principle of a rapidly rotating impeller located in the liquid flow. They provide high delivery rates and are very robust, i.e. the internals are exposed to little mechanical stress. They do, however, require a free-flowing intake arrangement, because they are not self-priming (regenerative).

Data of pumps

Practically all centrifugal pump characteristics are geared to water. They show the delivery rates for various heads, the achievable efficiency levels, and the power requirement for the pump motor. Consequently, such data cannot be directly applied to biogas systems, since the overall performance and efficiency level of a pump for re-circulating slurry may suffer a serious drop-off as compared to its standard "water" rating (roughly 5-10%).

Substrate

Sometimes, namely when the substrate is excessively viscous, a centrifugal pump will no longer do the job, because the condition of the substrate surpasses the pump’s physical delivery capacity. In such cases, one must turn to a so-called positive-displacement or reciprocating type of pump in the form of a piston pump, gear pump or eccentric spiral pump, all of which operate on the principle of displacing action to provide positive delivery via one or more enclosed chambers.

Positive displacement pumps

Positive displacement pumps offer multiple advantages. Even for highly viscous substrate, they provide high delivery and high efficiency at a relatively low rate of power consumption. Their characteristics - once again for water - demonstrate how little the delivery rate depends on the delivery head. Consequently, most of the characteristics show the delivery rate as a function of pump speed.

The main disadvantage as compared to a centrifugal pump is the greater amount of wear and tear on the internal occasioned by the necessity of providing an effective seal between each two adjacent chambers.

Pump delivery lines

Pump delivery lines can be made of steel, PVC (rigid) or PE (rigid or flexible), as well as appropriate flexible pressure tubing made of reinforced plastic or rubber. Solid substrate, e.g. dung, can also be handled via conveyor belt, worm conveyor or sliding-bar system, though none of these could be used for liquid manure. When liquid manure is conducted through an open gutter, small weirs or barrages should be installed at intervals of 20-30 m as a means of breaking up the scum layer.

Each such barrier should cause the scum to fall at least 20-30 cm on the downstream side. All changes of direction should be executed at right angles (90°). Depending on the overall length, the cross gutter should be laid some 30-50 cm deeper than the main gutter. Transitions between a rectangular channel and a round pipe must be gradual. An inclination of about 14% yields optimum flow conditions. The channel bottom must be laid level, since any slope in the direction of flow would only cause the liquid manure to run off prematurely. All wall surfaces should be as smooth as possible.

Weak ring

Position of the weak ring

The weak/strong ring improves the gas-tightness of fixed-dome plants. It was first introduced in Tanzania and showed promising results. The weak ring separates the lower part of the hemispherical digester, (filled with digesting substrate), from the upper part (where the gas is stored). Vertical cracks, moving upwards from the bottom of the digester, are diverted in this ring of lean mortar into horizontal cracks. These cracks remain in the slurry area where they are of no harm to the gas-tightness. The strong ring is a reinforcement of the bottom of the gas-holder, it could also be seen as a foundation of the gas-holder. It is an additional device to prevent cracks from entering the gas-holder. Weak and strong ring have been successfully combined in the CAMARTEC design.

Figure 21: Construction of the weak/strong ring of a 16 m^3, Tanzania
Photo: Kellner (TBW)

Materials and construction

The weak ring consists of mortar of a mixture of sand, lime and cement (15:3:1). The top of the weak ring restores the horizontal level. It is interrupted only by the inlet pipe passing through. The strong ring rests on the weak ring and is the first layer of the upper part of the hemispherical shell. It consists of a row of header bricks with a concrete package at the outside. In case of soft or uncertain ground soil one may place a ring reinforcement bar in the concrete of the strong ring. The brick of the strong ring should be about three times wider than the brickwork of the upper wall. A detailed description of the weak/strong ring construction can be found in Sasse, Kellner, Kimaro.

