
Biogas
Application

Balancing Biogas Production and Energy Demand

Determining the biogas production

The quantity, quality and type of biomass available for use in the biogas plant constitutes the basic factor of biogas generation. The biogas incidence can and should also be calculated according to different methods applied in parallel.

- Measuring the biomass availability
- Determining the biomass supply via pertinent-literature data
- Determining the biomass supply via regional reference data
- Determining biomass supply via user survey

It should be kept in mind that the various methods of calculation can yield quite disparate results that not only require averaging by the planner, but which are also subject to seasonal variation.

The biomass supply should be divided into two categories:

1. quick and easy to procure
2. procurement difficult, involving a substantial amount of extra work

Measuring the biomass availability (quantities of excrement and

green substrate)

This is a time-consuming, cumbersome approach, but it is also a necessary means of adapting values from pertinent literature to unknown regions. The method is rather inaccurate if no total-solids measuring is included. Direct measurement can only provide indication of seasonal or fodder-related variance if sufficiently long series of measurements are conducted.

Determining the biomass supply via literature data

According to this method, the biomass supply can be determined at once on the basis of the livestock inventory. Data concerning how much manure is produced by different species and per liveweight of the livestock unit are preferable.

Dung yield = liveweight number of animals specific quantity of excrements [kg/d]

Often, specific quantities of excrement are given in % of liveweight per day, in the form of moist mass, total solids content or volatile solids content

Determining the biomass supply via regional reference data

This approach leads to relatively accurate information, as long as other biogas plants are already in operation within the area in question.

Determining biomass availability via user survey

This approach is necessary if green matter is to be included as substrate.

Determining the energy demand

The energy demand of any given farm is equal to the sum of all present and future consumption situations, i.e. cooking, lighting, cooling, power generation etc. The following table helps to collect all data concerning the energy demand. To get more information about the specific energy demand, for example, see "Biogas appliances".

Table: Outline for determining biogas demand		
Energy consumers	**Data**	**Biogas demand [l/d]**

1. Gas for cooking Number of persons Number of meals Present energy consumption Present source of energy Gas demand per person and meal Gas demand per meal Anticipated gas demand Specific consumption		

rate of burner Number of burners Duration of burner operation Anticipated gas demand **Total anticipated cooking-gas demand**		
2. Lighting Specific gas consumption per lamp Number of lamps Duration of lamp operation Gas demand		

3. Cooling Specific gas consumption * 24 hours		
4. Engines Specific gas consumption per kWh Engine output Operating time Gas demand		
5. Miscellaneous consumers Gas demand		
Anticipated		

increase in consumption (%)		
Total biogas demand 1st-priority consumers 2nd-priority consumers 3rd-priority consumers		

The following alternative modes of calculation are useful:

Determining biogas demand on the basis of present energy consumption, e.g. for ascertaining the cooking-energy demand. This involves either measuring or inquiring the present rate of energy consumption in the form of wood, charcoal, kerosene and bottled gas.

Calculating biogas demand via comparable-use data: Such data may consist of

- empirical values from neighboring systems, e.g. biogas consumption per person and day,
- reference data taken from literature, although this approach involves considerable uncertainty, since cooking-energy consumption depends on local cooking and eating habits and can therefore differ substantially from case to case.

Estimating biogas demand by way of appliance consumption data and assumed periods of use: This approach can only work to the extent that the appliances to be used are known in advance, e.g. a biogas lamp with a specific gas consumption of 120 l/h and a planned operating period of 3 h/d, resulting in a gas demand of 360 l/d.

Then, the interested party's energy demand should be tabulated in the form of a requirements list. In that connection, it is important to attach relative priority values to the various consumers, e.g.:

1. priority: applies only when the biogas plant will cover the demand.
2. priority: coverage is desirable, since it would promote plant usage.
3. priority: excess biogas can be put to these uses.

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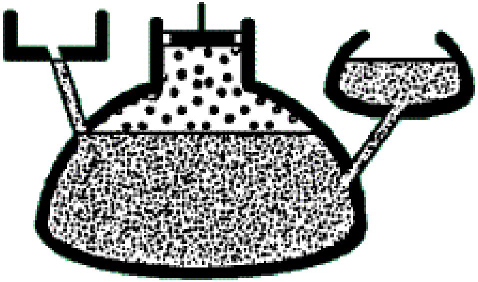

BIOGAS Digest

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Biogas plants constitute a widely disseminated branch of technology that came into use more than 30 years ago in developing countries. There are hundreds of thousands of simple biogas plants now in operation, and each one of them helps to improve the living conditions of people in rural areas. Biogas systems are an efficient way of dealing with organic waste, dung and crop residues while making optimal use of their energetic as well as nutrient content.

