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Is Biogas a Feasible Option?

Assessing anaerobic digestion in humanitarian contexts

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1. Introduction

Worldwide interest in renewable energy sources is growing. Anaerobic digestion (AD) with biogas production is increasing steadily as more people set up biogas plants given the inherent benefits as listed below.

Environmental benefits:

- Biogas is a renewable, as well as a clean, source of energy.
- The raw materials used in biogas production are wastes, and the gas generated through AD is non-polluting.
- The controlled treatment of waste in AD facilities reduces uncontrolled waste degradation and potential methane emissions into the environment.
- Reducing uncontrolled waste degradation in dumpsites avoids foul smells and leachate that may drain underground and contaminate surface water sources.

Livelihoods:

- Digestate, the by-product of the biogas generation process, is nutrient-rich and a perfect supplement to, or substitute for, chemical fertilizers.
- Biogas systems are a relatively simple and low-cost technology.
- Operating biogas plants may create livelihood opportunities and jobs.

Protection:

- Using waste in AD facilities goes hand in hand with improved waste collection and treatment and, therefore, improves hygiene and public health.
- Using biogas as fuel alleviates women and children from the challenging responsibility of gathering firewood, thereby reducing their exposure to potential protection-related risks.
- Cooking on a gas stove, instead of an open fire, prevents people from being exposed to smoke in the kitchen. This helps prevent deadly respiratory diseases.

However, many biogas projects have failed because a careful evaluation was not conducted at the onset of the project.

Before deciding to implement biogas systems at your location, an evaluation is needed to determine if such a solution is appropriate for the specific context and conditions.

This guide is part of a package that outlines all the aspects to consider when evaluating the feasibility of anaerobic digestion for humanitarian contexts. The package includes:

1. This guide: *Is biogas a feasible option? - Assessing anaerobic digestion for humanitarian contexts.*
   - Introduces the basics of biogas waste treatment
   - Instructs how to conduct an assessment and evaluation of your local context in order to obtain data that can then be used in the Technology Evaluation Tool (TET-Biogas Excel)
2. Excel-based tool: Technology Evaluation Tool Biogas (TET-Biogas Excel)
   - Provides a data entry interface for key information obtained by the local assessment
   - Checks waste feedstocks suitability for biogas production
   - Provides a results dashboard with an estimation of design parameters, biogas and energy output

Target users for this guide and its accompanying TET-Biogas Excel are field-based WASH and environment staff, implementing partners and operators who want to explore the option of installing and operating biogas systems in their specific context.

After a brief introduction of the basics of biogas waste treatment, this guide introduces a checklist of questions and tasks for a step-by-step evaluation of biogas as a potential solution for management of waste. For each task, this guide then provides more detail in subsequent chapters and specific tools as annexes.

It is relevant to keep in mind that this guide and the TET-Biogas Excel should be considered as a means to introduce biogas waste processing. The results shown in the supporting TET-Biogas Excel tool give only a first estimation of its potential and the expected biogas outputs. Before making any decisions on the design of an active bioreactor gasholder, digestate treatment, pipes and pumps, we recommend consulting either a technology supplier or a specialized consultant to obtain more specific and detailed support.

This guide is based to a large degree on the book *Anaerobic Digestion of Biowaste in Developing Countries: Practical Information and Case Studies*. This book and other more detailed readings on biogas waste treatment are referenced at the end of this document under "Further readings".

To efficiently navigate through the Biogas package, use **Figure 1** on page 4. Click on the chapters/annexes/tool relevant to you, and you will be directed to the relevant section of the guide.

