially in the older parts of the reader not all citations are given where they are due. For this we apologise.

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Content

1 Domestic Biogas and Sustainable Development

Sustainable development covers three aspects of society - economic, social and environmental. Biogas contributes to these three aspects of sustainable development in the following ways:

> **Biogas and the World Summit on Sustainable Development**
>
> As a follow-up to the Rio Summit of 1992, the World Summit on Sustainable Development was held in Johannesburg in 2002. Energy was highlighted as a key topic for discussion as it was felt that there had not been enough focus on it at the previous summit. As with the previous Plan of Implementation, waste management, pollution control and social sustainability were highlighted.
>
> The Plan of Implementation states that about two billion people, or one third of the world's population, presently lack access to electricity or modern energy services and rely on burning firewood or biomass to meet their cooking and heating needs. Meeting the energy needs of these people with modern energy services was a major issue at the Summit, and governments committed themselves to "improving access to reliable, affordable, economically viable, socially acceptable and environmentally sound energy services and resources."
>
> According to the International Energy Agency, currently about 2.7 billion lack access to clean cooking energy.

Domestic biogas digesters contribute to <u>economic development</u> because:

- The expenses for domestic energy are significantly reduced.
- The labour required to maintain traditional energy systems (such as firewood collection) can be used in more directly economically productive ways.
- Substitution of petroleum products will reduce the country's foreign exchange demand.
- Application of bio-slurry increases the yield and reduces the need` -and expenses- for synthetic fertilizer.
- A vibrant biogas sector creates significant employment and related economic activities, particularly in rural areas.
- Reduced disease (human and animal) can improve productivity.

Domestic biogas digesters contribute to <u>social development</u> because:

- The reduction in domestic workload, particularly for women and children, increases opportunities for education and other social activities.
- Respiratory illnesses resulting from indoor air pollution and gastro-enteric diseases as a result of poor sanitary conditions reduce significantly.
- In rural areas, biogas digesters often initiate innovation (education, sanitation, agriculture).
- Increase awareness of alternative farming and animal husbandry practices and environmental impacts of behaviour.

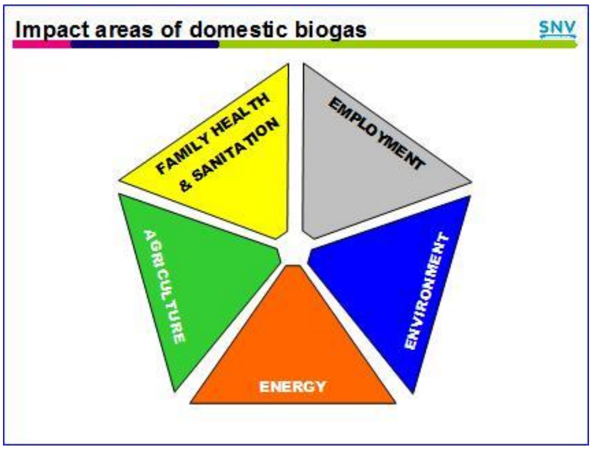
Domestic biogas digesters contribute to <u>environmental development</u> as follows:

- Substituting conventional fuels and synthetic fertiliser, and changing traditional manure management systems, biogas installations reduce the emission of greenhouse gasses significantly.
- Bio-slurry improves soil texture, thus reducing degradation, and reduces the need for further land encroachment.
- Reduction of firewood use contributes to checking deforestation and reduces forest encroachment.
- Improved manure management practices reduce ground and surface water pollution and odour and improve aesthetics.

> **Bruntland & biogas**
>
> The generally accepted definition of Sustainable development, published in the Bruntland Report in 1987:
>
> **"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."**
>
> Domestic biogas is compatible with the Bruntland definition by:
>
> - meeting household energy and income generation needs;
> - reducing greenhouse gas emissions;
> - reduces reliance on fire wood therefore pressure on forest resources;
> - reduces ground and surface water pollution;
> - reduces reliance on non-renewable energy sources and raises the profile of renewable energy technology;
> - providing a long term solution to pollution and energy needs;
> - reducing reliance on chemical fertiser and improving soil condition and fertility through proper application of bio-slurry.

The potential benefits of domestic biogas, then, go well beyond providing renewable energy to rural households. Additional and/or derived benefits can fall in the impact areas of:

- Agriculture, using bio-slurry to improve soil structure and agricultural yields;
- Family health and sanitation, reducing the workload for women or improving the sanitary conditions by connecting a toilet to the installation;
- Employment, creating direct employment in rural areas for the construction of biogas plants or the manufacturing of appliances;
- Environment, by reducing the pressure on forests, or stimulating (semi-) zero grazing practices.



The five presented impact areas provide a reasonable picture of the potential reach of a biogas programme, but the examples mentioned above are just a pick from a score of possible benefits. The precise nature of these benefits will depend on the situation, whereby they can be further distinguished into;

- formal / informal benefits;
- acting at micro, meso and macro level.

	MICRO	MESO	MACRO
INFORMAL	• Reduced indoor smoke-induced illnesses. • Reduced poor-sanitation induced illnesses. • Reduced drudgery from fuel wood collection. • Reduced pressure for illegal forest encroachment. • Reduction drudgery from weeding fields. • Reduced workload for food-preparation. • Reduced soil degradation. • Improved opportunity for education.	• Reduced risk of erosion and landslides in mountainous areas. • Improved forest quality and quantity. • Reduced pollution of surface water. • Reduced pollution of the environment as a result of uncontrolled dumping of animal waste.	• Reduction of illness-induced production losses. • Improved biodiversity. • Increased non-marketable (NT)FP availability. • Increased efficient productivity. • Reduced mortality. • Improved human resource base. • Reduced risks as result of global warming.
FORMAL	• Increased efficient productivity. • Reduced direct medical costs. • Reduced expenses on conventional energy sources. • Reduced chemical fertilizer expenditures. • Increased opportunity for (small scale) animal husbandry. • Increased opportunity for (small-scale) organic agriculture. • Improved agricultural yields. • Increased family income.	• Increased employment and income generating opportunities. • Opportunity to develop markets for (organic) agricultural produce.	• Reduced (forex) cost on medication. • Reduced health system expenses. • Reduced (forex) costs on chemical fertilizer. • Reduced (forex) costs on fossil fuels. • Increased availability marketable (NT)FP. • Increased agricultural production. • Increased tax revenues. • Generating CDM revenues.

Per situation, then, benefits can be grouped in a tangibility matrix (example Vietnam)

2 Domestic biogas and the Millennium Development Goals

Around 2.7 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:

2.1 MDGs

2.1.1 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.

2.1.2 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 1 to 3 hours per household per day.
- Biogas illumination is highly appreciated for lighting, facilitating reading / education / economic activities during the evening.

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

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

Around 2.7 billion people depend on traditional (mostly biomass based) energy fuels of which the collection becomes increasingly cumbersome. Indoor air pollution from burning of these fuels kills nearly 2 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 as well a large 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 surroundings, 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.

2.1.4 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 national 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.

2.2 The Contribution of Biodigester Technology to Development at Different Levels

Farmers may want to substitute inputs such as fertilisers by biodigester slurry and substitute household and engine fuels by 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, quality of life 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 fuel wood resources and better manure management. Less poverty also results in better future perspectives for a population and therewith less economic refugees.

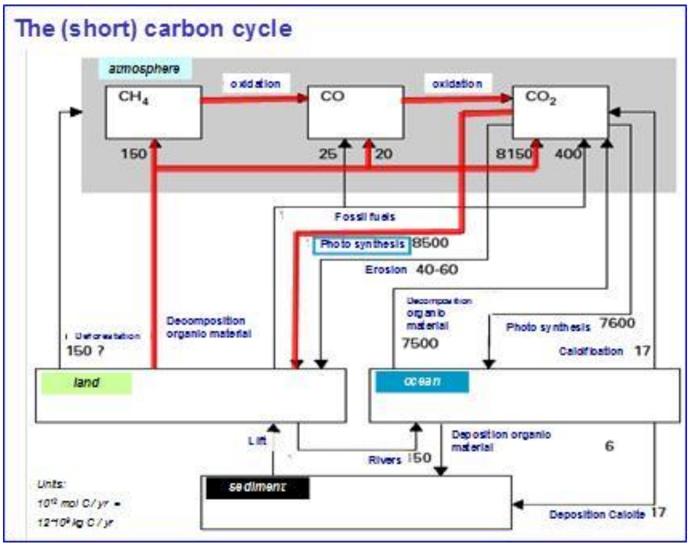
3 Biochemical process and Biogas

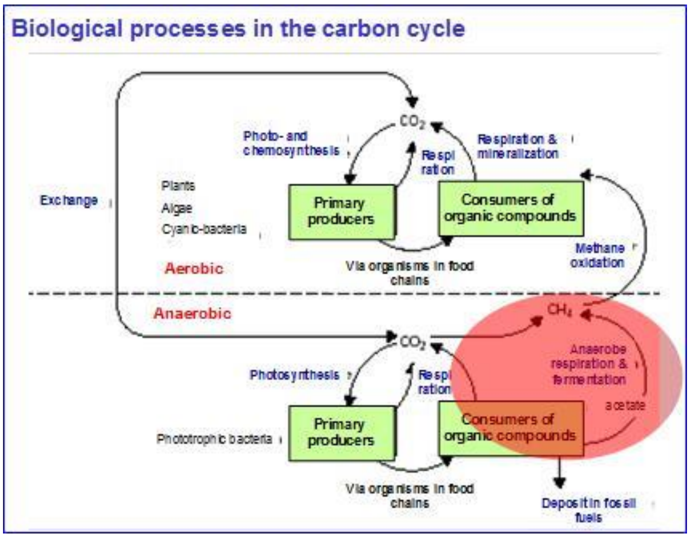
3.1 Introduction

"… Knowledge of the fundamental processes involved in methane fermentation is necessary for planning, building and operating biogas plants …"

Anaerobic digestion is the naturally occurring process of decomposition and decay, by which organic matter is broken down to its simpler chemical components (mineralization) under anaerobic conditions. Biogas, then, is produced by (anaerobe) micro-organisms[1] digesting organic material. The remaining digested organic material is referred to as bio-slurry. Biogas can be used for energy production and the bio-slurry is a nutrient rich organic fertilizer.

3.2 Biogas and the global carbon cycle





The natural generation of biogas is an important part of the biogeochemical carbon cycle. The two main processes in the (short) carbon cycle are carbon storage in vegetation through photosynthesis and carbon emission (in the form of CO_2 and CH_4) by micro-organisms through oxidation and fermentation.

Green vegetation converts carbon-dioxide into organic matter (biomass) and oxygen. This process requires, except light and water, also nitrate, phosphate (bio-limiting elements), hydrogen and a whole range of micronutrients.

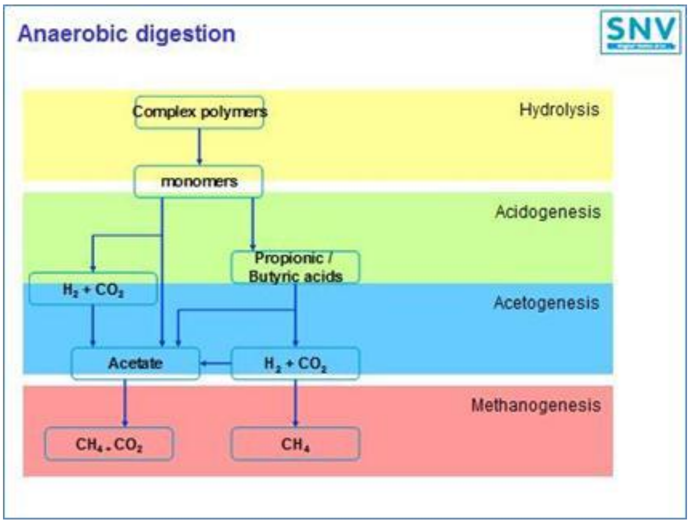
Micro-organisms, in the process of bio-degradation, convert organic material (biomass) into carbon-dioxide and methane. Through emission of these gasses, carbon is introduced back in the atmosphere. Annually some $180x10^9$ kg of carbon as methane is released worldwide into the atmosphere through microbial activity (biogenic), against $130x10^9$ kg of anthropogenic CH_4 emissions. With a Global Warming Potential (GWP) of 23, methane is a potent greenhouse gas. The present atmospheric methane concentration amounts to about 1.65 ppm (and rising).

The (facultative or obligate) anaerobic micro-organisms use nitrate, carbonate or sulphate compounds for their respiration. The methane producing micro-organisms (methanogens) are strictly anaerobe. These micro-organisms naturally appear in tundra's, swamps, ponds and paddies but also in the stomachs of ruminants and the intestines of termites. Soils have anaerobe micro-habitats, in which methanogens operate.

1 Although in many publications these micro-organisms have been grouped as bacteria, many of the processes are actually performed by archaea, a very different genus of prokaryotes, distinctly different from bacteria in cell wall and membrane structure, and more similar to eukaryotes in (some) genetic and metabolic arrangements.

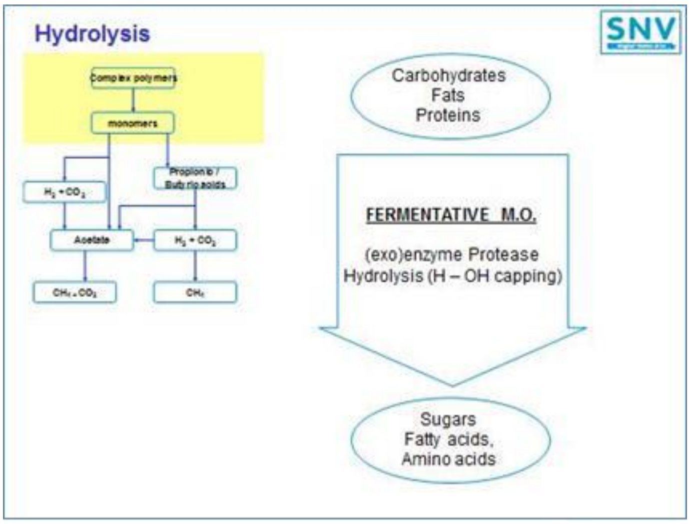
3.3 *Anaerobic Digestion*

Fermentation of the organic component of biomass involves a “concerted effort” of nitrogenous, carbonaceous and sulphurous micro-organisms. And within one such group, different consortia of micro-organisms act in different stages of the process and under different temperatures. The complex AD process can best be understood if divided in four main stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis.

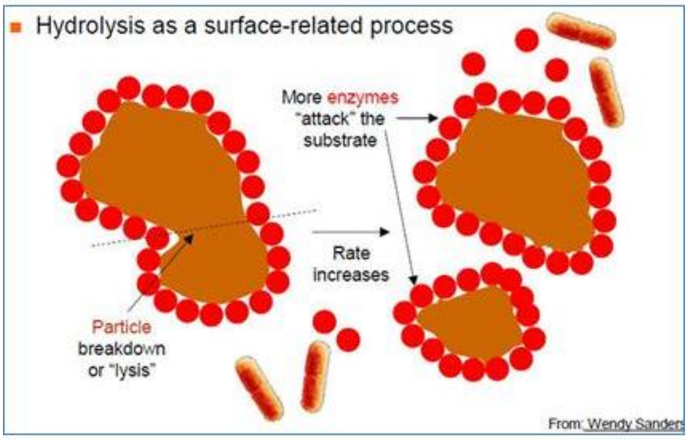


3.3.1 Hydrolysis

In the first step (hydrolysis), the organic matter is enzymolyzed externally by extracellular enzymes (cellulase, amylase, protease and lipase) of micro-organisms. Micro-organisms decompose the long chains of the complex carbohydrates, proteins and lipids into shorter parts. For example, polysaccharides are converted into monosaccharides. Proteins are split into peptides and amino acids. These soluble constituents can be processed through the bacterial cell wall.

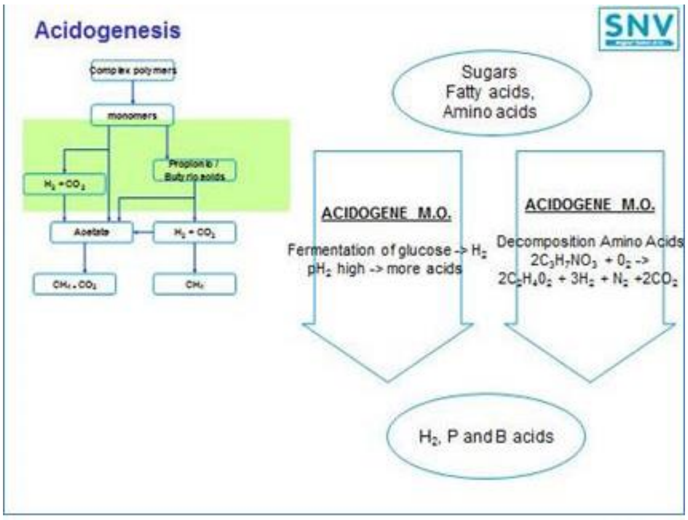


Hydrolysis is the rate-limiting step in anaerobic digestion and is a “surface-related process. Proper pre-mixing of the substrate, reducing particle size, will increase the hydrolysis rate.



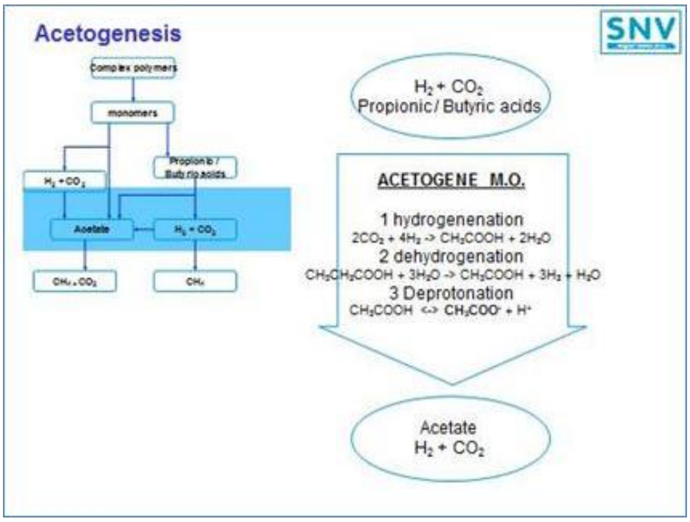
3.3.2 Acidogenesis

Acid-producing micro-organisms, involved in the second step, convert the intermediates of fermenting micro-organisms, glucose and amino acids, into Propionic and Butyric acids and hydrogen (H_2). With the conversion of glucose the hydrogen production is high, increasing the acidity of the substrate



3.3.3 Acetogenesis

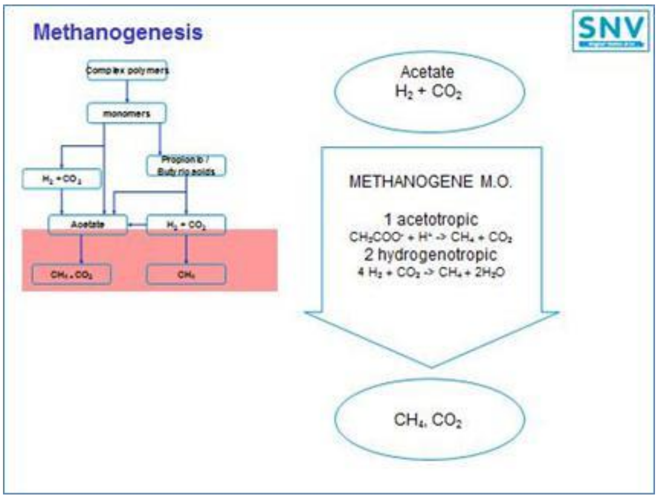
Hydrogen and carbon dioxide hydrogenate also to P-and B- acids where after these carbon acids deprotonate (splitting-off of H_2) to acetate (CH_3COO^-).

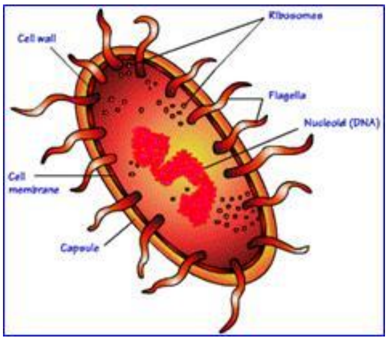


The micro-organisms in this and the above process are facultative anaerobe and can grow under acid conditions. To produce acetic acid and hydrogen they need nitrogen, oxygen and carbon. Preferring oxygen for their respiration, they use the oxygen dissolved in the solution or 'bounded-oxygen'. Hereby, the acid-producing micro-organisms create the anaerobic condition essential for the methane producing micro-organisms. Moreover, they reduce the compounds with a low molecular weight into alcohols, organic acids, amino acids, carbon dioxide, hydrogen-sulphide and traces of methane. From a chemical standpoint, this process is partially endothermic (i.e. only possible with energy input), since micro-organisms alone are not capable of sustaining this type of reaction.