In addition to generating renewable energy, biogas systems help to stimulate ecologically beneficial closed-loop systems in the agricultural sector while improving soil quality and promoting progress in animal husbandry and farming.

While the main focus is on biogas systems of simple design, the technology is nonetheless complex enough to warrant close attention to its proper application, planning and construction. Only a well-planned, carefully constructed and properly functioning biogas system will fulfill its purpose of improving living conditions in rural areas.

You will find useful and detailed information about all aspects of biogas plant design and maintainance, biogas appliances, social, political, economic and ecological framework conditions, planning and dissemination of biogas systems and last but not least country- and project-specific information.

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Step-by-Step Planning Checklist for Biogas Plants

The following table gives an overview of all the steps required to build a biogas unit. The order follows a usual time-line. There are steps which can be combined. However, to skip any of them might lead to future problems.

Customer	Contractor
	organizes advertisement, awareness creation
hears about biogas, develops interest, get's in contact with the contractor	
	gives first overview over costs
	writes letter to the customer
writes a request	
	starts file

	makes a side visit, including: discussion and calculations
	makes a quantity survey,
	does object planning
	writes invoice explains warranty performances
makes first payment (50%)	organizes a customer and constructor sign contract
	hands over a list of building material to be delivered by the customer
prepares the material he agreed to deliver	
	organizes material delivery,

	reference line, main construction work, finishing, landscaping, slurry component, piping.
starts to fill the plant second payment (50%)	
	finishes piping installation of gas consumption accessories
discusses handing over	
makes an agreement on co-operation regarding fertiliser utilisation	
	makes a follow up on fertiliser utilisation
	does customer monitoring

	conducts technical and agricultural service visits

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Biogas Planning Guide

This guide to planning is intended to serve agricultural extension officers as a comprehensive tool for arriving at decisions concerning the suitability of locations for family-sized biogas plants. The detailed planning outline has a **data** column for entering the gathered information and a **rating** column for noting the results of evaluation.

Evaluation criteria are:

+ Siting condition are favorable

o Siting condition are unfavorable, but

a) compensable by project activities
b) not serious enough to cause ultimate failure

- Siting condition are not satisfactory

Despite its detailed nature, this planning guide is only a framework within which the extension officer should proceed to conduct a careful investigation and give due consideration, however subjectively, to the individual conditions in order to arrive at a locally practical solution. By no means is this planning guide intended to relieve the agricultural extension officer of the responsibility to thoroughly familiarize himself with the on-the-spot situation and to judge the overall value of a given location on the basis of the knowledge thus gained.

Detailed planning guide for biogas plants		
0. Initial situation	Data	Rating
Addresses/project characterization Plant acronym: Address of operator/customer: Place/region/country: Indigenous proj. org./executing org.: Extension officer/advisor: **General user data**		

Household structure and number of persons:
User's economic situation:
Crops: types, areas, manner of cultivation:
Non-agricultural activity:
Household/farm income:
Cultural and social characteristics of user:

Problems leading to the "biogas approach"

Energy-supply bottlenecks:
Workload for prior source of energy:
Poor soil structure/yields:
Erosion/deforestation:
Poor hygiene and other factors:

Objectives of the measure "biogas plant"

User interests:

Project interests: Other interests:		
1. Natural / Agricultural conditions	Data	Rating
Natural conditions Mean annual temperature: Seasonal fluctuations: Diurnal variation: Rating:		**- o +**
Subsoil Type of soil: Groundwater table, potable water catchment area: Rating:		**- o +**

Water conditions Climatic zone: Annual precipitation: Dry season (months): Distance to source of water: Rating:		**- o +**
Livestock inventory (useful for biogas production) Animals: kind and quantity: Type of stable: Use of dung: Persons responsible for animals: Rating:		**- o +**
Vegetable waste (useful for biogas production)		

Types and quantities: Prior use: Rating:		**- o +**
Fertilization Customary types and quantities of fertilizer/areas fertilized: Organic fertilizer familiar/in use: Rating:		**- o +**
Potential sites for biogas plant Combined stable/biogas plant possible: Distance between biogas plant and livestock stable: Distance between biogas		

plant and place of gas consumption: Rating:		**- o +**
Overall rating 1		**- o +**
2. Balancing the energy demand with the biogas production	Data	Rating
Prior energy supply Uses, source of energy, consumption: **Anticipated biogas demand (kwh/day or l/d)** for cooking:		

for lighting:
for cooling:
for engines:

Total gas demand

a) percentage that *must* be provided by the biogas plant:
b) desired demand coverage:

Available biomass (kg/d) and potential gas production (l/d)

from animal husbandry

pigs:
poultry:
cattle:

Night soil

Vegetable waste (quantities and potential gas yield)

1.
2.