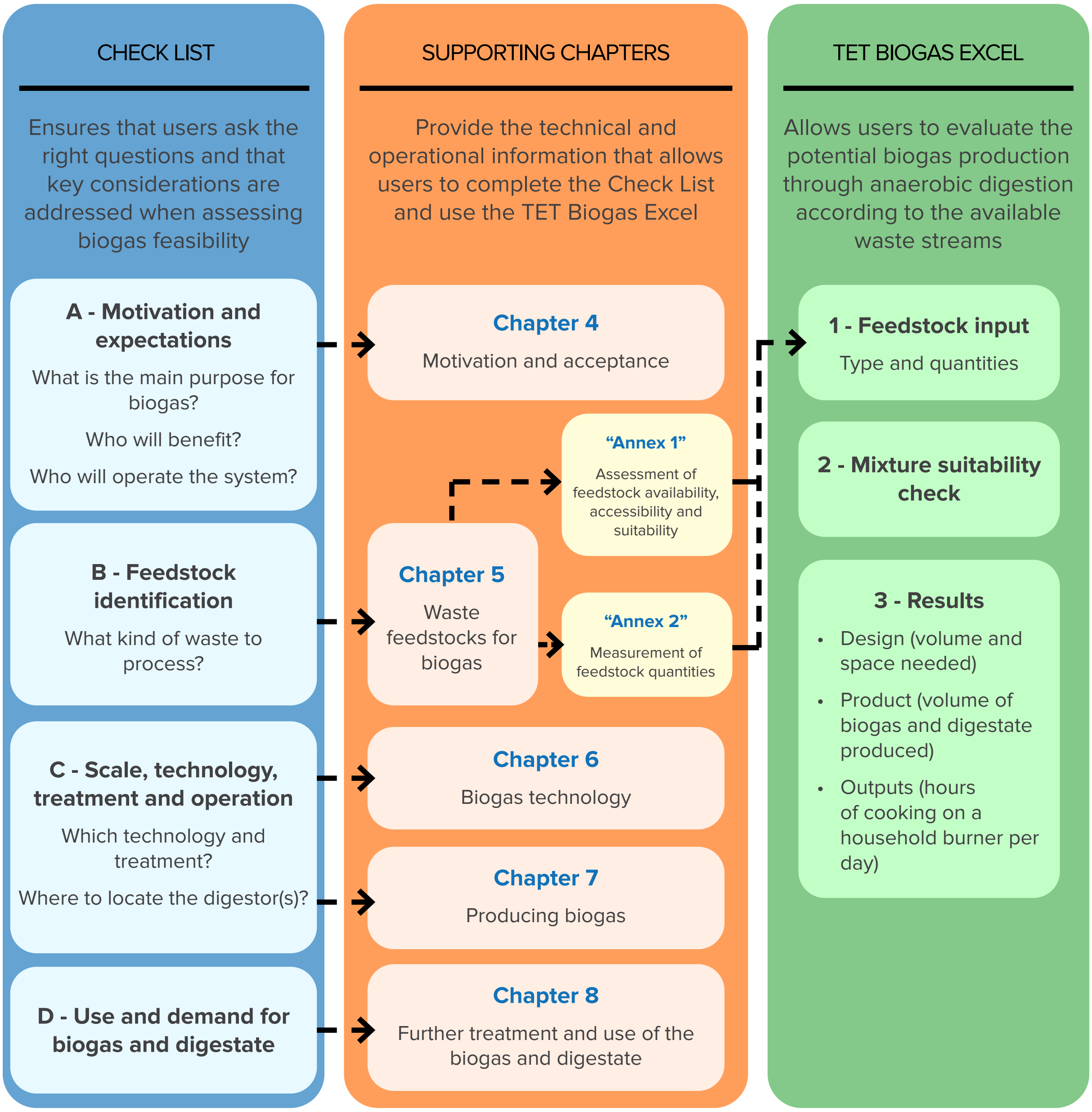

Figure 1: *Navigation tool for the "Biogas Package"*

2. Biogas production at a glance

Anaerobic digestion (AD) is the process where in the absence of oxygen, bacteria break down organic matter. The process generates biogas - a predominant mix of carbon dioxide (CO_2) and methane (CH_4), which can be used as fuel - and also generates digestate, a solid-liquid residue remaining after the AD process, which can be used as fertilizer.