3.3.4 Methane forming

Methane-producing archaea, using sulphur compounds for their respiration, decompose compounds with a low molecular weight. Methanogens are obligatory anaerobic and very sensitive to environmental changes. In contrast to the acidogenic and acetogenic micro-organisms, methanogens belong to the archaea genus, i.e. to a group of micro-organisms with a very heterogeneous morphology and a number of common biochemical





and molecular-biological properties that distinguish them from all other micro-organisms in general. The main difference lies in the makeup of the bacteria's cell walls.

There are many species of methanogens and their characteristics vary. The archaea 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).

During this final stage, methane is formed via two tracks (and two sets of methanogens); acetotropic methanogens produce CH_4 and CO_2 from acetate; hydrogenotropic methanogens produce CH_4 and H_2O from hydrogen and carbon dioxide. The second process is known as "black fermentation" and takes only place in the absence of light.

3.3.5 Symbiosis of micro-organisms

Methane- and acid-producing micro-organisms act in a symbiotic way. On the one hand, acid-producing micro-organisms create an atmosphere with ideal parameters for methane-producing micro-organisms (anaerobic conditions, compounds with a low molecular weight). On the other hand, methane-producing micro-organisms use the intermediates of the acid-producing micro-organisms. Without consuming them, toxic conditions for the acid-producing micro-organisms would develop.

3.3.6 Main properties of biogas

Biogas is a mixture of gasses (see table) with a calorific value biogas of ~ 20 MJ/kg = ~ 23 MJ/m^3. (= ~ 6 kWh/m^3 or 0.5 ltr... of diesel oil / m^3). The density biogas is ~ 1.16 kg/m^3 (Based on density CH_4 = 0.68 kg/m^3, density CO_2 = 1.87 kg/m^3 and 60% CH_4 in biogas).

Biogas 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.

Composition biogas

Methane	CH_4	40-70	vol%
Carbon-dioxide	CO_2	30-60	vol%

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

3.4 *Factors controlling the conversion of substrate to gas*

The rate and efficiency of the anaerobic digestion process is controlled by:

1. Substrate characteristics
2. Temperature
3. pH and alkalinity
4. Retention time

3.4.1 Substrate

Substrate is the organic material fed to a biogas installation for digestion.

3.4.1.1 Substrate parameters

Organic substrate, in terms of its decomposition ability, is mainly characterized by

- Fresh Weight: weight of the waste as produced.
- Total Solids (TS): weight of the waste after drying.
- Volatile Solids (VS): weight of that part of the waste that is actually decomposing.
- Chemical Oxygen Demand (COD): amount of oxygen needed for the decomposition.

For the manure of a North American dairy cow, the values of these characteristics are presented in the box. Please note that values for cattle in developing countries differ significantly. Typically, a dairy cow in Africa may weigh 250 kg, and produce 1 to 5 kg milk per day while the total solids share of the manure often will be higher than 20%. Fresh manure of (Danish) pigs contains 5% Total Solids (TS) of which the Volatile Solids content is 95%. A Vietnamese study however, measured between 27% and 30% Total Solids.

Mature "developed (!)" dairy cow		Live weight 635 kg
		Milk production 20 – 35 kg / day
Main dung characteristics:		
Daily fresh manure production:		51 kg per day (61 litres / day)
Total solids:		6.4 kg (TS (= DM) ~ 13% of fresh wght)
Volatile solids:		5.4 kg (VS ~ 11% of fresh wght, VS ~ 85% of TS)
Chemical Oxygen Demand:		5.7 kg (COD ~ 11% of fresh wgt)
Macro nutrients:		
Nitrogen	N_k:	0.39 kg (organic)
Phosphorus	P:	0.04 kg
Potassium	K:	0.16 kg

3.4.1.2 Degradability

The table below provides an insight in the production of Volatile Solids for some dairy and non-dairy cattle, buffalo and swine for different parts of the world. As the table shows, not only the VS-production –in [kg VS per day per head]- shows a significant range over different continents, in addition the biodegradability (B_o in [m^3 CH_4 / kg VS]) varies.

TABLE 1

PRODUCTION OF VS AND MAXIMUM ANAEROBIC BIODEGRADABILITY OF THE VS

Region	Dairy		Non-dairy		Buffalo		Swine	
	B_o [a]	VS [b]	B_o [a]	VS [b]	B_o [a]	VS [b]	B_o [a]	VS [b]
North America	0.24	5.2	0.17	2.4	0	0	0.45	0.5
Western Europe	0.24	5.1	0.17	2.7	0.1	3.9	0.45	0.5
Eastern Europe	0.24	4.1	0.17	2.7	0.1	3.9	0.45	0.5
Oceania	0.24	3.5	0.17	3	0.1	3.9	0.45	0.5
Latin America	0.13	2.9	0.1	2.5	0.1	3.9	0.29	0.3
Africa	0.13	1.9	0.1	1.5	0.1	3.9	0.29	0.3
Middle East	0.13	1.9	0.1	1.5	0.1	3.9	0.29	0.3
Asia	0.13	2.8	0.1	2.3	0.1	3.9	0.29	0.3
Indian Subcontinent	0.13	2.6	0.1	1.4	0.1	3.1	0.29	0.3

[a] in m^3 CH_4/kg VS

[b] Average VS production for per head per day for the average animal (kg VS/(head.day))

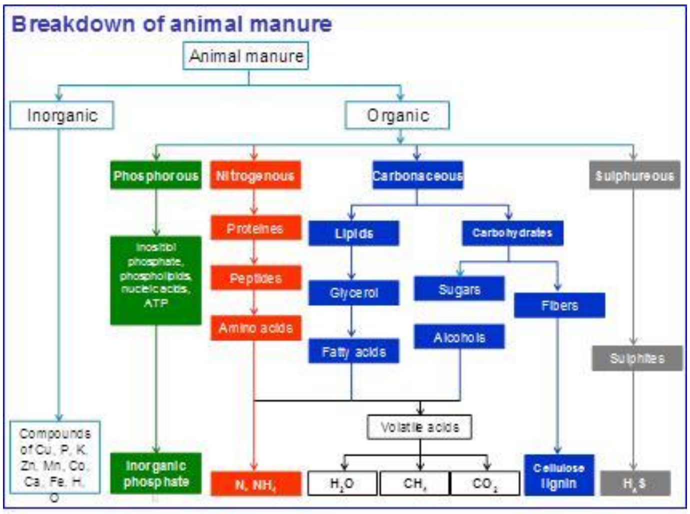
Source: IPCC 1997

Because of the variation in these two parameters, actual potential methane production per head, for instance for dairy cattle, can vary a factor five; between 0.247 m^3 in Africa or Asia to 1.248 m^3 in North America.

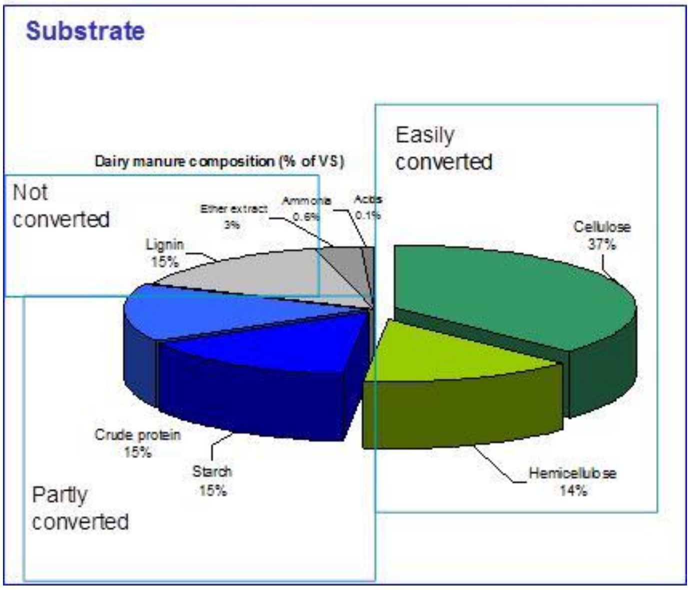
Similarly, for market swine, actual methane production per head can vary from 0.087 m^3 in Asia to 0.24 m^3 in North America[2]; a variation with nearly a factor three

[2] Literature shows a variation in B_o for pigs in developed countries from 0.45 m^3 CH_4 / kg VS (IPCC 1997) to 0.53 m^3 CH_4 / kg VS (Danish research).

In principle, all organic materials can be digested (microbial infallibility). For simple domestic biogas installations, however, only homogenous, liquid substrates can be considered (faeces and urine from cattle, pigs and poultry and the wastewater from toilets).



All waste constituents are not equally degraded or converted to gas through anaerobic digestion. Anaerobic micro-organisms do not degrade lignin and some other hydrocarbons. The digestion of waste containing high nitrogen and sulphur concentrations can produce toxic concentrations of ammonia and hydrogen-sulphide. Wastes that are not particularly water-soluble will breakdown slowly.



As can be observed from pie-chart, the majority of the volatile solids are composed of cellulose and hemicelluloses. Both are readily converted to methane gas by anaerobic micro-organisms. As pointed out earlier, lignin will not degrade during anaerobic digestion. Since a substantial portion of the volatile solids in dairy waste is lignin, the percentage of cow manure volatile solids that can be converted to gas is lower when compared to other manure and wastes.

3.4.1.3 Dilution

The waste characteristics can be altered by simple dilution. Water will reduce the concentration of certain constituents such as nitrogen and sulphur that produce products (ammonia and hydrogen-sulphide) that are inhibitory to the anaerobic digestion process. High solids digestion creates high concentrations of end products that inhibit anaerobic decomposition. Therefore, some dilution can have positive effects.

Literature suggests that greater reduction efficiencies occur at concentrations of approximately 6% to 7% total solids[3]. Dairy waste "as excreted" is approximately 12% total solids and 10.5% volatile solids. Most treatment systems operate at a lower solids concentration than the "as excreted" values; the water to fresh dung ratio for typical domestic biogas plants is advised at 1:1. In Vietnam, domestic biogas installations with pig-dung as substrate use a designed water to dung ratio of 2:1 to compensate the hydraulic retention time (see 2.4) for the larger amounts of washing water used.

Dilution also causes stratification within the digester. Undigested straw forms a thick mat on top of the digester while sand accumulates at the bottom. The optimum waste concentration is based on temperature and the quantity of straw and other constituents that are likely to separate within the anaerobic digester. It is desirable to keep the separation or stratification in the digester to a minimum.
For larger installations, mixing (involving the consumption of power) may reduce the stratification of diluted waste.

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3 Over the past decade, the research into dry-fermentation is increasing, and with promising results. Some studies even suggest gas production at 35°C to be similar for dry and wet fermentation.

3.4.1.4 *Agitation*

Many substrates and various modes of fermentation require some sort of substrate agitation or mixing in order to maintain process stability within the digester. The most important objectives of agitation are:

- Removal of the metabolites (gas) produced by the methanogens;
- Mixing of fresh substrate and micro-organism population (inoculation);
- Preclusion of scum formation and sedimentation;
- Avoidance of pronounced temperature gradients within the digester;
- Provision of a uniform micro-organism population density;
- Prevention of the formation of dead spaces that would reduce the effective digester volume.

In selecting or designing a suitable means of agitation, the following points should be considered:

- The process involves a symbiotic relationship between various strains of micro-organisms, i.e. the metabolites from one species can serve as nutrient for the next species, etc.
- Whenever the bacterial community is disrupted, the process of fermentation will remain more or less unproductive until an equivalent new community is formed. Consequently, excessive or too frequent mixing is usually detrimental to the process. Slow stirring is better than rapid agitation.
- A thin layer of scum does not necessarily have an adverse effect on the process. For systems in which the digester is completely filled with substrate, so that any scum always remains sufficiently wet, there is little or no danger that the extraction of gas being impeded by the scum.
- Some types of biogas systems can function well without any mechanical agitation at all. Such systems are usually operated either on substrates with such a high solid content, that no stratification occurs, or on substrates consisting primarily of soluble substances.

Since the results of agitation and mixing are highly dependent on the substrate in use, it is not possible to achieve a sufficiently uniform comparative evaluation of various mixing systems and/or intensity levels. Thus, each such system can only be designed on the basis of empirical data. The application of digester mixing systems for domestic biogas installations has long since been aborted, as advantages are hard to qualify and most systems affected the reliability of the installation in a negative way. Inlet mixing systems, however, are still widely used.

3.4.1.5 *Nutrients*

In order to grow, micro-organisms need more than just a supply of organic substances as a source of carbon and energy. They also require certain mineral nutrients. In addition to carbon, oxygen and hydrogen, the generation of bio-mass requires an adequate supply of nitrogen, sulphur, phosphorous, potassium, calcium, magnesium and a number of trace elements such as iron, manganese, molybdenum, zinc, cobalt, selenium, tungsten, nickel etc. "Normal" substrates such as agricultural residues or municipal sewage usually contain adequate amounts of the afore-mentioned elements. Anecdotal evidence, however, indicates that biogas digesters running on 100% maize may abruptly stop generating biogas as a result of shortage of micro-nutrients. Also higher concentrations of any individual substance usually have an inhibitory effect; analyses are recommended on a case-to-case basis to determine which amount of which nutrients, if any, still needs to be added (see also C/N ratio).

3.4.1.6 *Carbon to Nitrogen ratio*

Micro-organisms need both nitrogen and carbon for assimilation into their cell structures. Various experiments have shown that the metabolic activity of methanogenic micro-organisms can be optimized at a C/N ratio of approximately 8-20, whereby the optimum point varies from case to case, depending on the nature of the substrate. High C/N ratios (low N-content) result in low gas production through N-inhibition, whereas low C/N ratios (high N-content) may stop the process because the substrate gets to alkaline.

All substrates contain nitrogen. For higher pH values, even a relatively low nitrogen concentration may inhibit the process of fermentation. Noticeable inhibition occurs at a nitrogen concentration of roughly 1700 mg ammonium-nitrogen (NH_4-N) per litre substrate.

Some substrate C / N ratios

Dung / faeces			Crop rsidue		
Cow manure	16.5	25	Rice straw	51	67
Pig manure	6.2	13.5	Bagasse	140	150
Chicken manure	5	9.6	Soybean stalks		33
Night soil	6	10	Water lily		11.4

Nonetheless, given enough time, the methanogens are capable of adapting to NH_4-N concentrations in the range of 5000-7000 mg/l substrate, the main prerequisite being that the ammonia level (NH_3) does not exceed 200-300 mg NH_3-N per litre substrate. The rate of ammonia dissociation in water depends on the process temperature and pH value of the substrate slurry.

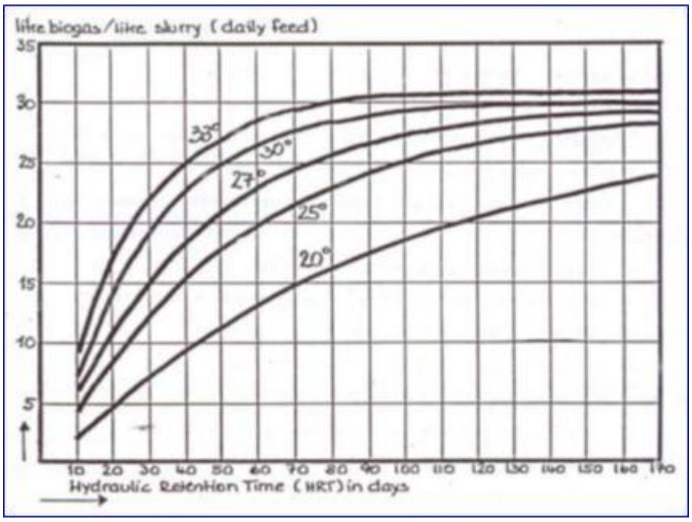
3.4.1.7 Toxic materials

Toxic materials such as fungicides, heavy metals, antibiotics (Bacitracin, Flavomycin, Lasalocid, Monensin, Spiramycin, etc.) and detergents used in livestock husbandry can have an inhibitory effect on the process of biogas production. The anaerobic process can handle small quantities of toxic materials without difficulty. The table lists the limit concentrations (mg/l) for various inhibitors.

Substance	[mg/l]
Copper:	10-250
Calcium:	8000
Sodium:	8000
Magnesium:	3000
Nickel:	100-1000
Zinc:	350-1000
Chromium:	200-2000
Sulfide (as Sulfur):	200
Cyanide:	2

3.4.2 Temperature

The rate of bacteriological methane production increases with temperature. Since, however, the amount of free ammonia also increases with temperature, the bio-digestive performance could be inhibited or even reduced as a result. In general, unheated biogas plants perform satisfactory only where mean annual temperatures are around 20°C or above or where the average daily temperature is at least 18°C. Within the range of 20-28°C mean temperature, gas production increases over-proportionally. If the temperature of the bio-mass is below 15°C, gas production will be so low that the biogas plant is no longer economically feasible.



3.4.2.1 AD temperature ranges

The anaerobic bacterial consortia function under three temperature ranges;

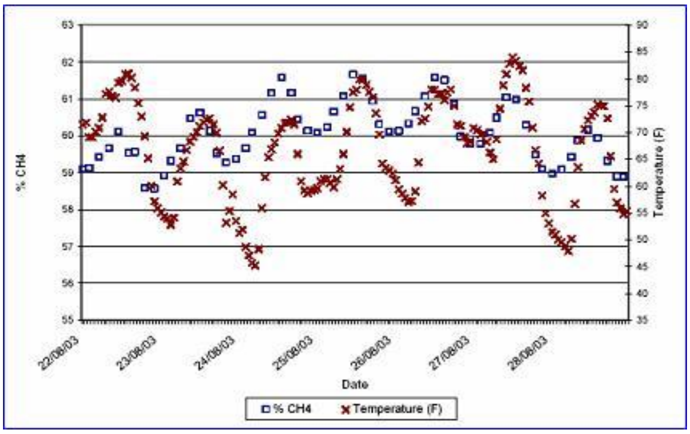
- Psychrophilic temperatures between 3 and 20°C, and produce the least amount of micro-organismsl action.
- Mesophilic digestion occurs between 20 and 40°C.
- Thermophilic digestion occurs between 40 and 70°C.

The optimum mesophilic temperature is between 35 and 37°C. The optimum thermophilic temperature is between 60 and 63°C. The rate of bacterial growth and waste degradation is faster under thermophilic conditions. On the other hand, thermophilic digestion is more prone to process inhibition by intoxication (ammonia) and produces a more odorous effluent. Thermophilic digestion substantially increases the heat energy required for the process.

3.4.2.2 Temperature fluctuations

Seasonal and diurnal temperature fluctuations significantly affect anaerobic digestion and the quantities of gas produced. The degree of sensitivity, in turn, is dependent on the temperature range. Brief fluctuations not exceeding the following limits may be regarded as still un-inhibitory with respect to the process of fermentation:

- Psychrophilic range: ± 2°C/h
- Mesophilic range: ± 1°C/h
- Thermophilic range: ± 0,5°C/h



The temperature fluctuations between day and night are lesser a problem for domestic plants built underground, since the temperature fluctuation of the earth below a depth of one meter is practically limited.
Temperature is a universal process variable influencing the rate of bacterial action as well as the quantity of moisture in the biogas. The biogas moisture content increases exponentially with temperature. Temperature also influences the quantity of gas and volatile organic substances dissolved in solution as well as the concentration of methane, ammonia and hydrogen-sulphide.

3.4.3 pH-value

The optimal pH-values for the acidogenesis and methanogenesis are different. During acidogenesis acetic, lactic and propionic acids are formed, resulting in a fall of the pH level. A low pH can inhibit acidogenesis whereas methane producing micro-organisms require a neutral to slightly alkaline environment (pH 6.8 to 8.5) in order to produce methane.

Acid forming micro-organisms grow much faster than methane forming micro-organisms. If acid-producing micro-organisms grow too fast, they may produce more acid than the methane forming micro-organisms can consume; excess acid builds up in the system. The pH drops, and the system may become unbalanced, inhibiting the activity of methane forming micro-organisms. Methane production may stop entirely. Maintenance of a large active quantity of methane producing micro-organisms prevents pH instability. Retained biomass systems are inherently more stable than micro-organism growth based systems such as completely mixed and plug flow digesters. A digester containing a high volatile-acid concentration requires a somewhat higher-than-normal pH value. If the pH value drops below 6.2, the medium will have a toxic effect on the methanogenic micro-organisms. An optimum pH range for all processes is between 6.8 and 7.2.

3.4.4 Hydraulic Retention Time (HRT)

Most anaerobic systems are designed to retain the waste for a fixed number of days. The number of days the materials stays in the tank is called the Hydraulic Retention Time or HRT. The Hydraulic Retention Time equals the volume of the tank divided by the daily flow (HRT=V/Q). The hydraulic retention time is important since it establishes the quantity of time available for bacterial growth and subsequent conversion of the organic material to gas.