Further reading:

- **Ringkamp, M.; Tentscher, W.; Schiller, H.**: Preliminary results on: statical optimization of family-sized fixed-dome digesters. Tilche, A.; Rozzi, A. (ed.): Poster Papers. Fifth International Symposium on Anaerobic Digestion, Bologna 1988, pp. 321-324
- **Sasse, L.; Kellner, Ch.; Kimaro, A.**: Improved Biogas Unit for Developing Countries. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Vieweg & Sohn Verlagsgesellschaft Braunschweig, 1991

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:

8. quick and easy to procure
9. 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.

$$\text{Dung yield} = \text{liveweight} \times \text{number of animals} \times \text{specific quantity of excrements } [\text{ kg/d }]$$

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.

Table 1: 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.

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:		**- o +**

Requisite materials and spare parts: Rating with regard to expected repair services:		
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		**- o +**

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:		
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 +**

Step-by-Step Planning Checklist for Biogas Plants

The following table 2 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

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**.

$$\mathbf{Vd} = \mathbf{Sd} \times \mathbf{RT} \text{ [} m^3 = m^3\text{/day} \times \text{number of days]}$$

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%.

$$\text{Substrate input } (\mathbf{Sd}) = \text{biomass } (\mathbf{B}) + \text{water } (\mathbf{W}) \text{ [}m^3\text{/d]}$$

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:

10. The *volatile solids content* **VS**

$$\mathbf{G} = \mathbf{VS} \times \mathbf{Gy}(\text{solids}) \text{ [} m^3\text{/d} = \text{kg} \times m^3\text{/(d}\times\text{kg)]}$$

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

$$\mathbf{G} = \mathbf{B} \times \mathbf{Gy}(\text{moist mass}) \text{ [} m^3\text{/d} = \text{kg} \times m^3\text{/(d}\times\text{kg)]}$$

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

$$\mathbf{G} = \text{number of } \mathbf{LSU} \times \mathbf{Gy}(\text{species}) \text{ [} m^3\text{/d} = \textit{number} \times m^3\text{/(d}\times\textit{number}\text{)]}$$

The temperature dependency is given by:

$$\mathbf{Gy}(\mathbf{T},\mathbf{RT}) = \mathbf{mGy} \times \mathbf{f}(\mathbf{T},\mathbf{RT})$$

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

$$\mathbf{Gp} = \mathbf{G} \div \mathbf{Vd} \ [\ (m^3/d)\ /\ m^3\ ]$$

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**:

$$\mathbf{Ld_T} = \mathbf{TS/d} \div \mathbf{Vd} \ [\ kg/(m^3\ d)\ ]$$
$$\mathbf{Ld_V} = \mathbf{VS/d} \div \mathbf{Vd} \ [\ kg/(m^3\ d)\ ]$$

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* $\mathbf{gc_{max}}$ (->$\mathbf{Vg_1}$) and
- hold the gas produced during the longest *zero-consumption period* $\mathbf{tz_{max}}$ (->$\mathbf{Vg_2}$)

$$\mathbf{Vg_1} = \mathbf{gc_{max}} \times \mathbf{tc_{max}} = \mathbf{vc_{max}}$$

$$\mathbf{Vg_2} = \mathbf{G_h} \times \mathbf{tz_{max}}$$

with

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

$\mathbf{tc_{max}}$ = *time of maximum consumption* [h]

$\mathbf{vc_{max}}$ = *maximum gas consumption* $[m^3]$

$\mathbf{G_h}$ = hourly gas production $[m^3/h] = \mathbf{G} \div 24$ h/d

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

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

$$\mathbf{Vg} = 1.15\ (\pm 0.5) \times \max(\mathbf{Vg_1},\mathbf{Vg_2})$$

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.

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.
- roofed. If it is totally roofed, sun should still enter and ventilation should be assured.
- 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.

Figure 22: A digester should be as close as possible to the source of dung.

Figure 23: 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 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.

Figure 24: A model of an agricultural digester in Germany with two horizontal steel tanks, a gas storage bag and a co-generation unit in a container.
Photo: Kr mer (TBW)

Substrate types and management

- Cattle dung and manure
- Pig dung and manure
- Goat dung
- Chicken droppings
- Human excrements
- Manure yield of animal excrements
- The problem of scum

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.

Figure 25: Destruction of the scum in a floating-drum plant in the Carribean
Photo: gtz/GATE

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.