Biogas production occurs in an airtight vessel called an active bioreactor, that is designed and constructed in various shapes and sizes. The active bioreactor contains the feedstock (the waste) and microbial communities that break down (or digest) this feedstock to produce biogas and digestate. The produced gas is stored and captured in the top part of the biogas unit, also called a gas holder. The gas is then removed and transported by pipes for direct on-site use as fuel for combustion or transformed into electricity through a gas-powered generator. Biogas can also be stored outside the gas holder and transported for off-site use as fuel.

Digestate is continuously discharged from the active bioreactor and is further treated before use as a fertilizer or disposal.

Figure 2 illustrates the process steps in an AD system to produce biogas and digestate. This is a very simplified summary. More information can be found in the online book: *Anaerobic Digestion of Biowaste in Developing Countries: Practical Information and Case Studies*.

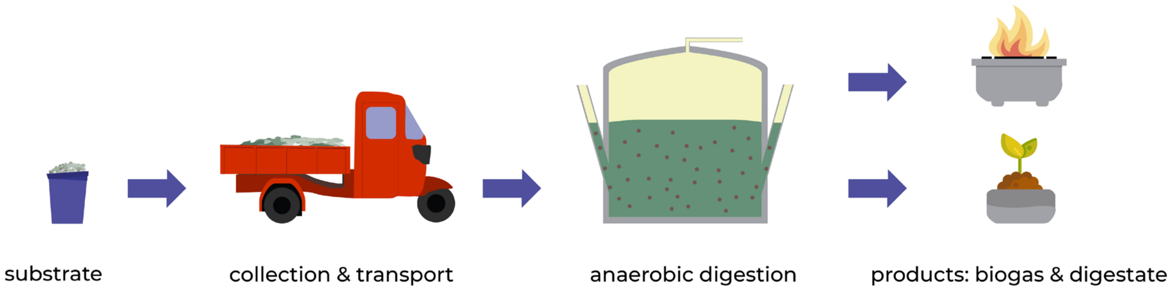

Figure 2: *Process steps in an AD system to produce biogas and digestate*

3. Checklist of tasks to evaluate the biogas option

This chapter summarises the essential tasks and aspects to consider in the evaluation procedure in order to make an informed decision. Answers to the questions listed below are ideally obtained by consulting and discussing with a wide range of stakeholders, using methods, such as individual interviews, focus group discussions, and community meetings. Possible stakeholders to consult are potential local beneficiaries, organic waste generators, local potential biogas operators, camp managers, donors, infrastructure suppliers, waste management consultants, local and national authorities and others that you might identify in your specific context.

A – What are your motivation and expectations for biogas as a solution?

Clearly formulate your motivation and expectations about biogas systems in your specific context.

See **Chapter 4 "Motivation and Acceptance"** for more details.

What is the main purpose for installing biogas systems in your location?

Possible (multiple) answers might be:

- Obtain energy and substitute other fuels
- Obtain digestate for soil amendment and fertilizer
- Reduce pollution (by solid waste, animal manure and sanitation) generated by the current system
- Create incentives to improve waste collection and management
- Create livelihood opportunities
- Others (please specify)

Do you already have some waste generators and wastes in mind for which you would want to use biogas systems as a treatment option?

Consider that you might want to set up a biogas unit for a specific larger waste generator, for instance, a restaurant or a market, or that you might want to provide individual biogas units at household level as a decentralised energy source.

Who is expected to benefit directly, and who are the indirect beneficiaries?

- Who will use the produced gas and the produced digestate?
- Who will obtain revenues and profit from biogas system products' sales (if any)?
- Who will benefit from improved waste management with these new waste treatment options?
- Who will benefit from new job opportunities?

Who is expected to operate the biogas plant(s)?

Depending on the scale and organisational setup, this might be household members, restaurant owners, waste managers, private enterprises, NGOs, etc.

Have biogas systems previously been implemented and operated in the specific location, region and country?

It is important to learn from others and from the past. If biogas systems are or have been used, what kind of setup and technology, at what scale, by whom and what are/were the key factors that influenced success or failure?

B - What waste feedstock are available and accessible for biogas production?