The retention time can only be accurately defined in batch-type facilities. Depending on the vessel geometry and actual dilution rate, the effective retention time may vary widely for the individual substrate constituents and situations. Selection of a suitable retention time thus depends not only on the process temperature, but also on the type of substrate used.

Optimizing the process parameters retention time - process temperature - substrate quality - volumetric load determine, among others, the cost efficiency of the biological processes. But as each cubic meter of digester volume has its price, heating equipment can be costly and high quality substrates may have alternative uses, the cost-benefit optimum in biogas production is almost always below the biological optimum. For liquid manure undergoing fermentation in the mesophilic temperature range, the following approximate values apply:

- Liquid cow manure: 20-30 days
- Liquid pig manure: 15-25 days
- Liquid chicken manure: 20-40 days
- Animal manure mixed with plant material: 50-80 days

For simple domestic biogas installations, applied HRTs vary from 45 days in warm areas to 55 days in temperate areas.

If the retention time is too short, the micro-organisms in the digester are "washed out" faster than they can reproduce, so that the fermentation practically comes to a standstill. On the other hand, with a retention time that is too long the end products of anaerobic digestion can adversely affect the digestion process. Such products include organic acids, ammonia-nitrogen, and hydrogen-sulphide. For any given volatile solids conversion to gas, the higher the influent waste concentration, the greater the end product concentration. End product inhibition can be reduced by lowering the influent waste concentration or by separately removing the soluble end-products from the digester.

In actual fact, not so much the HRT, but rather the Solids Retention Time (SRT) is the most important factor controlling the conversion of solids to gas. It is also the most important factor in maintaining digester stability. In a conventional completely mixed, or plug flow digester, the HRT equals the SRT. However, in a variety of retained biomass reactors the SRT exceeds the HRT. As a result, the retained biomass digesters can be much smaller while achieving the same solids to gas conversion rate. The volatile solids conversion to gas is a function of SRT (Solids Retention Time) rather than HRT. At a low SRT insufficient time is available for the micro-organisms to grow and replace the micro-organisms lost in the effluent. If the rate of micro-organism loss exceeds the rate of micro-organisms growth, "wash-out" occurs. The SRT at which "wash-out" begins to occur is the "critical SRT". A measure of success of biomass retention, thus, is the SRT/HRT ratio. In conventional digesters, the ratio is 1.0. Effective retention systems will have SRT/HRT ratios exceeding 3.0. At an SRT/HRT ratio of 3.0 the digester will be 1/3rd the size of a conventional digester.

3.5 Reference material

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4 Bio-digester 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.

4.1 Floating Drum Digester

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.

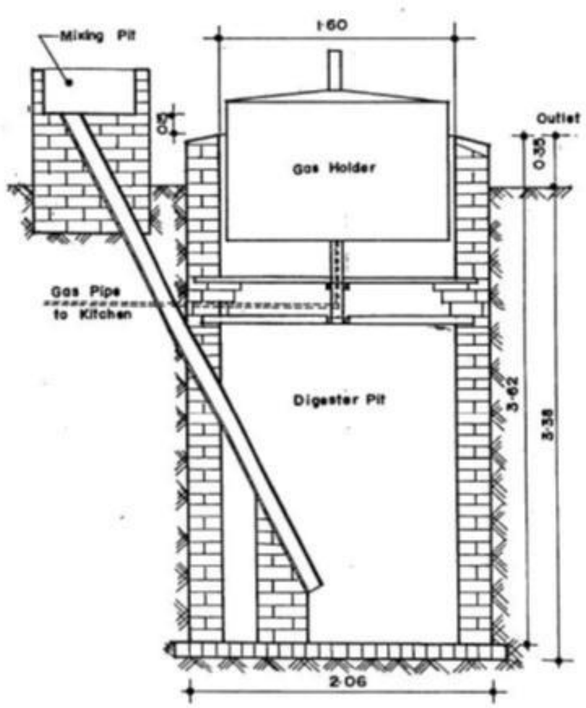
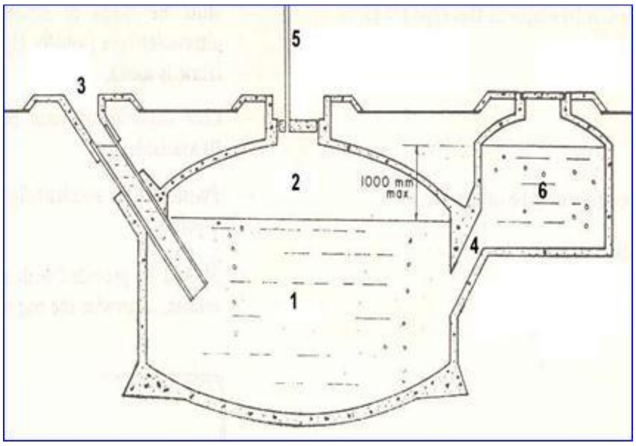


FIGURE 1·1 KVIC FLOATING GAS HOLDER SYSTEM

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.

4.2 Fixed dome digester or Chinese model digester

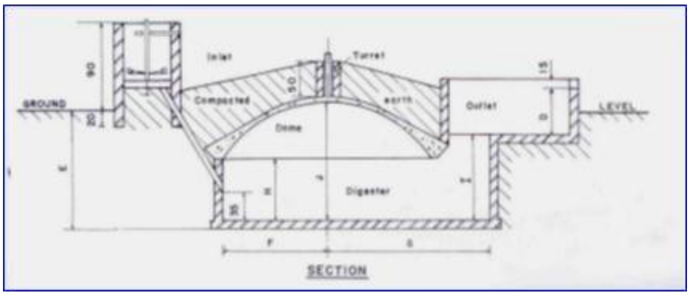
The fixed dome also known as Chinese model biogas plant was developed and built in China as early as 1936. It consists of an underground brick masonry compartment (fermentation chamber) with a dome on the top for gas storage. In this design, the fermentation chamber and gas holder are combined as one 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

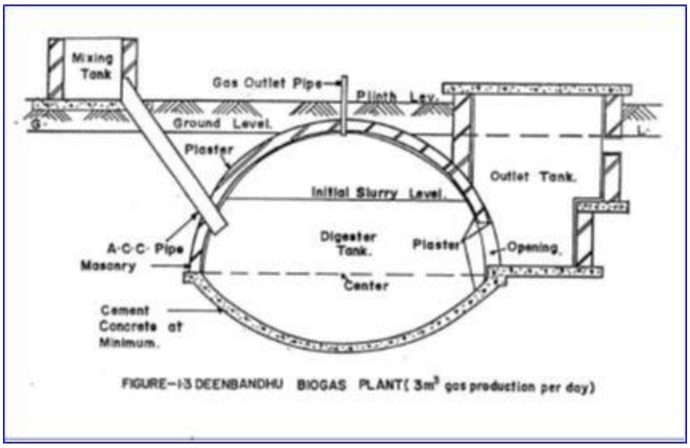
The original Chinese model is usually complete made out of concrete and constructed with the help of moulds.

4.3 GGC 2047 Nepal design



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.

4.4 Deenbandhu Model



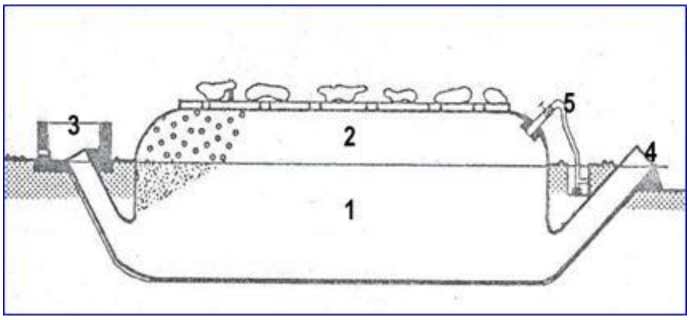
FIGURE–1.3 DEENBANDHU BIOGAS PLANT(3m³ gas production per day)

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 per cent cheaper than other fixed dome designs used at that time in India. It also proved to be about 45 per cent 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 nearly 4.5 million plants constructed up to the end of 2011.

4.5 Low cost digesters

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.



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.

4.6 Factors for design selection

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 cannot 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, which 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.

4.7 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.

4.8 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 be practical 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. when passing 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 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 is 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.

5 Gas Formation and Energy content of Biogas and 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 fertilising 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

			Av. gas flow		Const. gas press.	Gas purific.	
			Litres STP/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

5.1 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 an open fire, or wood stove.

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

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 one 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 greenhouse 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. Cooking on biogas is smokeless and diminishes the number of eye infections and respiratory problems particular among women who are 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.

5.1.1 The combustion process during cooking

The table below provides the 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 kg/m^3
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.

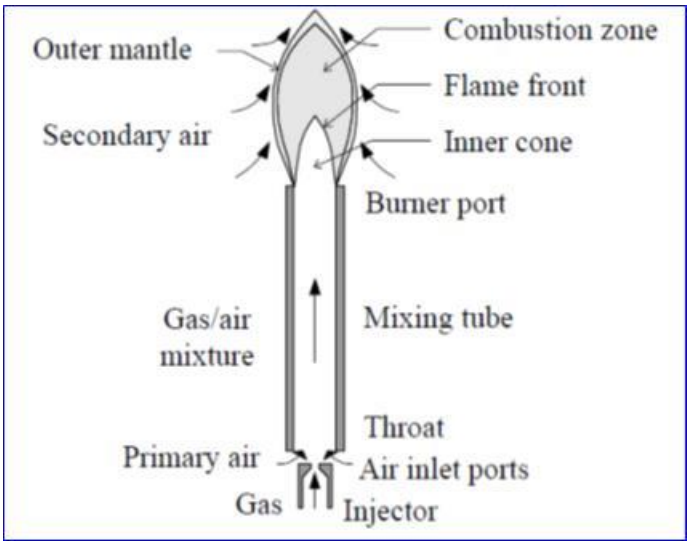
Biogas is a clean fuel – non-toxic in nature, odourless and smokeless. Chemically it contains 55 -70% methane, 35-40% carbon dioxide and less than 5% of other gases, such as ammonia, hydrogen, carbon monoxide, nitrogen, etc. On complete combustion of biogas, the amount of energy released is about 20-24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

Biogas-air mixture for complete combustion
Suppose biogas contains 60% methane and 21% 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% biogas in air (stoichiometric air requirement).

The biogas burns over a narrow range of mixtures from 9% to 17% 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.

5.1.2 Biogas Flame



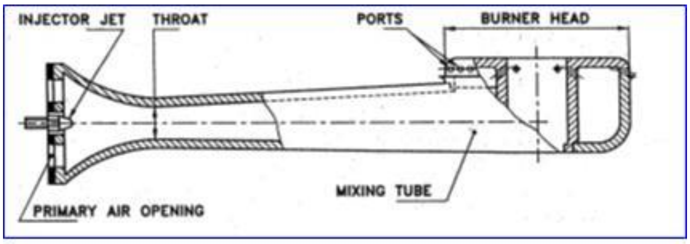
As shown in the figure, when biogas comes out of the injector, air is entrained and mixed with gas in the mixing tube. Then it reaches the burner ports. The unburned gas is heated up in an inner cone and starts burning at the flame front. The cone shape of the flame is a result of laminar flow in a cylindrical 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^{o}C 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.

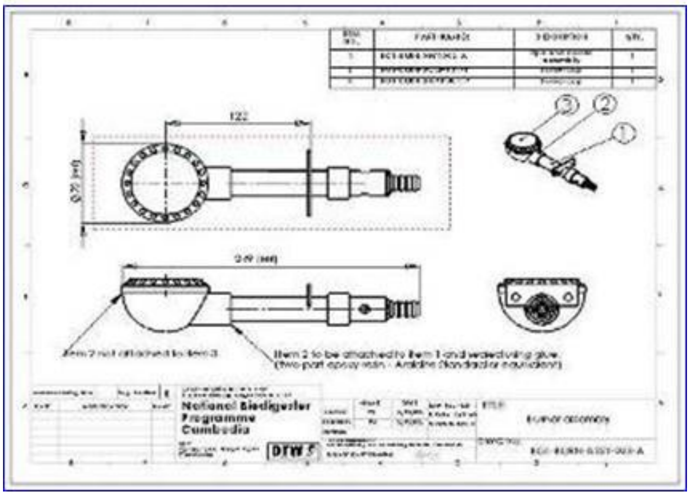
5.1.3 Effect of carbon dioxide and water vapours contained in biogas

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.

5.1.4 Stove 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.





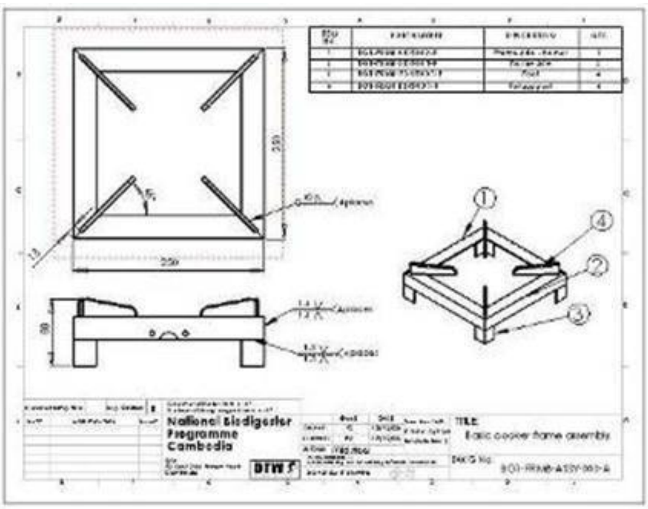
Biogas reaches with certain speed at the stove, depending upon the gas pressure in the pipeline of a certain diameter from the biogas plant. With the help of an injector jet at the inlet of the stove, the speed is increased to produce a draft to suck primary air. The gas and air get mixed in the mixing 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.

5.1.5 Main design 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.

5.2 Lighting

5.2.1 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 fibre 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.

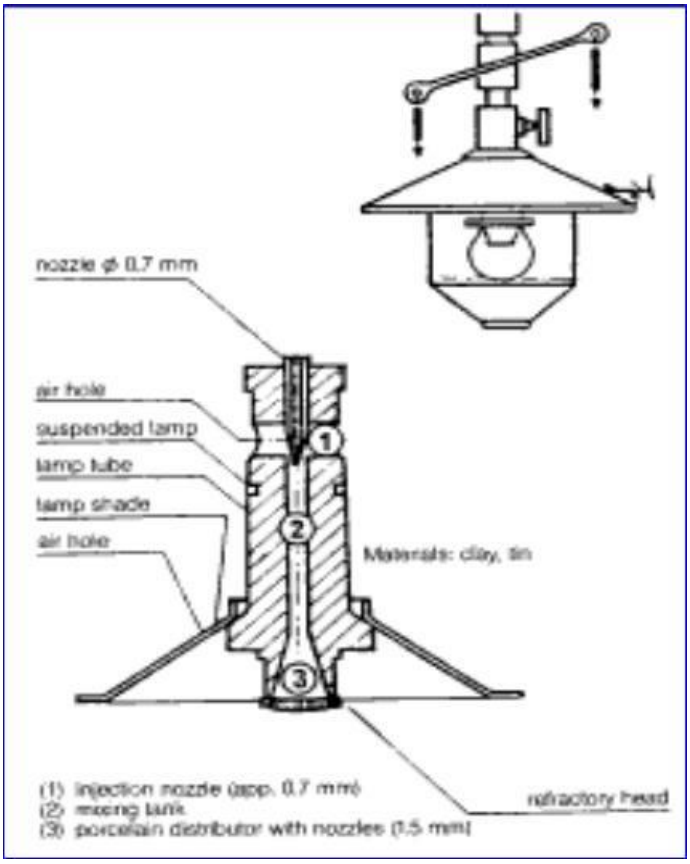
> Since thorium is radioactive material it should be handled with utmost care. The particles from thorium gas mantles could fall out over time and get into the air where they could be inhaled. Also of concern is the release of thorium bearing dust if the mantle shatters due to mechanical impact. Alternative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

5.2.2 Light output

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. 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 from 10 to 15 lm/W. One lamp consumes about 120-150 litre biogas per hour.

5.2.3 Optimal tuning

The performance of a biogas lamp is dependent on the 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.



Using biogas for lighting the following aspects should be considered:
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.
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.
Experience of lamps running on biogas in India and Nepal has shown that expectations of users are often too high.
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.

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 fertilisers. Such practice will help achieve better returns from fertilisers, minimise the loss of fertilisers from the soil and provide balanced nutrition to crops. Different methods of slurry applications are described this section.

6 Slurry

6.1 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 an 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”.

6.2 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 volatilisation. Therefore, the time factor has to be considered while applying the slurry and in this regard, immediate use can be a way of optimising the results.

6.3 Utilisation 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 utilised.
- 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 pulverised. The pulverised 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, Farm Yard Manure (FYM) and the digested slurry are presented in the table below.

Nutrients Available in Composted Manure, FYM 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.

6.3.1 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.

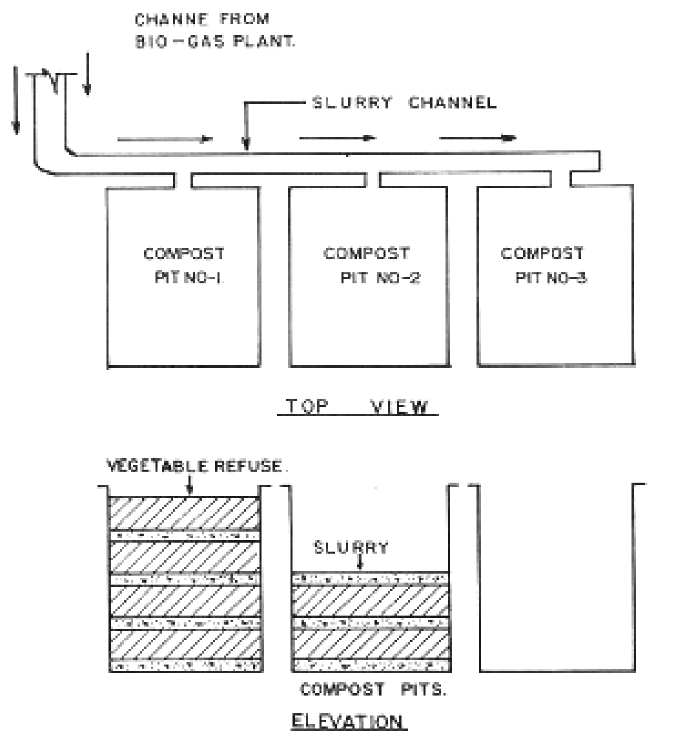


CHART-43 USE OF SLURRY IN MAKING COMPOST

6.3.2 Quality assessment of compost and bio-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.

6.3.3 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%, 79.8%and 31%, respectively.
- Compared to FYM, application of digested slurry increased the rice, maize and wheat yields by 6.5%, 8.9% and 15.2%, respectively.
- Compared to FYM, application of digested slurry along with ammonium bicarbonate (chemical fertiliser) increased the rice and maize yields by 12.1% and 37.6%, 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 fertiliser.

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

- Use of bio-slurry 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 bio-slurry to replace NPK in vegetable farming helps to increase the yield by 20% and reduce the incidences pest insects considerably
- Use of bio-slurry as pig-feed helps in saving food cost to an amount approximately 9 to 11 Euro/pig/feeding cycle of two months. However, feeding of bio-slurry for piglet is not recommended.
- Use of bio-slurry as feed for fish nurseries saves 67% fish-food cost equalling to 375 Euro/ha/harvest (about three harvests/year)
- Use of bio-slurry as feed for adult fish saves 40% fish-food cost, eliminates head floating and increases the yield by 12%, equalling to the saving of 1,000 Euro/ha/harvest (about 2 harvests/year)

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

6.3.4 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.

6.3.5 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 synthesised in the process of anaerobic digestion. The experiment has revealed that the digested slurry from biogas plant provides 10 to 15 % of the total feed requirement of swine and cattle, and 50 % for ducks (Gunnerson and Stuckey, 1986). Dried sludge could be substituted in cattle feed with satisfactory weight gains and savings of 50 % in the feed concentrate used (Alviar. et al., 1990). The growth and development of Salmonella chlorea-suis 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 % of rangelands are 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 kg slurry to 1.12 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 was not noticed (Tong, 1995).

6.3.6 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 utilisation 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 bio-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 bio-slurry treated tanks than in the control. Bio-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 % survival of fish in ponds fed with digested bio-slurry as compared to only 93 % survival rate in ponds fed with raw cow dung.t

6.3.7 Other Uses

Many extensive experiments performed in China have proved that the digested slurry, when used as fertiliser, has strong effects on plant tolerance to diseases such as potato wilt (Pseudomonas solanacearum), 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 % 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 % for one year and 70 % for more than two years along with increase in production.