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.

Construction Details of Biogas Plants

This section provides detailed information on materials and devices used in the construction of biogas plants:

- Checklist for construction
- Agitation
- Heating
- Piping systems
- Plasters and Coats
- Pumps
- Slurry equipement
- Underground water

Checklist for building a biogas plant

1. **Finishing the planning**, i.e. site evaluation, determination of energy demand and biomass supply / biogas yield, plant sizing, selection of plant design, how and where to use the biogas, etc., in accordance with the planning guide
2. **Stipulate the plant's location and elaborate a site plan**, including all buildings, gas pipes, gas appliances and fields to be fertilized with digested slurry
3. **Draft a technical drawing showing all plant components**, i.e. mixing pit, connection to stabling, inlet / outlet, digester, gas-holder, gas pipes, slurry storage
4. **Preparation of material / personnel requirements list and procurement of materials needed for the chosen plant**:
    - bricks / stones / blocks for walls and foundation
    - sand, gravel
    - inlet / outlet pipes
    - metal parts (sheet metal, angle irons, etc.)
    - gas pipes and fittings
    - paint and sealants
    - gas appliances
    - tools
    - mason and helper
    - unskilled labor
    - workshop for metal (gas-holder) and pipe installation
5. **Material / personnel assignment planning**, i.e. procedural planning and execution of:
    - excavation
    - foundation slab
    - digester masonry
    - gasholder
    - rendering and sealing the masonry
    - mixing pit - slurry storage pit
    - drying out the plant
    - installing the gas pipe
    - acceptance inspection
6. **Regular building supervision**

7. **Commissioning**
    - functional inspection of the biogas plant and its components
    - starting the plant
8. **Filling the plant**
9. **Training the user**

Piping Systems

The piping system connects the biogas plant with the gas appliances. It has to be safe, economic and should allow the required gas-flow for the specific gas appliance. Galvanized steel (G.I.) pipes or PVC-pipes are most commonly used for this purpose. Most prominently, the piping system has to be reliably gas-tight during the life-span of the biogas unit. In the past, faulty piping systems were the most frequent reason for gas losses in biogas units.

PVC piping

PVC pipes and fittings have a relatively low price and can be easily installed. They are available in different qualities with adhesive joints or screw couplings (pressure water pipes). PVC pipes are susceptible to UV radiation and can easily be damaged by playing children. Wherever possible, PVC pipes should be placed underground.

Figure 26: Final touches on a piping system with PVC pipes
Photo: Krämer (TBW)

Galvanized steel piping

Galvanized steel pipes are reliable and durable alternatives to PVC pipes. They can be disconnected and reused if necessary. They resist shocks and other mechanical impacts. However, galvanized steel pipes are costly and the installation is labor intensive, therefore they are only suitable for places where PVC is unavailable or should not be used.

Pipe diameters

The necessary pipe diameter depends on the required flow-rate of biogas through the pipe and the distance between biogas digester and gas appliances. Long distances and high flow-rates lead to a decrease of the gas pressure. The longer the distance and the higher the flow rate, the higher the pressure drops due to friction. Bends and fittings increase the pressure losses. G.1. pipes show higher pressure losses than PVC pipes. The table below gives some values for appropriate pipe diameters. Using these pipe diameters for the specified length and flow rate, the pressure losses will not exceed 5 mbar.

Table 3: Appropriate pipe diameter for different pipe lengths and flow-rate (maximum pressure loss < 5 mbar)

	Galvanized steel pipe			PVC pipe		
Length [m]:	20	60	100	20	60	100
Flow-rate [m^3/h]						
0.1	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"
0.2	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"
0.3	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"
0.4	1/2"	1/2"	1/2"	1/2"	1/2"	1/2"
0.5	1/2"	1/2"	3/4"	1/2"	1/2"	1/2"
1.0	3/4"	3/4"	3/4"	1/2"	3/4"	3/4"
1.5	3/4"	3/4"	1"	1/2"	3/4"	3/4"
2.0	3/4"	1"	1"	3/4"	3/4"	1"

The values in this table show that a pipe diameter of 3/4" is suitable for flow rates up to 1.5 m^3/h and distances up to 100 m (PVC pipe). Therefore one could select the diameter of 3/4" as single size for the hole piping system of small biogas plants. Another option is to select the diameter of l" for the main gas pipe and 1/2" for all distribution pipes to the gas appliances.