To operate anaerobic digestion to produce biogas, a constant supply of suitable waste is required as input. Therefore, it is critical to understand what kind and what amounts of waste are generated, available and accessible and how suitable they are for biogas production. As an example, the biogas generation potential is very different between dry straw and pig manure. For more details, see **Chapter 5 "Waste feedstocks for biogas"**.

Whose and what kind of waste do you intend to process?

A waste audit answers the questions related to:

AMOUNT: How much organic waste is generated by whom and daily?

This allows for estimating how large the biogas digester system might be.

QUALITY: What kind of organic waste type is it? Is this organic waste clean (sorted or mixed with other waste types)?

The TET-Biogas Excel will assist in calculating the expected biogas yield from different waste types and mixtures.

AVAILABILITY: Do others already use this organic waste for some purposes (e.g. direct animal feed, composting, briquettes for fuel, insect farming, etc.)? Do you have to pay to get this waste?

If there is already an existing use of this organic waste, a new system, such as biogas, might introduce competition and disrupt existing practices.

ACCESSIBILITY: Does the current waste collection system allow for access and separate transport of this organic waste to a location where the biogas system is located?

Understanding the collection and transport aspects are especially relevant if you intend to use a centrally located biogas facility that obtains waste from different sources.

If you have already identified potential waste generators and waste types to use for biogas, roughly estimate, by observation, the daily amounts from these generators. Enter each type of waste and amount in individual rows as feedstock input in the TET-Biogas Excel (*Sheet 1 - Biogas evaluation; 1*) *Feedstock Input*). The tool will then show: a) if the waste type (or combination of waste types) are suitable for biogas processing with regard to water content and C/N ratio (*Sheet 1 - Biogas evaluation in the Mixture Suitability Check section*); and b) will give you a first rough estimation of how much biogas you might expect from a biogas facility treating this waste (*Sheet 1 - Biogas evaluation in the Results – Potential outputs section*). If you want a more precise estimation, you should carry out a detailed waste audit, as explained in **Chapter 5 "Waste feedstocks for biogas".** This step is also recommended in case you have not identified any specific potential waste generators and waste types, but would still like to explore if there is suitable waste from different sources and how much there is.

C - What scale, biogas technology, digestate treatment and operator model do you envisage?

A wide range of biogas digesters types exists on the market, with different sizes, makes and configurations. You will need to make a decision on digester scale and technology type, as well as decide on who will be responsible to operate the system. For more details on scale selection, space considerations, digester technologies and considerations regarding digester components, see **Chapter 6 "Biogas technology"**.

Which digester technology and digestate treatment option are suitable for my situation?

There is no blueprint answer when choosing a digester technology. You will need to evaluate different biogas technologies and digestate treatment options available on the national and international markets. Contact suppliers - which can be local, national, or international, assess their products, as well as previous experience. Take particular consideration of their support package and the support they can provide you beyond implementation (e.g. training of operators and troubleshooting). See **Chapter 6.2** for more information on technologies.

Whenever possible, relying on national suppliers of products of international quality is recommended. National reliable supply chains and expertise will ease access to the operation, maintenance and repair know-how. Obtain quotes from suppliers for different technologies and sizes and identify if the suppliers also provide training and support during the first phase of the implementation.

Discuss different options for the management and operation of the biogas facility

- Who will secure the daily waste delivery in quantity and quality? Who will pay for the service?
- Who will operate the biogas unit(s)? Here, it is essential that those involved in its operation are well informed on what tasks are expected from them, and the time and human resources that will be needed.
- Discuss how fulfilling these tasks will fit into the daily existing working schedule and discuss the financial consequences of the time spent, which can then not be used for other economic activities.
- Evaluate the skills of potential operators and provide a training programme to develop the missing skills.

See **Chapter 7.3** for examples of different operator models.

How many and how large should the biogas facilities be?

Discuss options of scale and number of biogas units with the local stakeholders. Among others, this depends on waste sources, their suitability and amounts.