7 Plant size range

As each situation differs in terms of e.g. gas requirement or available feeding material, a unique plant size could be calculated for each household. For larger dissemination programmes, however, this would be impractical. Therefore, such programmes work with a limited number of plant sizes that are expected to cover the demand of (most) households. The following example shows how to develop a plants' size range with the lowest number of sizes covering a certain demand scope.

7.1 Plant size parameters

Although size calculations can become very complicated, for domestic application the following parameters suffice to arrive at a practical plant size range:

Parameter	Explanation	Values used
Dung / water ratio	Theoretically, the dung / water ratio depends on the total solids (TS) concentration of the dung, whereby optimum fermentation results are claimed at 6% to 7% TS. The TS of dung varies considerably, for livestock in development countries TS values in the 10% to 15% (cattle) and 15% to 20% (pigs) range are reported.	The TS values suggest a dung / water ratio of a little under 1:1 for cattle dung and 1:2 for pig dung. For practical reasons. A 1:1 ratio has the advantage that households can easily measure the amount of required process water.
Specific gas production	The specific gas production of dung depends on the type and quality of dung.	For cattle, typically 1 kg of dung fed to a digester produces about 40 litres of biogas. Values for other substrates will differ; pigs, poultry and human excreta typically have higher yields.
Minimum gas production	Depending on construction costs and gas demand patterns, below a certain nominal gas production the investment becomes uninteresting for the household.	One cubic meter of biogas daily will render 2.5 to 3.5 stove hours. This could, depending on family size, suffice for e.g. breakfast and lunch preparation, and would then provide a meaningful contribution.
Hydraulic Retention Time	The hydraulic retention time (HRT) is the period that the dung/water mix fed to the installation remains in the plant. As the fermentation process works better at higher ambient temperatures, installations in warmer climates can work with a shorter HRT and vice versa. As a longer HRT requires a larger digester volume, plants become more expensive to construct.	Typical HRTs for domestic (simple) biogas plants are 40 to 60 days for warm climates and 50 to 75 days for temperate climates.
Gas storage volume	Biogas is generated more or less continuously, but consumption in households typically takes place during 3 or 4 periods during the day. The generated gas needs to be stored in the installation.	For the gas storage volume, a fixed share of the maximum amount of daily generated gas, 60% is taken

The table summarizes the values of the main design parameters. As the aim is to develop a plant size range, the hydraulic retention time is applied as a minimum and maximum value.

Calculation examples hereunder use parameter values for a warm climate

Design parameters		Climate	
		warm	temperate
Dung / water ratio	[d/w -vol]	1.00	1.00
Specific gas production	[m^3/kg]	0.040	0.040
Minimum daily gas production	[m^3/day]	1.00	1.00
Maximum retention time	[days]	**60**	**75**
Minimum retention time	[days]	**40**	**50**
Gas storage volume	[% of max dgp]	**60%**	**50%**

7.2 Plant size range calculations

7.2.1 For the smallest plant size ("size 1") in the range:

i. The **minimum daily substrate feeding** (*min sub fee*$_1$) is equal to the minimum required gas production for the smallest installation divided by the specific gas production: *min sub fee*$_1$ = *min gas prod*$_1$ / *spec gas prod*.

Or: *min sub fee*$_1$ = 1.00 / 0.040 = 25 [kg dung day]

ii. A feeding of dung of 25 [kg dung / day] requires with a 1:1 dung to water ratio an equal amount of water. The minimum feeding (min fee1) to the plant thus arrives at 50 [ltr. / day].

iii. For the situation in which the daily feeding corresponds with the minimum feeding amount for which the plant will be designed, the hydraulic retention time is maximal (HRT max). The required digester volume (dig vol1) is equal to the hydraulic retention time multiplied by the daily feeding: dig vol1 = HRTmax x min fee1.

Or: *dig vol*$_1$ = 60 x 50 = 3,000 [ltr..]

iv. For the situation in which the daily feeding corresponds with the maximum feeding amount for which the plant will be designed, the hydraulic retention time is minimal (HRTmin). The maximum feeding (max fee2), then, equals the digester volume divided by the minimum hydraulic retention time: max fee1 = dig vol / HRTmin

Or: *max fee*$_1$ = 3,000 / 40 = 75 [ltr.../day]

v. A maximum feeding of 75 [ltr.../day], with a dung / water ratio of 1:1, then requires a maximum substrate feeding (max sub fee1) of 37.5 [kg/day].

vi The maximum gas production of this installation equals the maximum substrate feeding (max sub fee1) multiplied by the specific gas production: max gas prod1 = max sub fee1 x spec gas prod.

Or: *max gas prod*$_1$ = 37.5 x 0.040 = 1.5 [m^3 biogas/day]

vii The required gas storage volume for this plant then is 60% of the maximum daily gas production.

Or: *gas stor vol*$_1$ = 0.6 x 1.5 = 0.9 [m^3]

viii The resulting **main dimensions** of plant size 1 then are:

Digester volume: 3,00 m^3
Gas storage volume: 0.90 m^3
Total plant volume: 3.90 m^3

7.2.2 For the second smallest plant size ("size 2") in the range:

i. For a range of plant sizes, the minimum daily feeding for the next size (*min sub fee$_2$*) is equal to the maximum feeding for the next smallest installation (*max sub fee$_1$*). The minimum feeding for plant size 2 then equals 75 [ltr.../day] or, for the maximum substrate feeding (*max fee$_2$*), 37.5 [kg dung/day].

ii. The minimum gas production for size 2, consequently, is equal to the maximum gas production of size 1, and equal to the minimum feeding multiplied by the specific gas production4: min gas prod2 = min sub fee2 x spec gas prod.

Or: *min gas prod$_2$* = 37.5 x 0.040 = 1.5 [m^3 biogas/day]

ii. Similar to 2.1.ii, for the situation in which the daily feeding corresponds with the minimum feeding amount for which the plant will be designed, the hydraulic retention time is maximal (HRT max). The required digester volume (dig vol2) is equal to the maximum hydraulic retention time multiplied by the daily feeding: dig vol2 = HRTmax x min fee2.

Or: *dig vol$_2$* = 60 x 75 = 4,500 [ltr...]

iii. For the situation in which the daily feeding corresponds with the maximum feeding amount for which the plant will be designed, the hydraulic retention time is minimal (HRTmin). The maximum feeding (max fee2), then, equals the digester volume divided by the minimum hydraulic retention time: max fee2 = dig vol2 / HRTmin

Or: *max fee$_1$* = 4,500 / 40 = 112.5 [ltr../day]

This corresponds with a maximum substrate feeding (*max sub fee$_2$*) for this size of 56.25 [kg dung/day]

vi The maximum gas production of this installation equals the maximum substrate feeding (max sub fee2) multiplied by the specific gas production: max gas prod2 = max sub fee2 x spec gas prod.

Or: *max gas prod$_2$* = 56.25 x 0.040 = 2.25 [m^3 biogas/day]

vii The required gas storage volume for this plant then is 60% of the maximum daily gas production.

Or: *gas stor vol$_2$* = 0.6 x 2.25 = 1.35 [m^3]

viii The resulting main dimensions of plant size 2 then are:

Digester volume: 4,50 m^3
Gas storage volume: 1.35 m^3
Total plant volume: 5.85 m^3

4 This is an approximation; in reality a similar amount of feeding will generate slightly more biogas in a larger installation as the retention time is longer.

7.2.3 For the next plant sizes:

It will be clear that a repetition of the routine explained above will produce a range of non-overlapping plant sizes. For domestic applications, a daily gas production significantly over 5m³ will often not be consumed. Hence, larger installations would not be applicable for domestic use. Using parameter values from table 2, the tables below show the results for a warm and a temperate climate.

Plant size range warm climate					
Plant volume	[dm³]	**3900**	**5850**	**8775**	**13163**
Gas storage volume	[dm³]	900	1350	2025	3038
Digester volume	[dm³]	3000	4500	6750	10125
Min feeding	[kg/day]	25	38	56	84
Max feeding	[kg/day]	38	56	84	127
Min daily gas production	[m³/day]	1.00	1.50	2.25	3.38
Max daily gas production	[m³/day]	1.50	2.25	3.38	5.06
Avg feeding		31	47	70	105
Avg gas production		1.25	1.88	2.81	4.22

Plant size range temperate climate					
Plant volume	[dm³]	**4650**	**6975**	**10463**	**15694**
Gas storage volume	[dm³]	900	1350	2025	3038
Digester volume	[dm³]	3750	5625	8438	12656
Min feeding	[kg/day]	25	38	56	84
Max feeding	[kg/day]	38	56	84	127
Min daily gas production	[m³/day]	1.00	1.50	2.25	3.38
Max daily gas production	[m³/day]	1.50	2.25	3.38	5.06
Avg feeding		31	47	70	105
Avg gas production		1.25	1.88	2.81	4.22

8 Plant design

A simple plant design similar to the designs in Vietnam (KT), Cambodia (modified Dheenbandu) or Tanzania (modified Camartec) is used for this example.

In this hemi-spherical design, the digester volume is the volume under the lower slurry level (LSL), and the gas storage volume is the volume between the lower and higher slurry level (HSL).

For all plants with internal gas storage, the gas storage volume in the plant is equal to the volume of the compensation volume

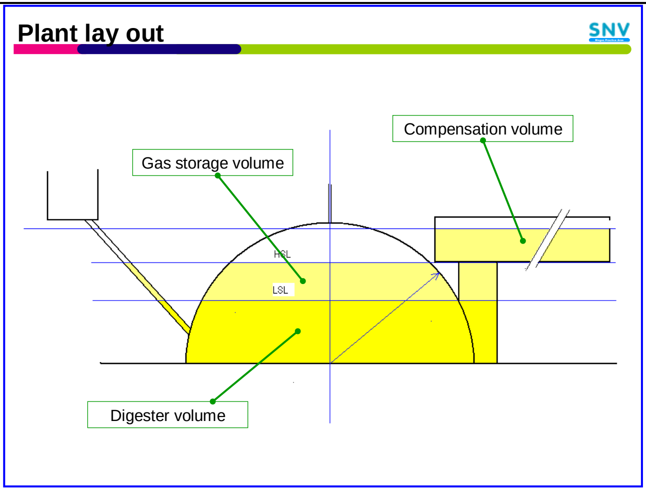
Formulas used:

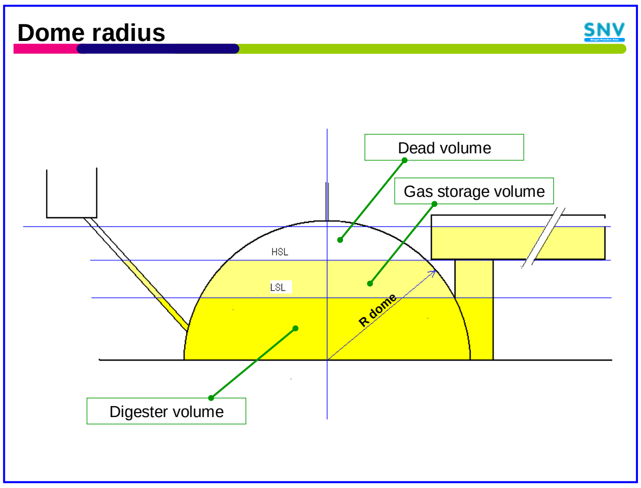
V dome = $^2/_3\ \pi\ R^3$

V cylinder = $\pi\ R^2 h$

V dome cap = $^{\pi}/_6 \times h \times (3a^2 + h^2)$

V dome segment = $^{\pi}/_6 \times (3R1^2 + 3R2^2 + h^2) \times h$





8.1 *Total plant volume*

As the plant layout pictures shows, part of the dome volume, over the higher slurry level, is not used by a well-functioning installation. The volume, often referred to as “buffer volume” is required, however, to accommodate the floating layer on top of the slurry. In addition, when gas production is less then nominal (cold seasons) or when gas is slowly leaking, the higher slurry level can rise (up to overflow level). For that reason, the total plant volume used for dimensioning should be higher than the plant size range volume results. For this example, 20% addition is allowed for this buffer volume. Hence, taking plant size 1 for the example, the total plant volume (digester + gas storage + buffer volume) arrives at 3.90 x 1.2 = 4.68 m^3.

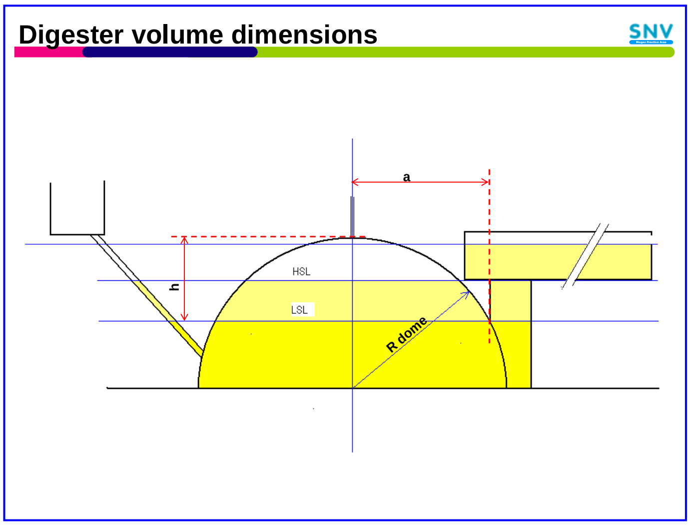
8.2 *Dome radius*

The dome radius, *R dome*, follows from: *R dome* = (*V tot* / 2/3 π)$^{1/3}$. For plant size 1, then:

$R\ dome_1 = (4.68 / {}^2/_3\ \pi)^{1/3} = 1.3$ [m]

8.3 Calculating digester volume dimensions

This calculation serves to find the upper level of the digester volume, or the height of the lower slurry level (LSL) in the dome. For this, the digester volume (calculated at 3.00 m^3 in 2.1.iii) can be seen as the total dome volume minus the volume of the "dome cap". In this way $V\ dig\ cap_1 = V\ dome_1 - V\ dig_1$.



Or: $V\ dig\ cap_1 = 4.68 - 3.00 = 1.68\ [m^3]$

To apply the formula V dome cap equals $\pi/_6 \times h \times (3a^2 + h^2)$, the dome (*R dome* = 1.3 [m]) has to be draw precisely on scale. Through "trial and error", then, you should find when *h* = 0.7 [m] *a* will be 1.16 [m],

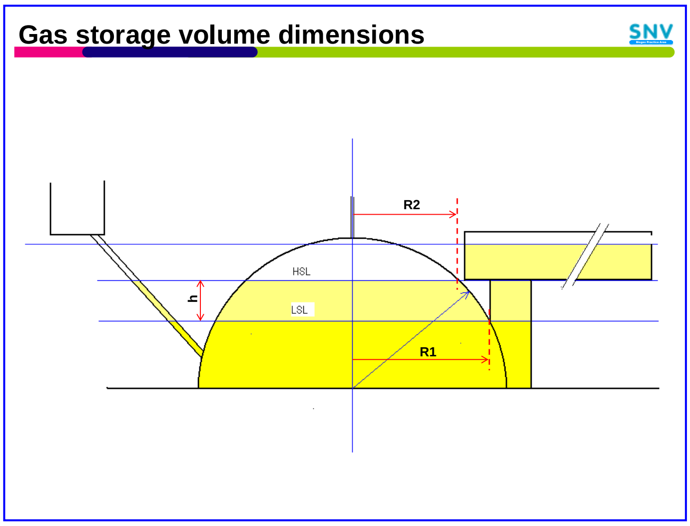
and $\underline{V\ dome\ cap_1 = \pi/_6 \times 0.7 \times (3 \times 1.16^2 + 0.7^2) = 1.66\ [m^3]}$.

The digester volume, then, results in $V\ dig_1 = Vdome_1 - Vdome\ cap_1$

$Vdig_1 = 4.68 - 1.66 = 3{,}02\ [m^3]$ which is close to the design volume of 3.00 $[m^3]$. The LSL equals $Rdome_1$ minus a_1; $LSL_1 = 1.30 - 0.70 = 0.60$ [m]

8.4 Calculating digester volume dimensions

The gas storage volume should be at least 0.90 $[m^3]$ (see 2.1.vii).



The volume of a segment of a sphere is:

$V\ segment = \pi/_6 \times (3R1^2 + 3R2^2 + h^2) \times h$

R1 is equal to *a* (from 2.3); *R1* thus equals to 1.66 [m].

To find *R2* you'll have to use the drawing again, and measure *h* and *R2* . You'll find that when h = 0.25 [m] then R2 = 0,97 [m] and

$Vseg1 = \underline{\pi/_6 \times (3 \times 1.16^2 + 3 \times 0.97^2 \times 0.25^2) \times 0.25 = 0.91\ [m^3]}$.

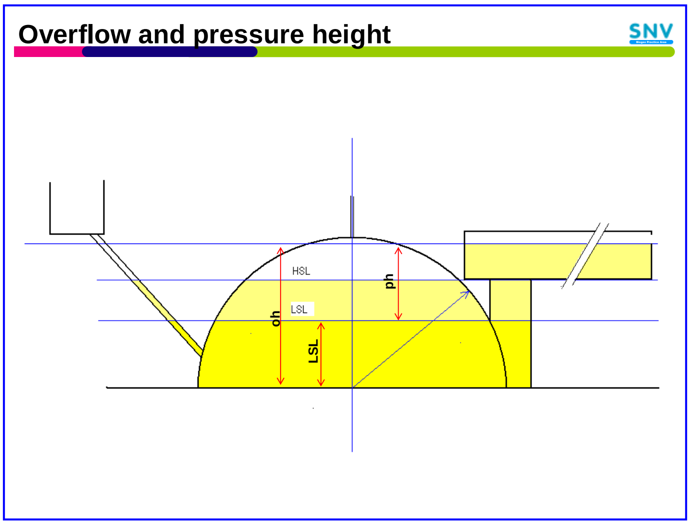
8.5 Plant dimensions

From the above follows for plant size 1 that:

R dome =	**1.30 [m]**	
LSL =	**1.30 – 0.70 =**	**0.60 [m]**
HSL =	**0.60 + 0.25 =**	**0.85 [m]**

Whereby:
The LSL is also the height of the manhole entry in the plant (beam height or, for Vietnam, outlet pipe height)
The HSL is also to floor level height of the compensation chamber.

8.6 Overflow height



The height of the overflow determines:
- the maximum pressure in the plant;
- the extent to which slurry can reach into the gas dome pipe, and;
- of course, the height determines the dimensions of the compensation chamber.

For the positioning of the overflow, there are two schools of thought:

1. The overflow should be positioned under the bottom of the dome pipe. This will avoid slurry reaching the bottom of the gas dome pipe. Slurry can reach the bottom of the dome pipe when plants are leaking gas or when, for temperature reasons or other, the gas production is significantly lower than the gas consumption over a prolonged period of time.
2. The overflow should be positioned higher than the bottom of the dome pipe. This allows a higher maximum pressure in the plant and makes the compensation chamber dimensions more economic. Slurry entering the dome pipe, then, is an indication of a mistake in the construction of the operation of the installation, and should be remedied.

In this example the overflow is placed 5 cm under the top of the dome.

Hence: <u>oh_1 = 1.30 – 0.05 = 1.25 [m]</u>.

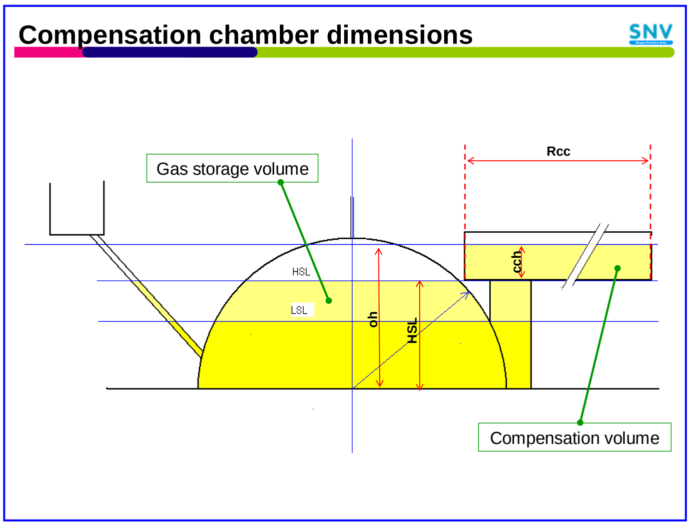
8.7 Pressure height check

The pressure height is the maximum pressure that the installation can produce. This maximum pressure is limited by the LSL; when pressure increases to the point whereby the LSL is pushed down further below the beam / outlet pipe level, biogas will escape through the compensation chamber.
As shown in the picture on the previous page, the pressure height (*ph*) is the difference between overflow height (*oh*) and LSL.

ph_1 = 1.25 - 0.60 = 0.65 [m].