Totals: biomass and potential gas production

a) easy to procure:
b) less easy to procure:

Balancing

Gas production clearly greater than gas demand -> positive rating (**+**)

Gas demand larger than gas

production -> negative rating (**-**); but review of results in order regarding: a) possible reduction of gas demand by the following measures -> b) possible increase in biogas production by the following measures -> If the measures take hold: -> qualified positive rating for the plant location (**o**) If the measures do not take hold: -> site rating remains negative (**-**)		

Overall rating 2		**- o +**
3. Plant Design and Construction	Data	Rating
Selection of plant design Locally customary type of plant: Arguments in favor of floating-drum plant: Arguments in favor of fixe-dome plant: Arguments in favor of other plant(s): Type of plant chosen: **Selection of site** **Availability of building materials**		

Bricks/blocks/stone: Cement: Metal: Sand: Piping/fittings: Miscellaneous: **Availability of gas appliances** Cookers: Lamps:		
Overall rating 3		**- o +**
4. Plant operation / maintenance / repair	Data	Rating
Assessment of plant		

operation Incidental work: Work expenditure in h: Persons responsible: Rating with regard to anticipated implementation:		**- o +**
Plant maintenance Maintenance-intensive components: Maintenance work by user: Maintenance work by external assistance: Rating with regard too anticipated implementation:		**- o +**
Plant repair Components liable to need		

repair: Repairs that can be made by the user: Repairs requiring external assistance: Requisite materials and spare parts: Rating with regard to expected repair services:		**- o +**
Overall rating 4		**- o +**
5. Economic analysis	Data	Rating
Time-expenditure accounting Time saved with biogas plant Time lost due to biogas plant Rating:		**- o +**

Microeconomic analysis Initial investment: Cost of operation/maintenance/repair: Return on investment: energy, fertilizer, otherwise: Payback time (static): Productiveness (static): Rating:		**- o +**
Quality factors, useful socioeconomic effects and costs Useful effects: hygiene, autonomous energy, better lighting, better working conditions, prestige: Drawbacks: need to handle night soil, negative social impact:		

Rating:		**- o +**
Overall rating 5		**- o +**
6. Social acceptance and potential for dissemination	Data	Rating
Anticipated acceptance Participation in planning and construction Integration into agricultural setting: Integration into household: Sociocultural acceptance: Rating:		**- o +**
Establishing a dissemination strategy		

Conditions for and chances of the professional-craftsman approach: Conditions for and chances of the self-help oriented approach:		**- o +** **- o +**
General conditions for dissemination Project-executing organization and its staffing: orgnaizational structure: interest and prior experience in biogas technology: Regional infrastructure for transportation: communication: material procurement: Craftsman involvement, i.e.		

which acitivities: minimum qualifications: tools and machines: Training for engineers, craftsman and users: Proprietary capital, subsidy/credit requirement on the part of user: craftsmen: Rating:		- o +
Overall rating 6		**- o +**
7. Summarization		
Siting conditions	No.	Rating

Natural/agricultural conditions	1.	**- o +**
Balancing the energy demand and the biogas production	2.	**- o +**
Plant design and construction	3.	**- o +**
Plant operation/maintenance/repair	4.	**- o +**
Economic analysis	5.	**- o +**
Social acceptance and potential for dissemination	6.	**- o +**
Overall rating of siting conditions		**- o +**

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Siting of the Biogas Unit

Stable

- The stable should be built on an

elevated position. This makes it possible to use gravity to collect urine and dung for feeding into the biogas plant. An elevated site on the farm also facilitates the distribution of slurry by gravity onto the farm land.

- For security reasons, the stable often is situated near the house.
- For easy access the feeding trough should be directed towards the area where fodder is grown.
- The milking place has to be at the higher end of the sloping stable floor. The milking should take place under clean conditions, away from the dung

alley.

- At least half of the stable has to be roofed. If it is totally roofed, sun should still enter and ventilation should be assured.