Lay-out of the piping system

PVC can be used for all underground pipes or pipes that are protected against sun light and out of the reach of children. For all parts of the piping system that are above ground one should install galvanized steel pipes. Therefore it is recommended to use l" G.I. steel pipes for the visible part of the piping system around the biogas digester. For the main pipe one uses l" PVC pipe placed underground. The distribution pipes should be 1/2" G.I. steel pipes or PVC pipes, depending whether they are installed above or under the wall plastering. But even though G.I. pipes are less susceptible to damage, placing them underground should always be the preferred solution.

PVC pipes have to be laid at least 25 cm deep underground. They should be placed in a sand bed and be covered with sand or fine earth. One should carefully back-fill the ditches in order to avoid stones lying directly above the pipe.

When the piping is installed - and before refilling the ditches - it has to be tested for possible gas leakage. This can be done by pumping air into the closed piping system up to a pressure that is 2.5 times the maximum gas pressure of the biogas plant. If pressure loss occurs within few hours, every joint of the piping system has to be checked with soap water. Soap-bubbles indicate any leakage of gas.

Water traps

Due to temperature changes, the moisture-saturated biogas will form inevitably condensation water in the piping system. Ideally, the piping system should be laid out in a way that allows a free flow of condensation water back into the digester. If depressions in the piping system can not be avoided, one or several water traps have to be installed at the lowest point of the depressions. Inclination should not be less than 1%.

Often, water traps cannot be avoided. One has to decide then, if an 'automatic' trap or a manually operated trap is more suitable. Automatic traps have the advantage that emptying - which is easily forgotten - is not necessary. But if they dry up or blow empty, they may cause heavy and extended gas losses. In addition, they are not easily understood. Manual traps are simple and easy to understand, but if they are not emptied regularly, the accumulated condensation water will eventually block the piping system. Both kinds of traps have to be installed in a solid chamber, covered by a lid to prevent an eventual filling up by soil.

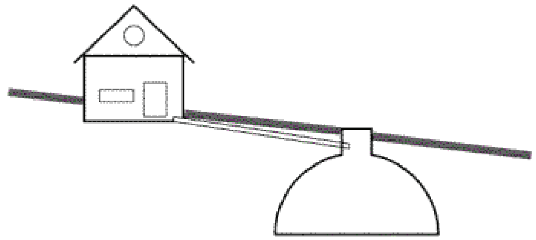

Figure 27: Piping system with straight slope from kitchen to digester. No water trap required as condensation water drains into the digester
Source: TBW

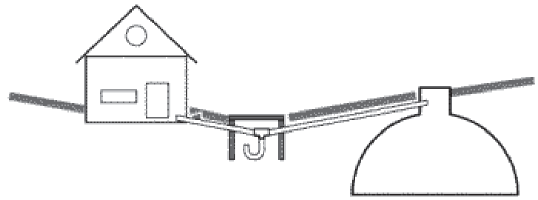

Figure 28: Wherever condensation water cannot drain back into the digester, a water trap becomes necessary
Source: TBW

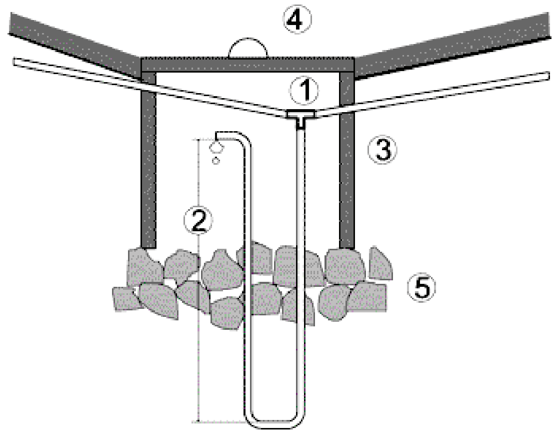

Figure 29: Automatic water trap: (1) T-joint in the piping system, (2) water column, equal to max. gas pressure + 30% security, (3) solid brick or concrete casing, (4) concrete lid, (5) drainage
Source: TBW