8.8 Compensation chamber dimensions

The volume of the compensation chamber (*V cc*) shall be equal to the plant's gas storage volume. In case of "size 1", then, *V cc* shall be 0.9 [m^3]. Following the earlier position that the overflow level should be lower than the top of the dome, the compensation chamber height (*cch*) is the difference between the overflow height (*oh*) and the higher slurry level (*HSL*) (= compensation chamber floor level).

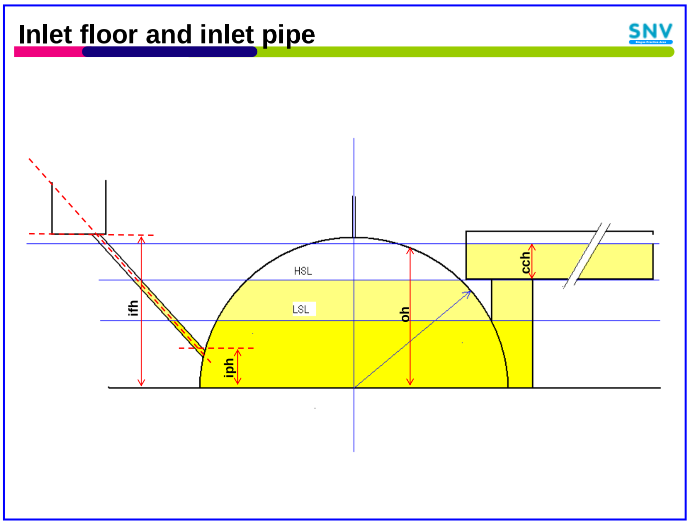


For the example size 1, the compensation chamber height then is 1.25 – 0.85 = 0.40 [m]. Assuming a cylindrical compensation chamber, the radius of the compensation chamber (*R cc*) follows from:
$R\ cc = (V\ cc / (\pi \times cch))^{1/2}$.

Or: $\underline{R\ cc_1 = (0.90 / (\pi \times 0.40))^{1/2} = 0.84\ [m]}$

8.9 Inlet floor and inlet pipe

To avoid reflux, the inlet floor height (*ifh*) should be higher than the overflow height (*oh*). For the example for plant size 1, *ifh* is 0.15 [m] higher than *oh*.



To avoid biogas escaping through the inlet pipe (toilet connection!), the top of the inlet entering the dome should be below the *LSL*. At the same time the inlet pipe height (*iph*) should not be too close to digester floor to prevent obstruction by debris. Typically, the *iph* should be about 0.30 [m] above the digester floor.

Finally, the inlet / pipe layout should allow entering a long stick in case of inlet pipe blockage.

9 Mass dissemination Programmes – The SNV Experience

For the past two decades, SNV 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.

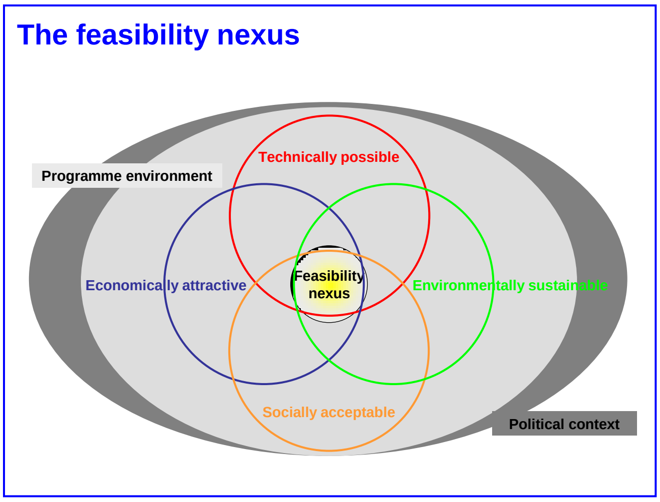
Taking the key question "What is the secret of the successful biogas programmes, and what is SNV doing to achieve this?" as its point of departure, five features are identified, and their challenges, of the approach:

- 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.

9.1 Thorough, participatory and context-specific preparation

("P5: Proper Preparation Prevents Poor Performance")



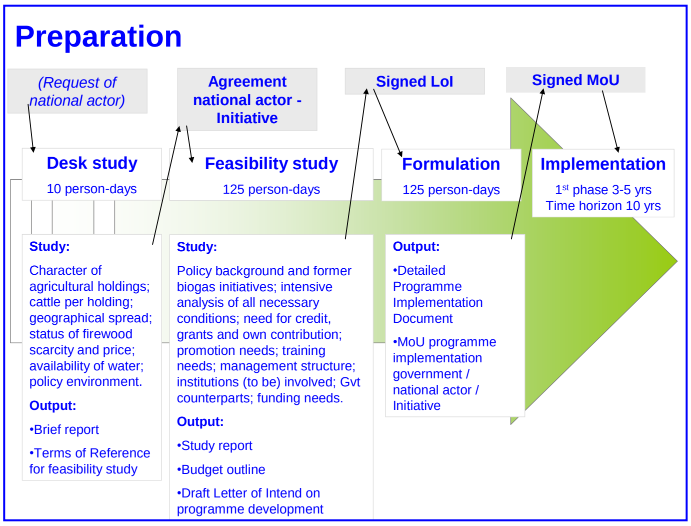
Although Nepal, Vietnam, Cambodia, Bangladesh, Pakistan, Indonesia, Bhutan and Lao PDR are all Asian countries, they show significant differences in their technical, economic, social / cultural, environmental and political make-up. A national biogas programme needs to fit this country-specific environment 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 three to five years- within an overall planning horizon of ten years.

Actual implementation will only take place after financial arrangements (increasingly including a carbon component) and organisational issues have been settled. Between desk study and implementation start easily one to two years can pass.

> *Example 1:*
> In 2005, 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.

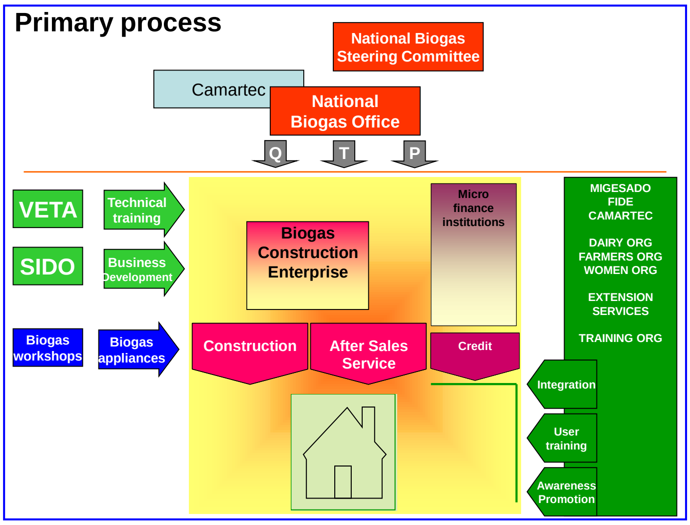
9.2 *Sustainable sector as the ultimate, long-term objective*

("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)5. 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.

5 ODA does not refer to carbon funds to be mobilised for the financing of national programmes on domestic biogas

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 cannot 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.

Example 2:
In Nepal, sector development has been on the agenda of the Biogas Support Programme (BSP) since its start in 1992. It took not less than two years to open the market for other constructors and lenders than Gobar Gas Company (GGC) respectively Agricultural Development Bank/Nepal (ADB/N). The establishment of the apex body, the Alternative Energy Promotion Centre (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 Government of Nepal (GoN) has been increasing its contribution to the programme and a start was made with self-financing through Clean Development Mechanism (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 Netherlands Ministry of Foreign Affairs (DGIS) since 1992, the German Development Bank (KfW) and the GoN since 1997. SNV played a very active role in advocating this support to the programme.

9.3 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.

> *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 than reacting directly on the market developments. To improve the performance of the Biogas Construction Teams, the Vietnam Biogas Programme developed a comprehensive “commercialisation component” to the programme, aiming to improve business and marketing skills of the construction teams.

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 & evaluation and quality control) of the SNV-supported national programmes in Asia and Africa. 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).

9.4 *Promoting the market-oriented approach*

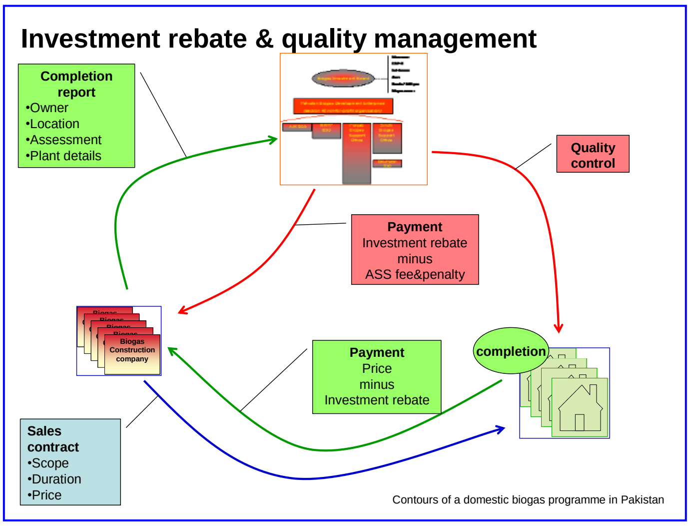
(“The customer is always right”)

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,



Contours of a domestic biogas programme in Pakistan biogas programmes create leverage on quality whereby a "carrot and stick" approach supports development towards a mature sector.

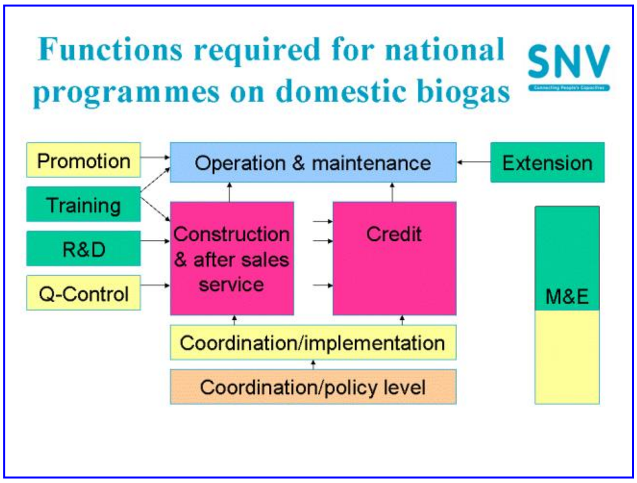
The *challenge* of this feature is striking the right balance between market-driven and programme enforced quality management. Although, eventually, the market will drive towards products with the highest user-satisfaction, actors operating in a *marginal market* may not have (the luxury of) a long-term 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 Programme 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.

9.5 Multiple functions, multiple actors

("Let the cobbler stick to his last")



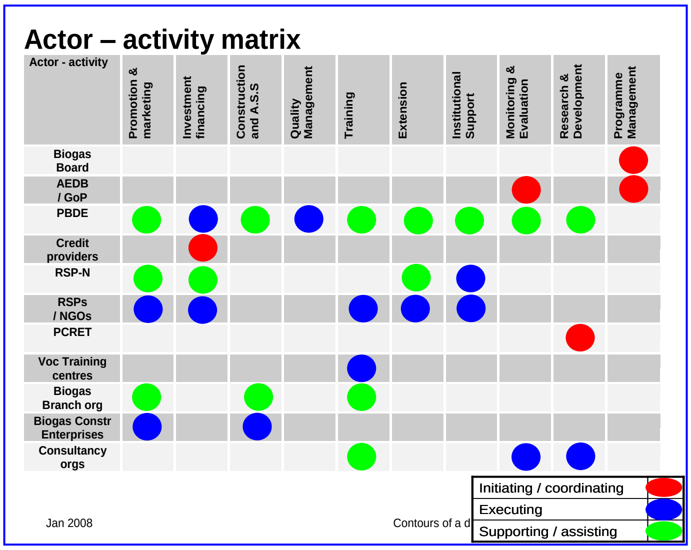
National biogas programmes require a wide range of functions to be executed in a comprehensive and coordinated manner. Examples of such functions are promotion and marketing, financing, construction & after sales, operation & maintenance, quality control, training & extension, research & development,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

9.6 Concluding observations

Building viable domestic biogas programmes revolves 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[6]. 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 might be another hidden aspect in SNV's approach. Within SNV's Biogas Practice Team, many advisors have been with the organisation for a 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.

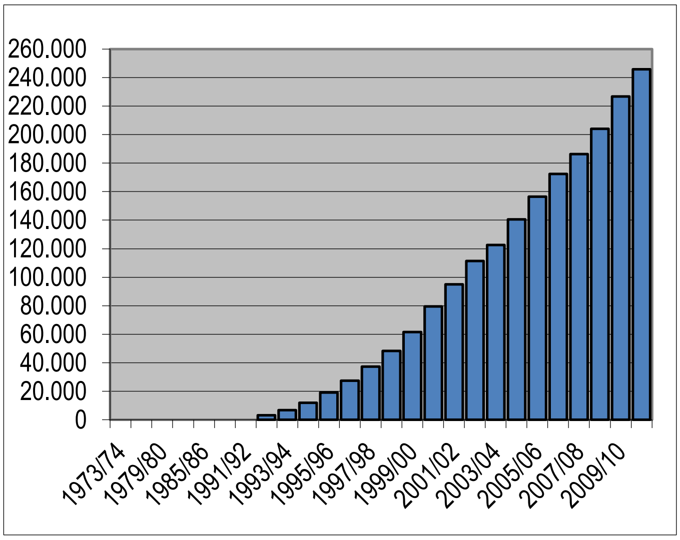
6 As a carbon component to biogas programmes would typically require performance verification, carbon components could improve the programmatic and technical sustainability of biogas programmes as well.

9.7 *The Biogas Support Programme in Nepal*

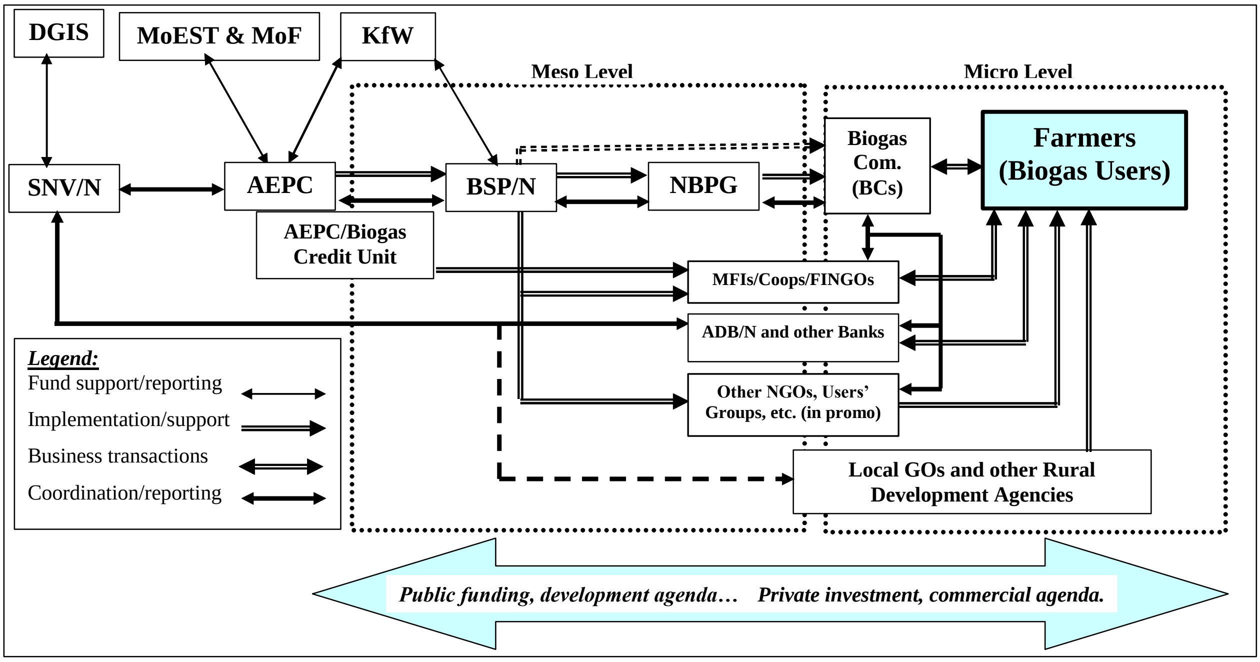
With financial support from the Netherlands Directorate-General for International Cooperation (DGIS), the Biogas Support Programme (BSP) in Nepal was started in 1992. At the time of its initiation, there was basically only one, state-owned, company, the Gobar Gas Company (GGC), producing and servicing 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 mid-2012, over 265,000 units have been installed throughout the country (see graph: cumulative number of biogas plants installed in Nepal over the period 1973/74 up to 2010/11).

Also the biogas sector has made significant developments, as:



- Approximately 85 qualified private companies by the end of 2011 install biogas plants throughout the country;
- Appliances are manufactured by some 17 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 Government of Nepal (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.



9.7.1 Programme objectives

The Netherlands Development Organisation (SNV) is assisting at the moment eight Asian countries (Nepal, Vietnam, Cambodia, Bangladesh, Lao PDR, Pakistan, Indonesia and Bhutan);eight African countries (Ethiopia, Kenya, Rwanda, Tanzania, Uganda, Burkina Faso, Cameroon and Benin) and two Central American countries (Honduras and Nicaragua) 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.

9.8 Feasibility studies

After the 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° C throughout the year. The biological process in a domestic biogas digester is temperature dependent. The optimum digester temperature is 35°C, below 15°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 1:1ratio

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, as then they spend less time on fuel collection, cooking and cleaning of cooking utensils. 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:

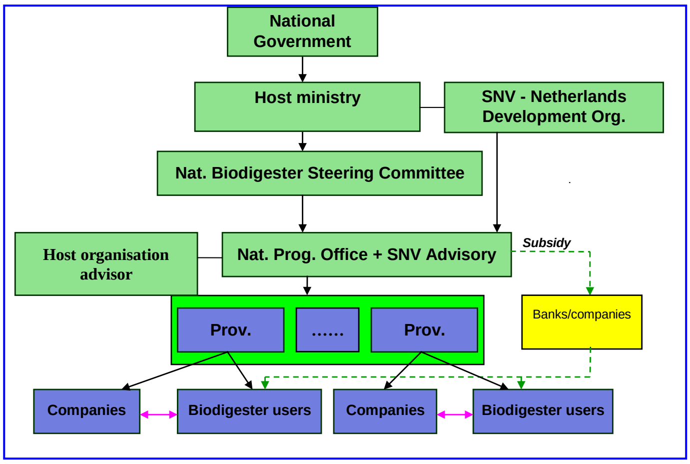
- Political will from the Government to support a national biogas programme. Preferably a Governmental institution should act as a national coordinating body for the programme and governmental extension services should be involved in promotion and on farm training. An important document here can be the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

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

9.9 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.



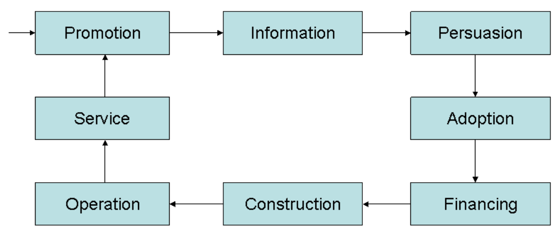
The overall programme will be guided and monitored by a national programme steering committee. The chart below shows a typical set-up.

9.10 Programme activities

9.10.1 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 six phases:.



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

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 gender
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 economic 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).

9.10.2 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.

9.10.3 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 two parts, a ten day training at a centrally located Biodigester Technical Training Centre and forty days (the time required to complete at least two 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 one 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 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 (e.g. 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, whenever opportune, contracted to appropriate institutes like polytechnics, NGOs and consulting firms.

9.10.4 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 database 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.

9.10.5 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 (Research & Development) 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 of Terms of References (ToRs) elaborated by the national programme office and programme proposals by the above mentioned parties.

9.10.6 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 fuel wood;
- 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.

9.10.7 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.

9.10.8 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 outsourced. The supervision is usually done by a National Steering Committee, chaired by an appointee of the host organisation.

SNV in usually provides technical assistance to the programme in the form of one or more biodigester advisor(s). Other advisors (e.g. CDM, business development, financial affairs) will be deployed on a temporary basis if the need arises, often via Local Capacity Building Organisations.

10 Financial analysis

Financial analysis and capital budgeting are normally associated with large companies rather than with individuals in developing countries. For such a household a digester is however a very large investment, therefore it is useful to know how the investment will financially impact the household.

The required calculations may seem complex but software such as excel enables people without a financial background to easily perform these calculations. In this chapter the basics of capital budgeting and its application for domestic biogas digesters are described.