A digester should be as close as possible to the source of dung
Photo: Krmer (TBW)

- The position of the stable should allow for later extension.
- The animals need constant access to clean and fresh water and feeds.
- If the present position of the stable is unsuitable as a place for the biogas unit, it is usually better to shift the stable to the optimal position on the farm.

Cowshed, directly connected to the plant: A urine chamber to the right collects the liquid which can be used to wash the dung into the digester.
Photo: Kellner (TBW)

Biogas plant

- A golden rule is: the plant belongs to the stable rather than to the kitchen. Preferably, the mixing chamber and inlet are directly connected to a concrete stable floor. A few meters of piping are more economic than the daily transport of dung from the stable to the biogas plant.

- The roof of the stable should neither drain on the digester nor on the soil covering the plant. Large amounts of water entering the ground around the plant weaken the soil and cause static instability. Excess rain water may cool down the slurry in the plant and cause the gas production to drop.
- The overflow point should guide into farmland owned by the plant user. It has been observed that plants which overflow on public or foreign land can cause social problems. A promise of the owner to remove the slurry daily should not convince the planner.
- Water traps in the piping are a constant source of trouble. If the site allows, the plant and its piping should be laid out in a way that a water trap in the piping can be avoided. This is only possible if the pipes are sloping all the way back to the plant.

- The piping is a major cost factor. It should not be unnecessarily long. This criterion, however, is given less priority than having the stable close to the inlet and the outlet directed towards the farm land.
- A fixed dome plant should not be located in an area required for tractor or heavy machinery movements.
- Trees should not be too close to the plant. The roots may destroy the digester or the expansion chamber. In addition older trees may fall and destroy parts of the plant. If the position of the biogas plant is too shady, the soil

A model of an agricultural digester in Germany with two

temperature around the plant will be low in general. This leads to a decrease in gas production.

- The area around a biogas plant should not be a playground for children. This is less important for underground fixed dome plants, more important for floating drum plants and essential for balloon plants.

horizontal steel tanks, a gas storage bag and a co-generation unit in a container
Photo: Krmer (TBW)

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Sizing a biogas plant

The size of the biogas plant depends on the quantity, quality and kind of available biomass and on the digesting temperature. The following points should be considered

Sizing the digester

The size of the digester, i.e. the digester volume **Vd**, is determined on the basis of the chosen retention time **RT** and the daily substrate input quantity **Sd**.

Vd = **Sd RT** [$m^3 = m^3$/day number of days]

The retention time, in turn, is determined by the chosen/given digesting temperature. For an unheated biogas plant, the temperature prevailing in the digester can be assumed as 1-2 Kelvin above the soil temperature.

Seasonal variation must be given due consideration, however, i.e. the digester must be sized for the least favorable season of the year. For a plant of simple design, the retention time should amount to at least 40 days. Practical experience shows that retention times of 60-80 days, or even 100 days or more, are no rarity when there is a shortage of substrate. On the other hand, extra-long retention times can increase the gas yield by as much as 40%.

The substrate input depends on how much water has to be added to the substrate in order to arrive at a solids content of 4-8%.

Substrate input (**Sd**) = biomass (**B**) + water (**W**) $[m^3/d]$

In most agricultural biogas plants, the mixing ratio for dung (cattle and / or pigs) and water (**B**:**W**) amounts to between 1:3 and 2:1.

Calculating the daily gas production G

The amount of biogas generated each day **G** $[m^3$ gas/d], is calculated on the basis of the specific gas yield **Gy** of the substrate and the daily substrate input **Sd**.

The calculation can be based on:

1. The volatile solids content **VS**

   G = **VS Gy**(solids) [m^3/d = kg m^3/(dkg)]

2. the weight of the moist mass **B**

   G = **B Gy**(moist mass) [m^3/d = kg m^3/(dkg)]

3. standard gas-yield values per livestock unit **LSU**

   G = number of **LSU Gy**(species) [m^3/d = *number* m^3/(d*number*)]

The temperature dependency is given by:

Gy(**T**,**RT**) = **mGy f**(**T**,**RT**)

where

Gy(**T**,**RT**) = gas yield as a function of digester temperature and retention time

mGy = average specific gas yield, e.g. l/kg volatile solids content
f(**T**,**RT**) = multiplier for the gas yield as a function of digester temperature T and retention time RT

As a rule, it is advisable to calculate according to several different methods, since the available basic data are usually very imprecise, so that a higher degree of sizing certainty can be achieved by comparing and averaging the results.