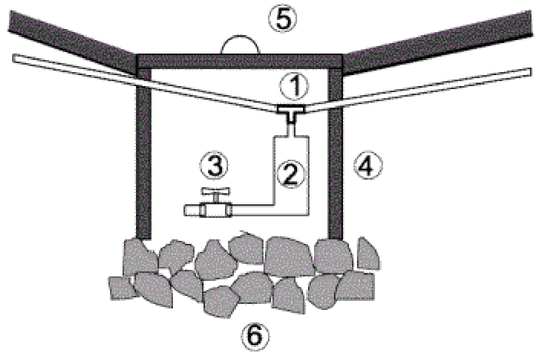

Figure 30: Manual water trap: (1) T-joint, (2) buffer storage for condensated water, (3) manual tap, (4) casing, (5) concrete lid, (6) drainage
Source: TBW

Valves

To the extent possible, ball valves or cock valves suitable for gas installations should be used as shutoff and isolating elements. The most reliable valves are chrome-plated ball valves. Gate valves of the type normally used for water pipes are not suitable. Any water valves exceptionally used must first be checked for gas-tightness. They have to be greased regularly. A U-tube pressure gauge is quick and easy to make and can normally be expected to meet the requirements of a biogas plant.

The main gas valve has to be installed close to the biogas digester. Sealed T-joints should be connected before and after the main valve. With these T-joints it is possible to test the digester and the piping system separately for their gas-tightness. Ball valves as shutoff devices should be installed at all gas appliances. With shutoff valves, cleaning and maintenance work can be carried out without closing the main gas valve.

Pumps for Biogas Plants

Pumps are required to bridge differences in height between the levels of slurry-flow through the biogas unit. They can also be required to mix the substrate or to speed up slow flowing substrates. If substrates have a high solids content and do not flow at all, but cannot be diluted, pumps or transport belts are essential.

Pumps are driven by engines, are exposed to wear and tear and can be damaged. They are costly, consume energy and can disrupt the filling process. For these reasons, pumps should be avoided where possible and methods of dilution and use of the natural gradient be utilized instead.

If pumps cannot be avoided, they can be installed in two ways:

- Dry installation: the pump is connected in line with the pipe. The substrate flows freely up to the pump and is accelerated while passing through the pump.
- Wet installation: the pump is installed with an electric engine inside the substrate. The electric engine is sealed in a watertight container. Alternatively, the pump in the substrate is driven by a shaft, the engine is outside the substrate.

Types of pumps

Rotary pumps

Rotary pumps operate with a rotor which presses the liquid against the outside wall of the rotor chamber. Due to the geometry of the chamber the liquid is pushed into the outlet pipe. Rotary pumps are very common in liquid manure technology. They are simple and robust and used mainly for substrates of less than 8% solids content. The quantity conveyed per time unit depends largely on the height of lift or the conveying pressure. The maximum conveying pressure is between 0,8 and 3.5 bar. The quantity that can be conveyed varies from 2 to 6 m^3per min. at a power input of 3 - 15 kW. Rotary pumps cannot, usually, be used as a sucking device. As a special form of rotary pumps, the chopper pump deserves mentioning. It's rotor is equipped with blades to chop substrates with long fibers like straw and other fodder parts before pumping them up. Both wet and dry installation is possible with rotary pumps.

Positive displacement pumps

Positive displacement pumps are normally used for substrates with higher solids content. They pump and suck at the same time. Their potential quantity conveyed is less dependent on the conveying pressure than with rotary pumps. The direction of pumping / sucking can be changed into the opposite direction by changing the sense of rotation. In biogas units, mainly the eccentric spiral pump and the rotary piston pump (both positive displacement pumps) are used. For better access, a dry installation is the preferred option.