Costs and benefits

In order to calculate the financial impact of any investment, basic information is required about the costs and the benefits of an investment. In the case of biogas digesters the costs and benefits are the following:

Costs

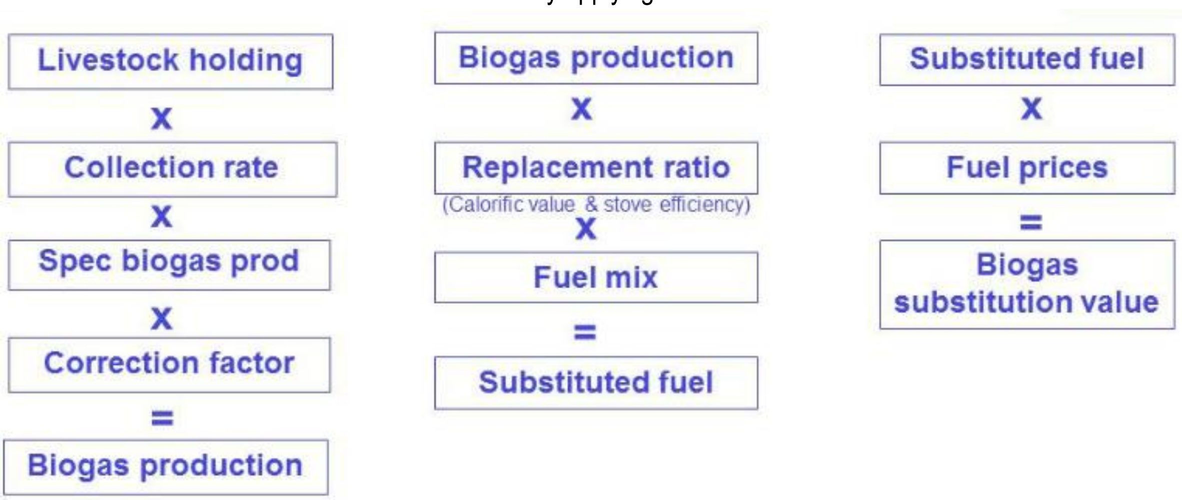
- Investment costs: these consist of the materials required for constructing the biogas plant and the labour costs associated with the construction of the plant. The costs of appliances that are required in order to use the biogas should also be taken into account.
- Maintenance costs: costs associated with keeping the plant in operation.
- Interest: cost of capital

Benefits

In most cases biogas is not sold in the market but used by the household, thereby replacing various fuels that would otherwise have to be purchased. The use of bio slurry may result in savings on chemical fertilizer and pesticides or in additional income due to increased crop yields. Biogas may also result in time savings associated with fuel collection, cooking time and cleaning cooking utensils. Finally biogas reduces indoor air pollution related diseases. All of these benefits could be given a monetary value. Before any of the capital budgeting instruments can be applied this information needs to be collected, unfortunately this is often quite a challenging task. At least the value of the biogas that is generated should be taken into account; this can be done by calculating the biogas substitution value.

Biogas substitution value

The purpose of this calculation is to find out how much fuels are displaced by the biogas that is generated and how much this fuel would have cost. This can be done by applying the calculation below



<u>*Livestock holding:*</u> amount of animals that the household has (and associated manure production)
<u>*Collection rate:*</u> How much of the manure is collected and inputted into the biogas digester
<u>*Specific biogas production:*</u> the maximum biogas production for a given amount of specific manure
<u>*Correction factor:*</u> the maximum biogas production may not always be reached. This could be due to an unfavourable retention time or ambient temperature.
<u>*Biogas production:*</u> the amount of biogas that can be produced with this manure if a suitable biogas plant is constructed

Replacement ratio: the amount of fuel that biogas will replace, this is dependent on the efficiency of the stove that is used and the calorific value of the fuel.
Fuel mix: the percentage of each of the fuels that is used by the household
Substituted fuel: fuel that has been substituted by biogas
Fuel prices: prices of fuel in local market
Biogas substitution value: the value of fuel that has been substituted by biogas

Capital budgeting instruments

There are various capital budgeting instruments which could be used to make investment decisions, three will be described here: simple payback period, net present value and the internal rate of return. Each tool has its advantages and disadvantages.

Simple payback period[7]: this is the simplest method of the three. It calculates how long it will take before a certain investment is earned back.

Payback period = Initial investment/cash inflow per period.

The advantage of this calculation is that it is simple and therefore suitable for the context in which domestic biogas digesters are sold.
The simple payback period unfortunately doesn't take the time value of money into account and also doesn't inform about the actual revenue that the investment will yield (as cash flows after the payback period are not taken into account).

Net present value

The NPV method calculates the present value of (future) cash flows minus the initial investment.

The NPV formula incorporates two additional concepts; the time value of money and the discount rate.
Time value of money: Money that is at your disposal today has a higher value than money that you will receive in the future (due to its potential earning capacity).

- Discount rate: interest rate (or cost of acquiring capital)

The formula for the net present value is as follows[8]:

$$\text{NPV} = \text{R} \times \frac{1 - (1 + \text{i})^{-\text{n}}}{\text{i}} - \text{Initial Investment}$$

Where **R** is the cash inflow expected in each period, **i** is the discount rate, **n** is the amount of periods in which the project is expected to operate and have cash flows.

If the result of the NPV calculation is positive the investment should be made, as the investment will result in a profit to the investor.

Advantages: the NPV takes the time value of money into account and therefore gives a clear indication of the financial impact of the investment.
Disadvantages: it is quite a complicated calculation which may limit its use in convincing a rural household in a developing country. Another downside of this method is that it makes use of estimations of future cash flows that in practice are difficult to assess.

7 http://accountingexplained.com/managerial/capital-budgeting/payback-period

8 http://accountingexplained.com/managerial/capital-budgeting/npv

Internal rate of return

Internal rate of return (IRR) is the discount rate at which the net present value of an investment becomes zero.

This will give the investor information how much return he/she would receive on his investment. If the IRR is larger than the cost of capital (to the investor) the investment will result in a profit. The formula for the IRR is as follows[9]:

$$\left[\frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \frac{CF_3}{(1+r)^3} + \dots\right] - \text{Initial Investment} = 0$$

In this formula **r** is the internal rate of return, **CFn** represents the cash flow in different time periods.

The advantage of this method is that it results in a percentage which is easily comparable between different investment decisions; it is often used in addition to the NPV method. This method has the same disadvantages as the NPV.

The NPV and IRR formulas may seem complicated and laborious and therefore may scare people away from using them. The three methods are explained with a simplified biogas digester example to show that it is not very difficult to calculate them with the help of an excel spreadsheet.

Example

A specific biogas digester costs €500 to build (including labour and construction material). Each year the biogas digester will result in €210 in savings/revenues per year, maintenance costs are €10/year. The household could take a loan at the local bank at an interest rate of 15% if it wants to invest in the biogas plant. We assume the lifetime of this biogas plant to be 10 years (in reality the lifetime of a biogas plant may be up to 20 years). At the end of the lifetime of this biogas plant it cannot be sold and therefore the salvage value is 0.

Simple payback period:

Payback period = Initial investment/cash inflow per period: 500/(210-10)=2,5

It will take the household 2.5 years to earn back the investment.

NPV:

We will use excel to calculate the NPV value.

D2 | =NPV(B2/1,A6:A15)+A5

	A	B	C	D	E
1	Net present value of a digester				
2	Discount rate	15%	NPV	€ 503.75	
3					
4	Cash flows	period			
5	-500	0			
6	200	1			
7	200	2			
8	200	3			
9	200	4			
10	200	5			
11	200	6			
12	200	7			
13	200	8			
14	200	9			
15	200	10			

We list all of the data as was given in the example, the discount rate and all the cash flows: the investment of €500 and ten times the expected income (210-10=200). The formula that is used for the NPV is listed on the top right of the picture. As can be seen this results in a NPV of €503,75. This means that at a discount rate of 15% the decision to invest in a biogas plant for this household will result in a profit of €503,75.

9 http://accountingexplained.com/managerial/capital-budgeting/irr

Internal rate of return

D3 | f_x =IRR(A5:A15)

	A	B	C	D
1	Net present value and internal rate of return of a digester			
2	Discount rate	15%	NPV	€ 503.75
3			IRR	38%
4	Cash flows	period		
5	-500	0		
6	200	1		
7	200	2		
8	200	3		
9	200	4		
10	200	5		
11	200	6		
12	200	7		
13	200	8		
14	200	9		
15	200	10		

We can use the same excel sheet in order to calculate the Internal rate of return for the digester in this example. The formula that is used is indicated in the formula bar. Investing in this digester results in an annual return of 38% for the household because this is considerably higher than the interest that needs to be paid on the loan (15%).

Economic vs. Financial

Costs and revenues may be valued differently between an individual investor and society as a whole.

		Costs	Benefits
Financial	Household	Investment at subsidized rate Repair and maintenance Time for plant operation Financing	Fuel savings Time savings Fertilizer value (?) Avoided health expenses
Economic	Society	Full investment Repair and maintenance Time for plant operation Financing Subsidy Programme support	Fuel savings Time savings Fertilizer value Local employment generation Avoided health expenses GHG reduction Environment improvement

Costs and benefits that apply to the investor are considered to be financial, costs and benefits that apply to society are considered to be economic. In case the economic benefits are larger than the economic costs it could be worthwhile for society to promote the adoption of biogas through subsidies.

Besides capturing economic benefits subsidies also have other functions:

- 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), especially in the case of a low NPV and IRR.

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.

11 Carbon Finance, standards and approaches

11.1 Introduction to Carbon finance, the compliance market

Carbon finance is revenue obtained from trade in certified emission reductions. Most of the emission reductions are traded on the compliance market under the Kyoto Protocol. The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) is an international treaty that sets binding obligations on industrialised countries to reduce emissions of greenhouse gases. The UNFCCC is an environmental treaty with the goal of preventing "dangerous" anthropogenic (i.e., human-induced) interference of the climate system.

Under the protocol countries (Parties) that signed the treaty have committed themselves to reduce emissions whereas emissions from developing countries are allowed to grow according to their development needs. This is an important principle under the Protocol, the so called '*common but differentiated responsibility principle'*.

Under the Protocol three "flexibility mechanisms" were identified that can be used by developed countries (Annex I Parties) to trade their emission limitation commitments. One of the mechanisms of interest to the biogas sector is the Clean Development Mechanism (CDM). CDM allows Annex I parties (developed countries that ratified the Protocol) to meet their emission reduction obligation by investing in emission reducing projects in developing countries in return for Certified Emission Reductions and thereby assisting the developing country with sustainable development. Through this principle biodigester programmes could obtain carbon finance by trading the emission reductions realised by the dissemination of biodigesters.

The second commitment period for Protocol, lasting from 2013-2020, is approved by COP18 in Doha. Countries with emission reduction commitments can continue to trade CERs under the Protocol, these countries are at time of writing limited to the EU and its accession countries. Other countries, like Japan and Canada have stepped out of the Protocol.

11.1.1 Carbon Standards and Markets

In parallel to the CDM a number of other carbon standards and markets have materialized, the ones applicable for domestic biodigesters are the Voluntary Gold Standard (VGS) and the Voluntary Carbon Standard (VCS). CDM is a compliance based offset standard under the Kyoto Protocol managed by the UNFCCC whereas the VGS and VCS are voluntary carbon standards. The main market for carbon credits from CDM is the European Trading Scheme (EU-ETS) which was put in place by the EU as one of the flexible mechanisms in order to meet its Kyoto emission reduction target. CDM creates carbon credits, called Certified Emission Reductions (CERs) through emission reduction projects in developing countries. Emitters in the EU who have exceeded their emission allocations can purchase these CERs to make up the difference.

Credits from the voluntary market are sold to entities (companies, individuals or others) that volunteer to offset their emissions by purchasing carbon credits that reduce the amount of carbon in the atmosphere. It is driven by a company's desire to demonstrate leadership and/or '*do the right thing*' and by responsible citizens who wish to limit the impact of their high carbon lifestyle. The next table shows the basic characteristics of the aforementioned standards.

TABLE 1: MAIN CARBON STANDARDS

Carbon standard	CDM	VGS	VCS
Market	Compliance	Voluntary	Voluntary
Trading volume 2010 and 2011 ($MtCO_2e$)	1,664* 1,734*	6.8 8.5	23 44
# Project registered	6,640	136	965
Offset (eq. to 1 tCO_2e)	Certified Emission reduction (CER)	Gold Standard Voluntary Emission reduction (GS-VER)	Voluntary emission reduction (VER)
Methodologies for ER assessment	CDM	CDM & VGS	CDM and VCS
Average offset price 2011[10]	$7[11]	$10	$5
# registered domestic biogas projects	18 (CDM) and 2 PoA**	11	0

**traded on the ECX (European Climate Exchange)*

*** A PoA is a single administrative umbrella under which an unlimited number of component project activities across a country or region can be registered*

The Gold Standard has many advantageous over the VCS, such as a higher credit values and suitable methodologies for domestic biogas. The VCS is for that reason not further discussed in this chapter.

Under each of the selected standards, a number of approaches are possible with each of them having specific advantages and disadvantages. The main approaches and their thresholds are listed in the table hereunder, which are: micro scale, small scale, large scale and programmatic.

TABLE 2: APPLICABLE APPROACHES UNDER CDM AND VOLUNTARY GOLD STANDARD

Scale/approach	CDM	VGS
Micro Scale (MS)	Activities up to 15 MWth combined. Project cycle is per SSC procedure.	Activities up to 10,000 VERs.
Small scale (SSC)	Activities up to 45 MWth combined	Same as for CDM
Large Scale (LS)	No limit on the project size and mandatory use of large scale methodologies which are not applicable to domestic biogas	No limit. Under the VGS large scale domestic biogas projects are possible using VGS methodologies
Programmatic (P)	A bundle of project activities of micro, small or large scale, which can cover multiple countries	Same as with CDM

Gold Standard CDM

A combination of the GS and the CDM is also possible, which is especially interesting for projects that have a clear and unambiguous impact on sustainable development as is the case with domestic biogas. In that case the project will follow all the CDM rules and procedures for the emission reduction certification and will on top of that develop two separated documents, the Gold Standard Passport and a Local Stakeholder Report for the Gold Standard certification. Credits are then labelled GS-CER and often fetch prime value on the carbon market. It is estimated that the price range for credits originating from least developed countries will fetch 5 to 8 euro[12] compared to a record low

[10] Ecosystem Marketplace & Bloomberg New Energy Finance, State of the Voluntary Carbon Market 2012.
[11]CDM prices have plummeted since 2011, the current spot price is around $0.35/CER
[12]Estimation by HIVOS March 2013

CER price of €0.34/CER on the ECX currently. The CER market has essentially collapsed and under these circumstances CDM without GS certification is not an option.

11.2 Introduction to the carbon project cycle

The development of a carbon project starts with a feasibility study. If the outcome of the study is positive and there is sufficient confidence on the viability and capacity to develop a carbon project, the project will enter the project carbon cycle. The carbon cycle can be categorized in two phases (1) the preparation phase in which the project is designed and (2) the implementation phase or the crediting period. The next figure shows these two periods/phases of the CDM project and introduces a number of documents and responsible parties involved, which are hereunder explained in detail, including the additional requirement in case one opts for the Gold Standards (in combination with or without the CDM).

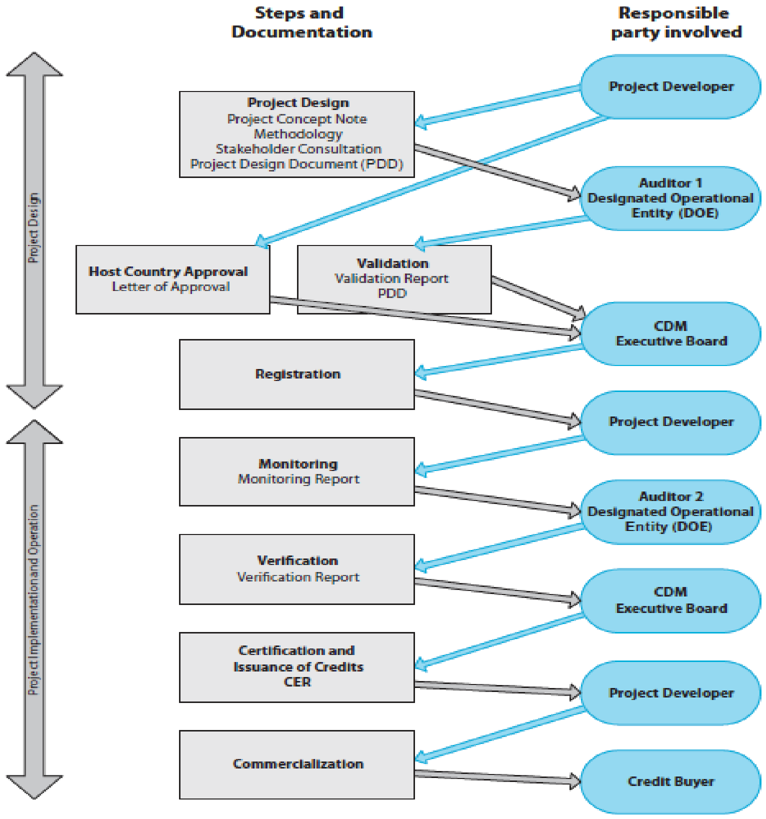


FIGURE 11: CDM PROJECT CYCLE

The figure shows the CDM project cycle, the project cycle for Voluntary Gold Standard (VGS) is essentially the same except that the cycle is not governed by the CDM EB but by the Gold Standard. In addition, a few extra reports have to be developed in parallel to the carbon cycle, the Gold Standard Passport and the Local Stakeholder consultation report. In these reports the GS focusses on sustainable development and 'do-no-harm' issues.

11.2.1 The preparation phase

This phase entails all the activities from formulation of a project concept, baseline and feasibility study document preparation to approval and registration by the United Nations Framework Convention on Climate Change (UNFCCC) CDM Executive Board or the Gold Standard Foundation in case of VGS.

a. Development of a PIN or Project Concept Note

In this Project Identification Note (PIN), the initial concept of a carbon activity is developed. The PIN is a primary document prepared and submitted for the purposes of confirmation of the planned carbon project to the investor (carbon buyer) and the Designated National Authority (DNA). The PIN will serve as a mechanism of introduction of the project to the relevant environmental authorities on both local and central level and will gauge the interest of carbon buyers in the project.

In the case of CDM, feedback from the DNA is required on the PIN. Often a specific format is not required by the DNA, a summary of the project is sufficient. If the DNA does not foresee any issues, a letter of no objection (LONO) will be issued.

b. Prior notification to the CDM Executive Board (EB) and DNA

Project participants must inform the host party DNA and the CDM EB on the commencement of the project activity and the intention to seek CDM status. The notification is a submission of a standardized form (F-CDM-Prior Consideration) that includes the precise geographical location and a brief description of the project activity (EB 49 annex 22). It is advisable to submit this form as early as possible, possibly even before the development of PIN. This stage is also relevant to the VGS as it will serve as a credible evidence of prior consideration.

c.1 Development of a PDD and stakeholder consultation

The Project Design Document (PDD) is the key document involved in the validation and registration of a CDM project activity. A PDD contains a general description of the project, the application of the used methodology, proof that the project is additional, detailed information of the GHG reduction potential and a summary of the mandatory stakeholder consultation. The stakeholder consultation consists of target participants that may be affected by the project activities. In the case of the VGS or GS-CDM a separate stakeholder report shall be developed, the local stakeholder consultation report (LSCR). This is a structured report with strict guidelines and contains a public consultation round and a feedback round. Mandatory topics to be discussed include sustainable development and a do-no-harm assessment as per participant's impression[13].

c.2 Gold Standard passport

In case the project seeks registration as a VGS project or as a GS-CDM project, the development of an additional document is required, the Gold Standard Passport Report (GSPR). The GSPR contains the outcome and summary of the GS-LSCR, a sustainability assessment and a sustainable development monitoring plan and the do no harm assessment. More on the SD assessment can be found here http://www.cdmgoldstandard.org/wp-content/uploads/2012/05/v2.2_ANNEX-H.pdf and more on the do no harm assessment here http://www.cdmgoldstandard.org/wp-content/uploads/2012/05/v2.2_ANNEX-H.pdf.

d. Approval by Designated National Authority

The role of the DNA is to provide the letter of approval to project participants in CDM projects. This letter of approval (LoA) must confirm that the project activity contributes to sustainable development in the host country. The issuing of a LoA can be a real hurdle as the DNA often requires consultation with other government bodies or stakeholders involved in the project. In case of VGS, it is only required to notify the DNA that the project is taking place, approval is not required.

e. Validation through a Designated Operational Entity

Independent evaluation and validation of the project activities is executed by a contracted accredited third party, a Designated Operational Entity (DOE). A DOE will perform a technical check to establish whether administrative and legal procedures are followed correctly, the correct methodologies are applied, documentation on the environmental impacts of the projects, the letter of approval, comments received during the stakeholder consultation and if the targeted emission reductions are realistic. The DOE will perform an on-site visit as part of this process. In the case of CDM, the DOE publishes the PDD on the UNFCCC website for public display, the Global Stakeholder Process (GSP). During that period, which is 30 days, Parties, stakeholders and UNFCCC accredited observes may make comments. In case the DOE determines that the proposed project activity is valid, it will request the CDM Executive Board or the GS secretariat to register the project. Review of the Gold Standard documents, LSCR and the GSPP are also part of the review in case of VGS or the GS certification of a CDM project (GS-CDM)

[13] More on the LSC can be found here http://www.cdmgoldstandard.org/wp-content/uploads/2012/05/v2.2_ANNEX-Q.doc

f. Registration with the CDM Executive Board of the UNFCCC or GS secretariat

The validated PDD is subsequently submitted to the CDM Executive Board (EB) or GS for registration. In the case of CDM, this starts with a completeness check. In case issues are identified or in case the CDM EB doubts the validation report, it will instruct the Registration and Issuance Team (RIT) to perform a review. In such a case, it is only after RIT clearance that the project will be registered by the CDM EB. The crediting period starts upon registration. In the case of GS, the project is reviewed (PDD, LSCR and GSPP) for a fixed period of 8 weeks and often results in one or more rounds with comments. When these comments are closed satisfactory, the crediting period starts.