Establishing the plant parameters

The degree of safe-sizing certainty can be increased by defining a number of plant parameters:

Specific gas production Gp

i.e. the daily gas generation rate per m^3 digester volume **Vd**, is calculated according to the following equation

Gp = **G Vd** [$(m^3/d) / m^3$]

Digester loading Ld

The digester loading **Ld** is calculated from the daily total solids input **TS/d** or the daily volatile solids input **VS/d** and the digester volume **Vd**:

$$Ld_T = TS/d \; Vd \quad [\, kg/(m^3\, d)\,]$$

$$Ld_V = VS/d \; Vd \quad [\, kg/(m^3\, d)\,]$$

Then, a calculated parameter should be checked against data from comparable plants in the region or from pertinent literature.

Sizing the gasholder

The size of the gasholder, i.e. the gasholder volume **Vg**, depends on the relative rates of gas generation and gas consumption. The gasholder must be designed to:

- cover the peak consumption rate gc_{max} (->Vg_1) and
- hold the gas produced during the longest zero-consumption period tz_{max} (->Vg_2)

$$Vg_1 = gc_{max}\, tc_{max} = vc_{max}$$

$$Vg_2 = G_h \, tz_{max}$$

with

gc_{max} = maximum hourly gas consumption [m^3/h]

tc_{max} = time of maximum consumption [h]

vc_{max} = maximum gas consumption [m^3]

G_h = hourly gas production [m^3/h] = **G** 24 h/d

tz_{max} = maximum zero-consumption time [h]

The larger **Vg**-value (**Vg_1** or **Vg_2**) determines the size of the gasholder. A safety margin of 10-20% should be added:

$$Vg = 1.15\ (0.5)\ \max(Vg_1, Vg_2)$$

Practical experience shows that 40-60% of the daily gas production normally has to be stored.

The ratio **Vd Vg** (digester volume gasholder volume) is a major factor with regard to the basic design of the biogas plant. For a typical agricultural biogas plant, the **Vd/Vg**-ratio amounts to somewhere between 3:1 and 10:1, with 5:1 - 6:1 occuring most frequently.

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Substrate types and management

Cattle dung and manure

Cattle dung is the most suitable material for biogas plants because of the methane-producing bacteria already contained in the stomach of ruminants. The specific gas production, however, is lower and the proportion of methane is around 65% because of pre-fermentation in the stomach. Its homogenous consistency is favourable for use in continuous plants as long as it is mixed with equal quantities of water.

Fresh cattle dung is usually collected and carried to the system in buckets or baskets. Upon arrival it is hand-mixed with about an equal amount of water before being fed into the digester. Straw and leftover fodder or hay is removed by hand in order to prevent clogging and reduce scum formation. Since most simple cow-sheds have dirt floors, the urine is usually not collected. When it is, it usually runs along the manure gutter and into a pail standing in a recess at the end of the gutter. The pail is emptied into the mixing pit - thereby replacing some of the mixing water - in preparation for charging the digester. Urine can considerably increase the gas production. A cemented stable floor, directly attached to the mixing pit, is the best solution to make optimum use of dung and urine and to save time for charging the digester.

Liquid cattle manure, a mixture of dung and urine, requires no extra water. However, the simple animal housing found on most farms in developing countries normally does not allow the collection of all animal excrement. Hence, most of the urine with its valuable plant nutrients is lost.

Pig dung and manure

When pigs are kept in unpaved areas or pens, only the dung can be collected. It must be diluted with water to the requisite consistency for charging the digester. This could result in considerable amounts of sand being fed into the digester, unless it is allowed to settle in the mixing vessel. Once inside the digester, sand and soil accumulates at the bottom and has to be removed periodically. Some form of mechanical mixer should be used to dilute the dung with water, since the odor nuisance makes manual mixing so repulsive that it is usually neglected. Similar to cow stables, a cemented floor, sloping towards the mixing pit, is a preferable solution.

Compared to cattle, pigs are more frequently kept on concrete floors. The water used for washing out the pens yields **liquid manure** with a low solids content. Thus, whenever the topography allows, the liquid manure should be allowed to flow by gravity into the digester. Wash-water should be used as sparingly as possible in order to minimize the necessary digester volume. Very frequently, the pig manure is collected in pails, which is advantageous, even though a sand trap should be provided to prevent sand from entering the digester.

Goat dung

For goats kept on unpaved floors, the situation is comparable to that described for pigdung. Since a goat farm is practically the only place where any substantial amount of goat dung can accumulate, and then only if the animals are kept on straw bedding, the available feed-stock for a biogas system will usually consist of a mixture of dung and straw bedding. Most such systems are batch-fed versions into which the dung and an appropriate quantity of water are loaded without being pre-mixed. The feed-stock is usually hauled to and from the digester in wheelbarrows or baskets.