Eccentric spiral pump

This pump has a stainless steel rotor, similar to a cork screw, which turns in an elastic casing. Eccentric spiral pumps can suck from a depth of up to 8.5m and can produce a pressure of up to 24 bar. The are, however, more susceptible to obstructive, alien elements than rotary pumps. Of disadvantage is further the danger of fibrous material wrapping round the spiral.

Rotary piston pump

Rotary piston pumps operate on counter-rotating winged pistons in an oval casing. They can pump and suck as well and achieve pressures of up to 10 bar. The potential quantity conveyed ranges from 0.5 to 4 m^3/min. The allow for larger alien objects and more fibrous material than eccentric spiral pumps.

Table 4: Types of pumps in comparison

	rotary pumps	chopper pumps	eccentric spiral pump	rotary piston pump
solids content	< 8 %	< 8 %	< 15 %	< 15 %
energy input	3 - 15 kW	3 - 15 kW	3 - 22 kW	3 - 20 kW
quantity conveyed	2 - 6 m^3/min	2 - 6 m^3/min	0,3 - 3,5 m^3/min	0,5 - 4 m^3/min
pressure	0,8 - 3,5 bar	0,8 - 3,5 bar	< 25 bar	< 10 bar
structure of substrate	medium long fibers	long fibers	short fibers	medium long fibers
max. size of obstructive elements	approx. 5 cm	depending on choppers	approx. 4 cm	approx. 6 cm
intake	**not** sucking	**not** sucking	sucking	sucking
suitability	suitable for large quantities; simple and robust built	suitable for long-fiber substrates which need to be chopped up.	Suitable for high pressures, but susceptible to obstructive bodies	higher pressures than rotary pumps, but higher wear and tear
price comparison	cheaper than positive displacement pumps	depending on choppers	similar to rotary piston pump	similar to eccentric spiral pump

Heating

To achieve the optimum biogas yield, the anaerobic digestion needs constant environmental conditions, preferably close to the process optimum. The digester temperature is of prime importance. In temperate areas, a heating system and an insulation of the digester is necessary. Hence, the needed temperature for digestion can be reached and a loss of energy by transmission is compensated.

Because of the high costs for material and installation of a heating system, a low-cost biogas plant, as needed in developing countries, can only be build without heating. To boost the biogas yield for those plants, the building of a bigger digester to increase the retention time would be cheaper. A bigger digester reduces the required maintenance, while a heating system, increases maintenance requirements. A bigger digester serves also as a buffer for sediments, pH-variations and gas storage. For example, a fixed dome plant sized 50% bigger, is only 10% more expensive.

Figure 31: Heating system for a biodigester under construction (Germany)
Photo: Krieg (TBW)

The mean surrounding temperature and it's seasonal variations are very important. Biogas plants without heating system work, therefore, only in warmer regions for the whole year. In regions with extreme temperature variations, for instance in Turkey (hot summer, cold winter), the biogas plant should be built under the stable. Hence the biogas yield would be lower in summer, but constant over the year and at the end higher. Before implementation, at least an approximated average temperature profile and expected extremes over the year should be available for the site.

A biogas plant with heating system and co-generation can be operated with process energy. Nevertheless the dimensioning of such a heating system is difficult, as the substrate, which has to be heated up, is not homogenous.

A guiding figure for a digester with a hydraulic retention time of 20 days is 270 W/m^3 digester volume. The increasing of the hydraulic retention time makes it possible to reduce the heating power per volume. With a hydraulic retention time of 40 days the digester needs only 150 W/m^3.

Following figures are for heating systems with a heating water temperature difference of 20 K:

hydr. retention time	40 days	30 days	20 days
temperature difference	20 K	20 K	20 K
heating power	150 kW/m^3	210 kW/m^3	270 kW/m^3

A heating system located in the digester produces a thermal circulation, which is, especially for non-agitated digesters, very important.

An indirect energy transfer by heat exchanger is most common. Exceptions are steam injection, liquefying of solid manure with heated water and the heating by pre-aeration.

Internal and external heating systems

External heating systems have a forced flow on both sides. Due to the turbulent flow patterns of both media, a very good heat transportation can be reached. Therefore, the surface of the heat exchanger can be comparatively small. Nevertheless those systems cannot be recommended for non-agitated digesters.