11.2.2 Implementation Phase

This phase entails all the activities from the project performance verification and issuance of the certified emission reductions (CERs) or voluntary emission reductions in the case of VGS.

a. Implementation and execution the monitoring activities

In this step a project performance check is executed by the implementation of the monitoring system according to the monitoring methodology described in the PDD and the GSPP (in case of GS). The outcome of the monitoring activities is the ex-post estimation of the emission reductions (ERs) based on the project performance. The outcome of this process is a monitoring report to be verified by a DOE.

b. Verification through a DOE

Verification is the process of confirming the authenticity of emissions reduction over a defined period of time (a verification period), and the SD benefits in case of the GS, by a DOE, which includes a side-visit. The outcome of this process is a verification report by the DOE and includes a description of how the verification methodology stipulated in the PDD was applied.

c. Certification

Certification is essentially the formal written confirmation by an independent auditor (being a different designated operational entity that did the validation) that the emission reductions which are set out in the verification report were actually achieved (and the SD benefits in case of GS). Certification is a written assurance confirming that the achieved reductions in greenhouse gas (GHG) emissions during a specific period (usually the verification period preceding certification); and the activities are performed by a DOE.

d. Issuance

Issuance of Certified Emission Reductions (CERs) refers to the creation of CERs which correspond to Greenhouse Gas (GHG) emission reductions or GHG removals, equivalent to 1 ton of CO2 equivalent (tCO2e), resulting from the carbon project activity. In case the CDM EB doubts the validity of the verification report submitted by the DOE, it will instruct the Registration and Issuance Team (RIT) to perform a review. After clearance by the RIT, the Executive Board will instruct the administrator of the CDM Register to issue the specified quantity of CERs.

In case of the GS, also the SD monitoring results are reviewed as per GSPR. The GS will review the verification of the DOE and the monitoring report for a fixed period of 3 weeks. That process may result in 1 or more rounds of comments. Once these comments are closed satisfactory the credits are issued. This review will also take place in case of a combination with the CDM, but in that case on only on the SD part and local stakeholder feedback.

11.2.2.1 General Market Eligibility

The first step in carbon project identification is to ascertain whether the project is eligible under the CDM and if it will receive host country support. Considering that the CDM and other carbon market rules are still evolving, a conservative approach should be taken when assessing the eligibility. The main eligibility requirements are:

1. Participation requirements;
   a) The host country is a Party in the Kyoto Protocol (KP);
   b) The host country has a Designated National Authority (DNA);
2. The project is additional;
3. The project results in real and measurable emission reductions;
4. The project is participating in a voluntarily project activity;
5. The project does not result in ODA diversion;
6. The project results in sustainable development.

11.2.2.2 Additionality

Additionality is a key concept in carbon finance. A project can be considered additional if it can be demonstrated that in absence of carbon finance the project would not have been implemented or would not have reached the same level of adoption.

Demonstration of additionality is not required for a number of project activities that are on the positive list of Annex 27 CDM EB meeting 67. Domestic Biogas, falling in the category of renewable energy to households, is on this positive list provided that the capacity of the individual biodigester is less than 5% of the small scale (SSC) CDM threshold of 45 MWth, 5% of this limit is 101.25 kWth.

The threshold of 101.25 kWth equals to 1128 m^3 biogas per day, assuming 5 hours of cooking per day and with a Net Calorific value (NCV) of biogas of 0.0359 GJ/m^3 this equals roughly 1128 m^3 biogas[14] per day. Domestic biodigesters go normally not over a volume of 10 m^3 and with a maximum feeding of 200 kilo (assuming dilution 1:1 and HRT of 25 days). The maximum biogas production from 200 kilo manure is around 8 m^3/day (assuming 40 litre biogas/kg manure).

Domestic biodigesters fall well below the 5% SSC threshold and therefore this activity is considered automatically additional as per EB67 Annex 27. Any further demonstration of additionality is thus not required.

11.2.3 The project results in real and measurable emission reductions

Three main pathways of emission reductions identified are:

1. Fuel switch from non-renewable fuels used for cooking and lighting to biogas;
2. Methane emission avoidance from animal waste management systems (AWMS) by capturing and destroying methane for an thermal energy service;
3. The displacement of chemical fertilizers by bio-slurry: The production of chemical fertilizers is energy intensive and the application to the soil result in GHG emissions such as N_2O.

The next figure illustrates this graphically:

[14] From SSC AMS-I.E version 5.0

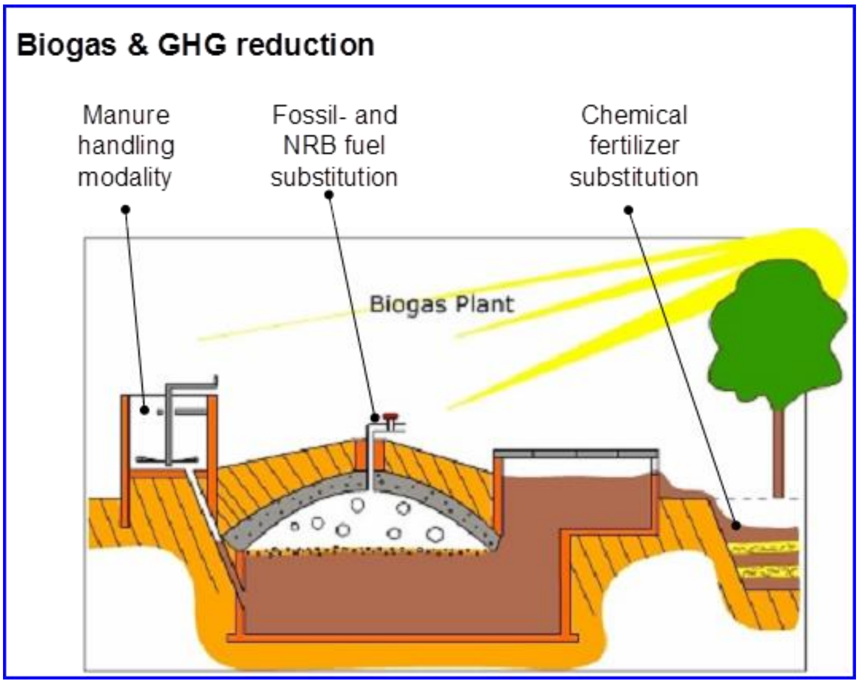


FIGURE 2: PATHWAYS OF GHG EMISSION

11.2.4 The project does not result in ODA diversion

The project developer has to declare that public funding of a CDM project has not and will result in the diversion of official development assistance (ODA); a disclosure on the nature of the public funding from Annex-I countries is required for that. In such a declaration, the project developer should be able to demonstrate that the funding of a CDM project is not counted towards the financial obligations of any donor to the country hosting the CDM project. When using public financing, the developer/operator should list any sources of Annex-I government funding committed to the project, or sources that the developer is, or is considering applying for. The CDM project validator (a DOE) will then assess whether these funding sources have been diverted from previous commitments under the official development assistance programs and/or whether such funding sources are listed as a financial obligation.

11.2.5 The project is undertaken voluntarily

The project developer has to show that the activity is voluntarily undertaken; not because of a specific law or regulation, and that other (less desired) alternatives exists. A non-voluntary activity would, for instance be governmental regulation stating that farms should treat their waste in a biodigester. The project developer has to provide evidence for this, by for example, supplying a copy the relevant legislation on a particular issue to the DOE, if requested.

The project results in sustainable development

CDM stipulates that emission reducing projects must assist developing countries in meeting their own sustainable development goals, which is the core objective of CDM next to emission reductions. It is up to each party to determine whether a particular project activity contributes to sustainable development (Article 12 of CDM).
Therefore a biodigester programme has to demonstrate to the DNA that it helps the nation with sustainable development. Suitable indicators for this are, but not limited to, increase in soil fertility due to application of bio-slurry, reduced deforestation due to decreased wood demand, reduction in indoor air pollution etc. A substantiation of these positive impacts are required for the application of the letter of approval (LoA).
Demonstration of sustainable development is different in the case of the Gold Standard. The Gold Standard has developed a specific document for this, the so called Gold Standard Passport which includes not only an assessment of the impact but also a Sustainable Development (SD) monitoring plan[15]. This is also necessary when CDM is combined with GS.

[15] Relevant rules on SD assessment can be found here http://www.cdmgoldstandard.org/project-certification/rules-and-toolkit

Demonstrating SD should not be difficult for domestic biogas. A number of projects have shown that domestic biodigester project results in tangible benefits at various levels, from household scale to a national scale.

11.3 Emission Reductions

11.3.1 Methodologies

Under the CDM simplified baseline and monitoring methodologies have been developed for type I (renewable energy project), type II (energy efficiency projects) and type III (other projects). Biodigester programmes are usually both a type I project category C (thermal energy for the user) and type III category M (methane recovery). Approved Methodologies for Small scale (AMS) that are applicable to type I category C and type III category M biodigester projects are[16]:

1. AMS-I.E: Switch from non-renewable biomass for thermal applications by the user;
2. AMS-I.I: Biogas/biomass thermal applications for households/small users;
3. AMS-III.R: Methane recovery in agricultural activities at household/small farm level.

Each methodology has specific applicability conditions, and is listed here:

TABLE 3: BASIC CHARACTERISTICS OF THE APPLICABLE METHODOLOGIES[17]

Methodology	AMS-I.E	AMS-I.I	AMS-III.R
Project activity	Generation of thermal energy by introducing renewable energy technologies for end users that displace the use of non-renewable biomass.	Activities for generation of renewable thermal energy using renewable biomass or biogas for use in residential, commercial and institutional applications	Recovery and destruction of methane from manure and wastes from agricultural activities through: Installation of a methane recovery and combustion system to an existing source of methane emissions;
Type of GHG emission mitigation Action	Displacement of more-GHG-intensive, non-renewable biomass-fuelled applications by introducing renewable energy technologies.	Displacement of more-GHG-intensive thermal energy generation by introducing renewable energy technologies.	Destruction of methane and displacement of a more-GHG-intensive energy generation
Important conditions	Demonstrate that NRB was used since 1989; Project appliances are continuously in operation; Determine share of NRB.	Each unit shall have a rated capacity equal or less than 150 kW thermal.	Limited to measures at individual households or small farms Sludge should be handled aerobically All methane collected should be destroyed.
Important parameters	Biennial check of the project appliances; Monitoring of quantity of biomass saved; Assessment of NRB used by non-project households who previously used renewable energy;	Number of biodigester commissioned Proportion that remain in operation in year y Annual consumption of fossil fuel in the baseline and project	As with AMS-I.I + Annual average animal population; Amount of waste/animal manure generated on the farm and the amount of waste fed in to biodigester; Proper soil application of the final sludge (e.g. not resulting in methane emissions)

[16]*Large scale methodologies are not considered as these are not applicable or too complicated for decentralized energy projects.*

[17] *From the CDM methodology booklet, available online on http://cdm.unfccc.int/methodologies/documentation/1211/CDM-Methodology-Booklet_fullversion_PART_4_low.pdf*

GS Methodology
The Gold Standard had developed a methodology for decentralized energy projects including biodigester projects: Technologies and practices to displace decentralized thermal energy consumption (TPDDTEC)[18]. This methodology is applicable to programs or activities introducing technologies and/or practices that reduce or displace greenhouse gas (GHG) emissions from the thermal energy consumption of households and non-domestic premises, like biodigesters. The main conditions of this methodology are much alike the CDM methodologies and therefore not discussed in detail.

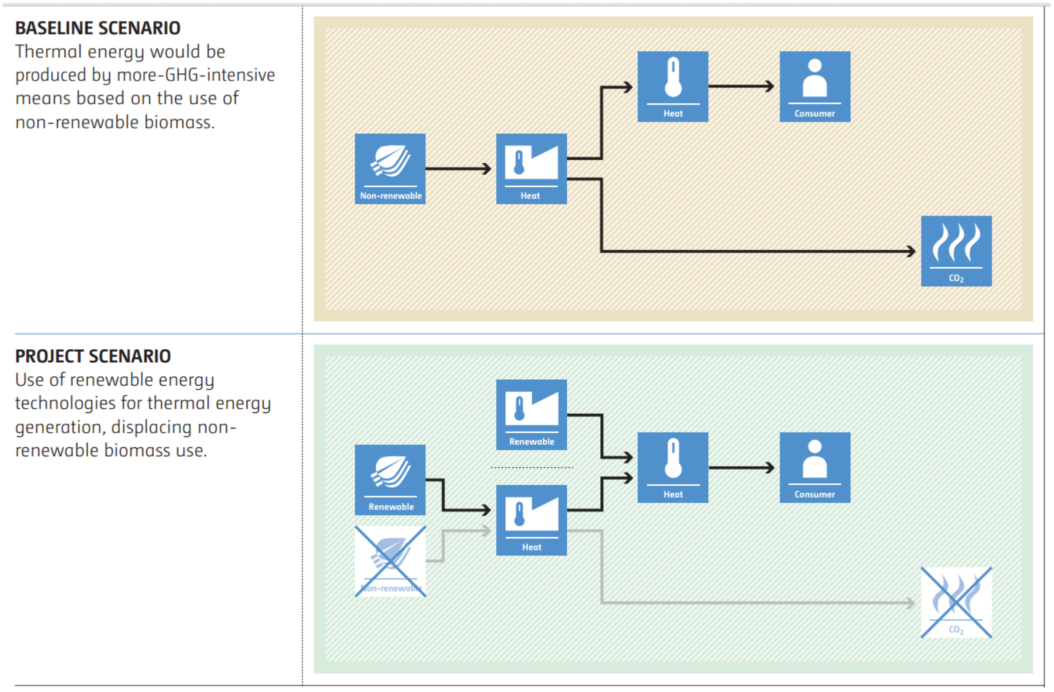
All the methodologies mentioned are applicable to domestic biodigester activities and will be considered in the next sections.

Identified Project scenario
The project scenario is the situation after the installation of a number of biodigesters. Biogas is mostly used for cooking activities and for lighting. However, the fuel displacement potential of lighting fuel is very low and therefore this emission reductions source is often excluded, this is conservative. The identified project scenario is therefore biogas used for cooking and thereby reducing the amount of wood fuel used otherwise.

Manure is treated in the biodigester, which is the project scenario of manure management.

Methodologies
The methodology suitable for the project and baseline scenario is AMS-I.E: Switch from non-renewable biomass for thermal applications by the user and AMS-III.R. As usually fuel wood is used and there is no fossil fuel component in the baseline, AMS-I.I is not applicable. In case VGS without CDM is chosen, the suitable methodology is TPDDTEC.

The next 2 figures show the baseline and project as per generic description of AMS-I.E and AMS-III.R.



[18]http://www.cdmgoldstandard.org/wp-content/uploads/2011/10/GS_110411_TPDDTEC_Methodology.pdf

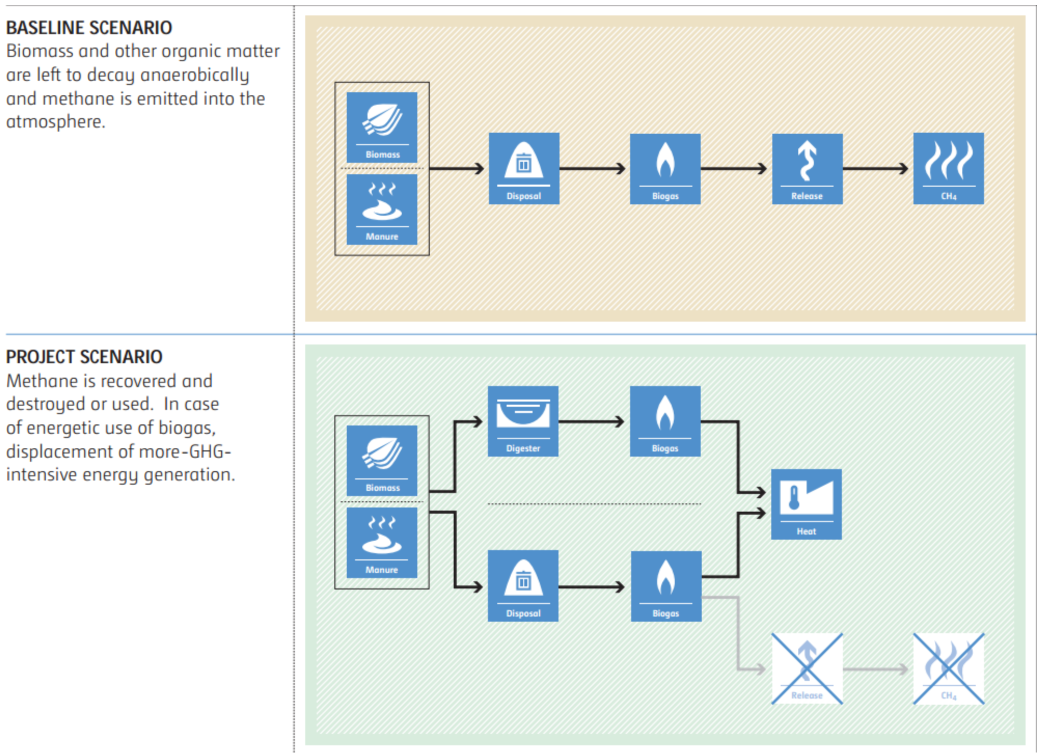


FIGURE 3: BASELINE AND PROJECT SCENARIO OF AMS-I.E (TOP) AND AMS-III.R

Excluded emission sources and leakage

Biogas is also used for lighting. Fuel saved by the switch to biogas lamps is however minimal and therefore usually not included in the baseline scenario in order to be conservative.

Leakage emissions are additional and unintentional emission sources caused by the project activities. The following leakage emission sources are included:

- Physical leakage emission from the biodigester (10%, AMS-III.R default value)
- Incomplete combustion of biogas (0.6%[19] of total biogas production and is only estimated when applying the GS methodology, TPDDTEC)

AMS-I.E specifies that projects that save non-renewable biomass (NRB) may make NRB more available to households that are using renewable energy at the moment. It shall be demonstrated that this does not happen using survey methods or alternatively a default fraction of 95% shall be applied.

Eligible GHGs included in the assessment

Emission sources and gases eligible and included in the project boundary are listed in the next table. Also the global warming potentials of the GHGs are included in that table.

TABLE 4: TYPE OF GHG INCLUDED IN THE METHODOLOGIES AND THEIR GWP

GHG/methodology	CO_2	CH_4	N_2O
AMS-I.E	Yes	No	No
AMS-III.R	No	Yes	No
TPPDEC	Yes	Yes for both fuel and AWMS related emissions	
GWP	1	25	298

[19] http://www.snvworld.org/sites/www.snvworld.org/files/publications/efficiency_measurement_of_biogas_kerosene_and_lpg_stoves_nepal_2001.pdf

The VGS methodology, TPDDTEC, includes GHGs with a high Global Warming Potential (GWP) from fuel use and therefore the baseline emission will be higher compared to the CDM methodologies. The project emissions however are also a bit higher as emission from incomplete combustion of biogas and bio-slurry[20] is included.