Chicken droppings

Chicken droppings can only be used if the chickens roost above a suitable dung collecting area of limited size. Otherwise, the sand or sawdust fraction would be disproportionately high. Chicken droppings can be fed into plants which are primarily filled with cow dung without any problem. There is a latent danger of high ammoniac concentration with pure chicken dung, but despite this there are many well functioning biogas plants combined with egg or meat producing factories. The collected droppings are hard and dry, so that they have to be pulverized and mixed with water before they can be loaded into the digester. Mechanical mixing is advisable. The proportion of methane in biogas from chicken excrement is up to 60%.

Human excrements

In most cultures, handling human excrement is loaded with taboos. Thus, if night soil is to be used in a biogas system, the toilets in question should drain directly into the system so that the night soil is fermented without pretreatment. The amount of water accompanying the night soil should be minimized by ensuring that no water taps or other external sources drain into the toilet bowls, and cleaning/flushing should be limited to rinsing out with about 0.5 - 1 liter water from a bowl. Western-style flush tanks should not be used in connection with small-size biogas plants.

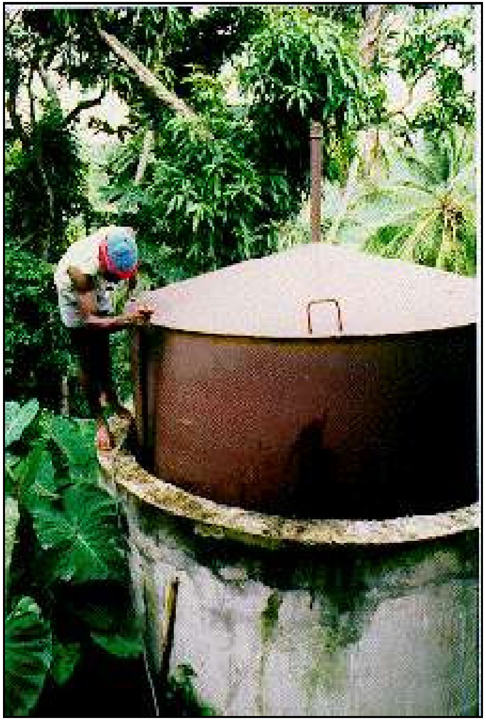
In areas subject to frequent or seasonal water shortages, sand traps are a must, since wiping with stones is often the only means of cleaning after using the toilet.

The problem of scum

If there is heavy gas release from the inlet but not enough gas available for use, a thick scum layer is most likely the reason. Often the gas pressure does not build up because of the continuous gas release through the inlet for weeks. There is a danger of blocking the gas pipe by rising scum because of daily feeding without equivalent discharge. The lid (or man-hole) must be opened or the floating drum removed and scum is to be taken out by hand.

Separation of material

Straw, grass, stalks and even already dried dung tends to float to the surface. Solid and mineral material tends to sink to the bottom and, in the course of time, may block the outlet pipe or reduce the active digester volume. In properly mixed substrate with not too high water contents, there is no such separation because of sufficient friction within the paste-like substance.



Destruction of the scum in a floating-drum plant in the Carribean
Photo: gtz/GATE

Substrate

With pure and fresh cattle dung there is usually no scum problem. Floating layers will become a problem when e.g. undigestible husks are part of the fodder. This is often the case in pig feeds. Before installing a biogas plant at a piggery, the kind of fodder and consequently the kind of dung, must be checked to ensure that it is suitable for a biogas plant. It might be necessary to grind the fodder into fine powder. The user must be aware of the additional costs before deciding on a biogas unit. The problem is even bigger with poultry droppings. The kind of fodder, the sand the chicken pick up, and the feathers falling to the ground make poultry dung a difficult substrate. In case of serious doubt, the building of a biogas plant should be re-assessed.

Scum can be avoided by stirring, but...

Scum is not brittle but very filthy and tough. Scum can become so solid after only a short time, that it needs heavy equipment to break it. It remains at the surface after being broken up. To destroy it by fermentation, it must be kept wet. Either the scum must be watered from the top or pushed down into the liquid. Both operations demand costly apparatus. For simple biogas plants, stirring is not a viable solution for breaking the scum.

The only solution for simple biogas plants to avoid scum is by selecting suitable feed material and by sufficient mixing of the dung with liquid before entering the plant.