11.4 Carbon Standards

11.4.1 Applicability of approaches

The next figure shows which approaches can be considered under the CDM and the Voluntary Gold Standard

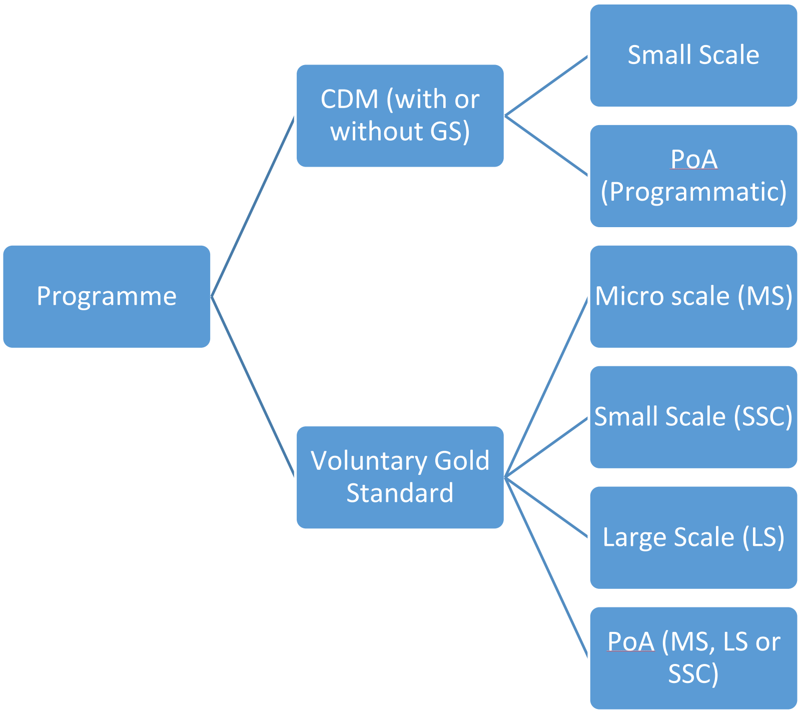


FIGURE 4: APPLICABLE CDM AND VGS APPROACHES

The table describes the details of each approach. Hereunder it is studied how the specific thresholds of the approaches relate to the PNB project in Burkina Faso.

TABLE 5: TRESHOLDS OF THE APPROACHES

Market/scale	CDM	VGS
Micro scale	Not applicable	10,000 VERs or around 2,000 units at 5 VERs/unit[21]
Small scale (SSC)	A bundle of 45 MWth or around 15,000 units[22]	A bundle of 45 MWth or around 15,000 units
Large scale (LS)	Not applicable	Unlimited bundle size
Programmatic micro scale	Not applicable	10,000 VERs or around 2,000 units at 5 VERs/unit per project activity
Programmatic small scale	As with SSC but an unlimited number of CPA can be added	Same as CDM
Programmatic large scale	Not applicable	As with large scale

[20]*Emissions from bio-slurry however are not mentioned in the methodology. It is likely that the GS requests a PP to include this as similar projects, i.e. GS751 and GS 1083 (NBP Cambodia and BP Vietnam) had to include these emissions*

[21]Depends on the methodology applied, with the regular approach of CDM AMS-I.E + AMS-III.R this would be around 3,300 units and with TPPDEC around 1,700 units

[22]Estimated average thermal output is 3 kWth of one unit

The table shows that a micro scale project or a micro scale project activity under a PoA can only bundle 2,000 units. National biodigester programmes are projected to build several thousand units per year. Developing a new micro scale project or adding one under a PoA every few months is not really feasible due to costs and time associated with that, furthermore, managing many micro scale projects would administratively be very challenging. Micro scale VGS is therefore not considered to be suitable for larger programmes.

11.4.2 Credit value

There are three types of credits that can be considered:

1. CERs from CDM
2. GS-CER, CDM and GS certification
3. VERs from VGS

1. CERs
The value of carbon credits are governed by demand and supply. The value of CDM CERs have decreased substantially in value since 2011 due to the financial crisis resulting in a dramatic decrease in demand for CERs. The price has been further depressed by an increase in supply of CERs. The next figure shows the OTC CER price development from 2008 to the end of 2012.

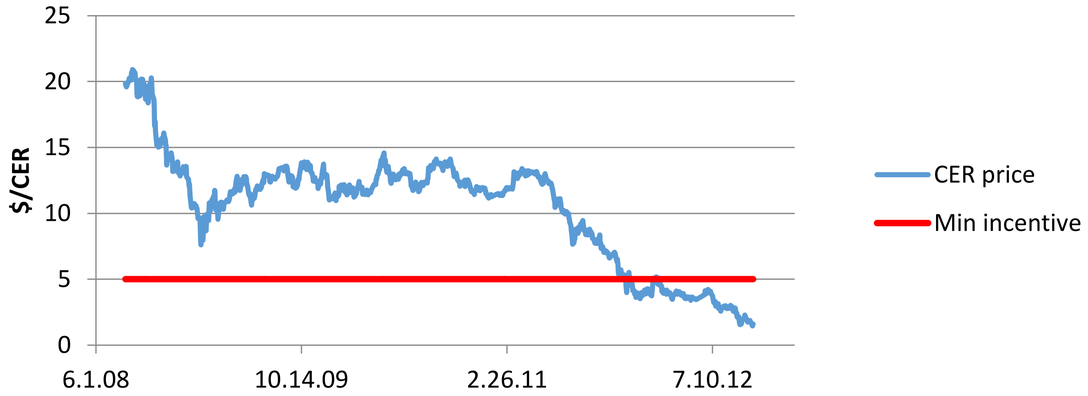


FIGURE 2: OTC CER PRICE DEVELOPMENT

A figure often quoted is that the minimum incentive required for a renewable energy project is $5/CER. The current CER price, of around $0.34, is far too low for any project to consider CDM. It is even projected that until 2020 the demand for CERs will remain lower than the supply of *currently registered* project[23], and will consequently only worsen when new projects are registered. Some 'sovereign buyers' like the Swedish Energy Agency, KfW from Germany and multilateral organisations like the WB, continue supporting the CDM market with above market price offers to purchase CERs, at least until the end of the Second Kyoto commitment of 2020.

2. GS-CER and GS-VER
Gold Standard certified credits, both compliance and voluntary, still fetch relatively high prices and it is expected by HIVOS that credits from Burkina Faso will fetch 5 to 8 euro per credit. GS-CERs can be sold both on the voluntary and on the compliance market.

Developing a project that results in credits that can access both markets can be advantageous as the CER market is much larger than the GS-VER market. In addition, the EU is considering in intervening in the EU-ETS and backload a number of credits with the objective to increase prices[24]. As CER market is a political market, political intervention, whether by the EU or by ratification of a post-Kyoto protocol can results in CER price recovery.

[23] *IGES policy report 2012. Towards the CDM 2.0. Lessons from the capacity building in Asia*
[24] Intervention in the EU-ETS is being discussed at the moment http://carbonmarketwatch.org/short-fix-to-the-ailing-ets-what-next-for-the-worlds-largest-carbon-market/

Another argument for having access to both market are concerns that the GS-VER market may see a decrease in prices due to a rapid growth in VER issuances. This is due to:

(1) the huge number of projects that are in the pipeline seeking registration and verification,

(2) project switching from CERs to GS-VER and mammoth VER issuances.

For example, in 2012 the Vestergaard Frandsen Lifestraw Gold Standard project[25] was issued 1.4 million GS-VERs that were produced in only 6 months, or the Biogas Programme of Vietnam which in February 2012 produced 0.5 million VERs over a period of 1.5 years[26]. These two projects combined comprise almost 25% of the GS-VER market in 2011. In summary, supply is rapidly increasing and it is questionable if demand will keep up.

Lifestraw

11.4.3 Methodologies and emission reductions

During the past few years the CDM-EB has made great efforts to help projects in underrepresented regions to gain access to CDM by introducing standardized baselines (SB). Many methodologies have an SB option and choosing for that option often implies that it is not necessary to execute elaborative surveys and this simplifies the process significantly. A pitfall is that the SBs are often more conservative than the value that would have been obtained by executing a survey. This is a trade-off for the decrease in complexity and development costs.

For the VGS methodology SB is applicable. TPPDEC in contrast, does not have the SB provision and is, compared to the regular method of the CDM methodologies, much more complicated. The monitoring requirements are also substantially higher due the large number of surveys required:

1. **Annual usage survey**
   Consisting of 30 randomly sampled households of each year of technology installed (after 10 years that means 300 households);
2. **Biennial kitchen performance test:**
   On a biennial interval starting with the first verification the PP shall monitor baseline fuel consumption and project fuel consumption for a recommended period of 3 days. The estimated required sample size is around 50 baseline and 50 project households[27].
3. **Annual user survey**
   This survey includes user characteristics, type of fuel used, and manure management. The minimal sample size is 100 households based on an ex-ante calculated confidence/prevision level of 90/10.

These three surveys are difficult to combine due to their different sampling requirements and are therefore likely to be executed separately. The usage survey for example is cluster sampling, while for the later 2 only simple random sampling shall be used, unless a statistician is included and added for review by the DOE. Other projects that tried to propose cluster sampling faced some impossible demands from the GS. In Cambodia for example, the GS accepted cluster sampling for the KPT provided that the clusters are selected based on a confidence/precision interval of 90/10. That meant surveying 44 districts out of a population of 120 which is much more demanding that simple random sampling.

The national Biodigester Programme of Cambodia and of Vietnam have experience significant difficulties with TPPDEC and that has led to increased survey costs for baseline establishment and monitoring.

[25]http://www.vestergaard-frandsen.com/carbon-for-water/how-it-works.html

[26]http://www.snvworld.org/en/vietnam/news/first-vietnamese-gold-standard-project-celebrates-its-first-issuance-of-vers

[27]*NBP Cambodia recently executed a KPT, based on ex-post significant calculations a sample size of 30 would have been sufficient.* ***Nevertheless****, it is good sampling practice to include extra households.*

In general the higher the monitoring requirements, the higher the emission reductions and therefore it can be argued that the higher monitoring costs can be a good trade-off for the higher emission reductions. The next table compares this:

TABLE 6: MONITORING REQUIREMENTS AND EMISISON REDUCTIONS

Methodology	Monitoring requirements	Emission reductions in Burkina Faso
TPPDEC	Very high	5.75
AMS-I.E + AMS-III.R	High	3.05
SB AMS-I.E + SB AMS-III.R	Low	4.98

There is a clear trade-off between monitoring requirements and emission reductions. However, that only applies to the SB option and TPPDEC. The standard approach of AMS-I.E and AMS-III.R do not yield in high emission reductions despite the relatively high monitoring requirements.

The ER difference between the SB and TPPDEC is low while the monitoring requirements of TPPDEC are substantially differ. In addition, additionality is automatic with SSC methodologies while the TPPDEC for large scale projects still requires the execution of an additionality assessment. Although it is expected that additionality is warranted, it will increase the workload and costs. There is no clear cut recommendation possible here, but CDM SB is probably more interesting due to the lower monitoring requirements.

11.4.4 Crediting of units

Applying for carbon finance is a long and tedious process. The next map illustrates the project cycle and the steps in entails from identification to issuance of carbon credits. The GS certification is taken as example as all the considered options are either VGS or GS with CDM. The CDM process will follow a similar parallel path.

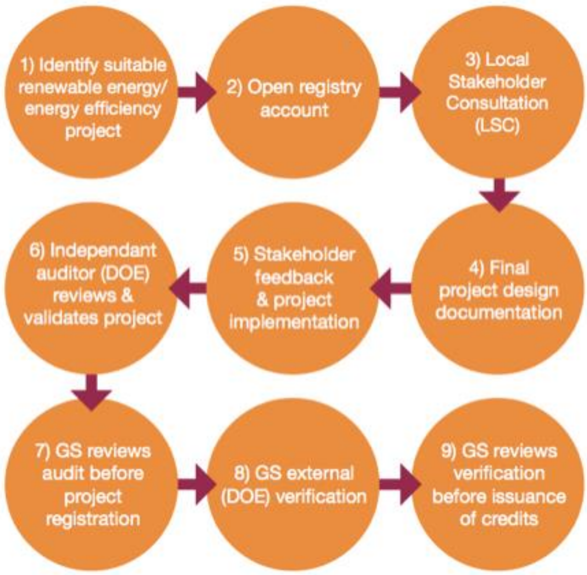


FIGURE 6: GOLD STANDARD CERTIFICATION PROCESS

The period from identification (1) to issuance varies (9) typically varies between 1.5 year to 2.5 years.

In a GS-CDM PoA only units can be included that are built after the global stakeholder consultation (GSC), that is the moment when the DOE publishes the project documents on the UNFCCC website for commenting (in step 6). The start date of the crediting period however is the moment when the project is registered or included in the PoA.

The VGS is more flexible in this respect and units can be included from the start of the project and crediting from the moment that the project is registered. Next to the regular projects cycle it is also possible to apply for the retroactive project cycle under the VGS, in that case crediting could start 2 years prior to registration. Applying for the retroactive crediting period is only possible after successful completion of the mandatory pre-feasibility assessment (PFA). The GS charges a fee for this of $0.10 per annual average VER over the first crediting period (CP).

The next table details the differences between the standards in terms of unit inclusion in the carbon project.

TABLE 7: UNITS THAT CAN BE INCLUDED IN GS-CDM OR VOLUNTARY GOLD STANDARD

Option	**Units included**	**Start date CP (regular)**	**Retroactive CP**
GS-CDM PoA	All units from GSC	From registration or CPA inclusion	Not possible
VGS LS or VGS PoA	All from the start of project	From registration or CPA inclusion	Up to 2 year prior to registration after successful completion of the PFA

In conclusion, with CDM only units can be crediting after registration and units can be included after the GSC. VGS allows for retroactive crediting and the inclusion of all units, i.e. also the first ones built by a programme.

11.4.5 Financial analysis of the options

The next table shows the carbon finance options and the estimated development costs at mid-2013
These costs are excluding the in-house cost and the possible hiring of a carbon consultant.

TABLE 8: CARBON FINANCE OPTIONS CONSIDERED

Market	**Compliance market**	**Gold Standard**	
Remaining approaches	GS-CDM PoA	VGS SSC PoA retroactive	VGS LS
Methodology	SB	SB	TPPDEC
Validation	$35,000 (PoA + 1CPA)	$25,000 (PoA + 1CPA)	$25,000
Validation development costs	$35,000	$35,000	$20,000
Inclusion new project activity*	$15,000 + $10,000 development costs	$15,000 + $10,000 development costs	N/A
Monitoring (annual)	$20,000 1CPA and $30,000 with 2 CPAs	$20,000 1CPA and $30,000 with 2 CPAs	$25,000
Verification	As above	As above	$20,000
GS registration fee**	$0.10/CER	$0.30/VER	$0.30/VER
Share of proceeds*	1.5%	2%	2%
Share of proceeds issuance fee	None	$0.05/VER	$0.05/VER
Issuance fee	$0.10/CER	$0.30/VER	$0.30/VER
Credit price***	$6.5	$6.5	$6.5
ER	4.98	4.98	5.75

** Only applicable to GS certification, the fee is waived by the CDM EB for LDCs*
*** applies to the first 12 months of ERs*
**** Based on low estimate of 5 euro of HIVOS*

11.5 Work plan

Carbon readiness

Administratively a programme must also be fully prepared for carbon finance. The following issues require specific attention:

- Unique user identification: At the household is must be possible to uniquely identify the biodigester. This decreases the risk that units are double counted. A paper trail of the most important documents, i.e. warrantee certificate, sales contract should be available at the households.
- Project database. With the use of an it must be possible to extract data w.r.t. plant population and ownership, size, construction date, construction company, etc.
- User manual. Whereas this is not required for carbon, it is advisable to ensure proper use of digester and to maximize the benefits that arise from it
- Quality control procedures have to be formalized and standardized in a transparent way.
- Operation ratio. Digesters not in operation will reduce the emission claims. Therefore a good digester monitoring system has to be in place, e.g. via annual user surveys, to be able to act on digesters out of operation for technical reasons.
- Communication: Development of a website. Visibility of the programme internationally is important when it comes to credit sales. It is advisable to build an attractive website for donors and carbon buyers, not a website with only technical information. A good example of a website that 'speaks' is: http://www.proyectomirador.org/. One of the reasons that improved cook stove project receive high carbon prices is that are good at selling their story, that is often not the case with biodigester programmes.

Decide on the most appropriate carbon approach and select a consultant

Carbon finance is an expert field and therefore programmes usually recruit a company or consultant with hands-on experience with CDM and GS.

The registration process

See the next figure:

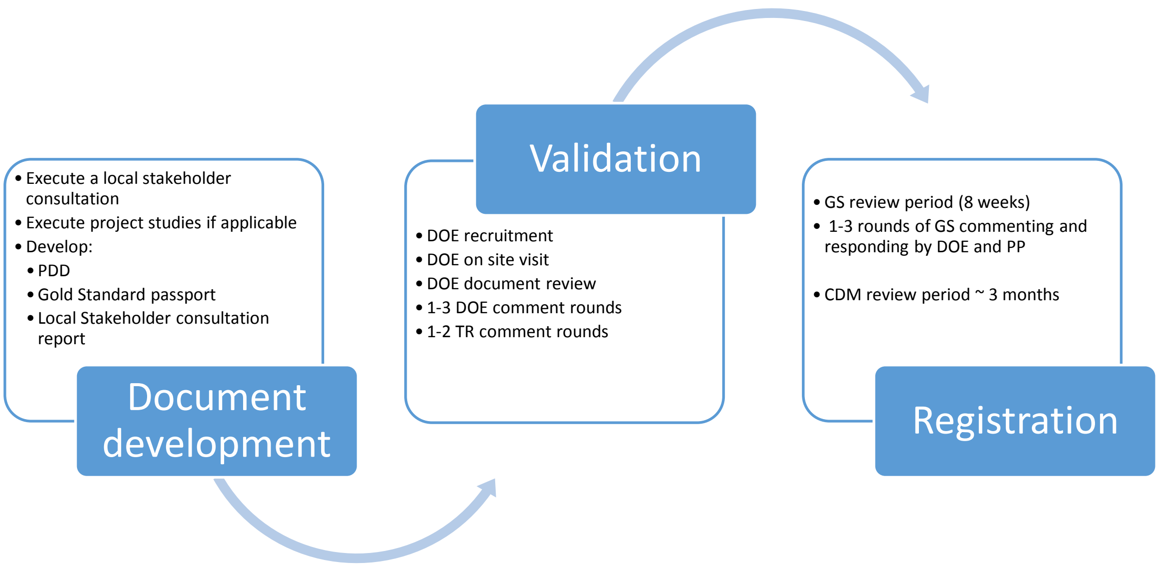


Figure 7: Registration process (preparation phase)

After this process, that can take 1 to 2 years, the issuance process would start. In the case of retroactive crediting these processes can take place in parallel.

4. Issuance process

The issuance process is listed in the next figure:

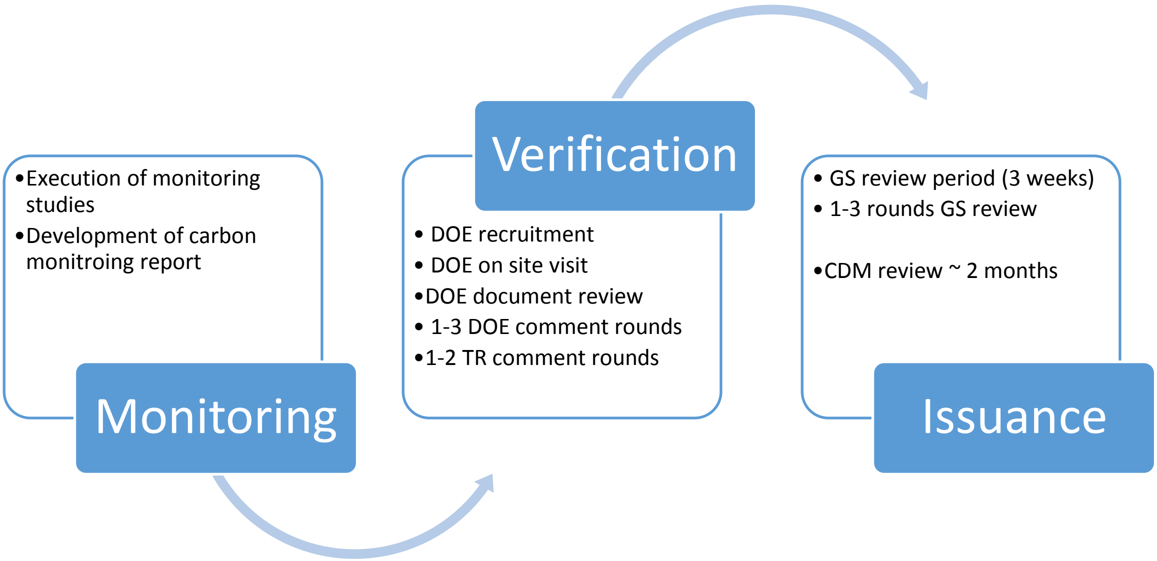


Figure 8: Issuance process (implementation phase)

The activities required for this process all depend on the chosen approach. In general it starts with the monitoring activities, which are then reviewed by the DOE. After DOE certification the documents are reviewed by the GS (sustainable development monitoring) and the CDM for the CDM part.