- The TET-Biogas Excel will help estimate the total volume required based on the suitable waste amounts. This total volume can be either processed in one single digester or in several small digesters.
- It is typically more convenient to treat waste as close to the generation source as possible to avoid transporting it. Therefore, when biogas use and available space allow, scaling and siting the digester at the location of specific waste generators is preferable.

Where will the biogas digester(s) be located?

Criteria for an ideal location are space availability, proximity to waste feedstock and to biogas and digestate users.

- The TET-Biogas Excel helps estimate the total space required for the digester. The estimation includes an extra 30% of space needed for the feedstock preparation, inlet, outlet and buffer area.
- Do not forget that the digestate treatment and storage will also require space. Space requirements will depend on the digestate treatment technology.
- The location of the digester should be close to where the biogas is used as this avoids the need for storage and transport of gas. Gas transport through piping systems should not exceed 100 meters. It is easier to transport waste feedstock to the biogas plants than transporting gas to the user.
- Location selection will also depend on the community mobilisation, acceptance and endorsement.

See **Chapter 6.1** for more details on scale and space considerations of a biogas digester and **Chapter 8.2** for more details on digestate treatment.

D – Who will use the gas and digestate?

The TET-Biogas Excel allows you to estimate the expected biogas and digestate production (Sheet 1 - Biogas evaluation in the Results - Products section). Now, it is up to you to discuss and evaluate who will use this gas and digestate, for what purpose, and what revenues might be generated from the sale of biogas and digestate fertilizer. Make sure that the modalities of use of the biogas are clear and validated by all relevant stakeholders before moving ahead with the project. See **Chapter 8** for more details on gas and digestate treatment and use.

- Who is interested in using the gas, why and where are they located?
- Evaluate the amount of conventional fuel the biogas would replace and calculate the cost savings. First you need to assess how much conventional fuel is used per hour of burning and how much this amount costs. The TET-Biogas Excel (Sheet 1 - Biogas evaluation in the Results – Potential outputs section) estimates how many hours your expected daily biogas production can fuel a household biogas stove. With these two parameters you can easily calculate the cost savings. The TET-Biogas Excel may show that your biogas production will cover only a part of the overall current fuel consumption. Using two different fuel types and sources and the respective modalities will, therefore, need to be considered.
- Evaluate if gas and or digestate can be sold to earn revenues. Compare these revenues with operational costs and calculate the rate of cost recovery (with and without considering capital investment costs).

4. Motivation and acceptance

The main motivations for pursuing biogas waste processing, relates to the expected advantages, such as: reducing the need for other fuels, protecting the local environment and supporting livelihood opportunities. Implementing biogas systems, however, also come with some risks and challenges which, when discussed openly, may significantly impact the motivation of and acceptance by operators and direct beneficiaries of biogas systems.

Depending on the expected beneficiaries and operators, assessing their willingness to collaborate and engage on managing biogas solutions is essential to ensure that anaerobic digestion becomes and remains successful in the long run. The questions in **Table 1** will help to evaluate acceptance and willingness/motivation to engage.

Table 1: *Motivation and acceptance - key questions and methods*

Elements	Questions	Methods
Operating biogas systems requires clear responsibilities and daily tasks	• Are the dedicated staff that will be operating the biogas systems motivated to fulfil this role and do they have the necessary skills or can these be developed through training? The tasks involve regularly feeding the biogas system with waste, as well as regular preventive and reactive maintenance. • Are there individuals committed to use the biogas as fuel? • Are the future beneficiaries fully aware of the required tasks, space needed and the changes it implies in their daily routines? Are they aware that biogas production includes the addition of water, and that daily management of the liquid effluent (digestate) is needed?	Focus group discussions and interviews
Social acceptance of biogas systems	• Does the community have previous negative/positive experiences with biogas production, which could discourage/favour biogas technology?	Interview
Social acceptance of the use of biogas	• Do the biogas users accept to use biogas from organic waste as cooking fuel? • What about the acceptance of specific waste feedstocks that might be used for biogas production (e.g. excreta)? • Will the use of biogas be accepted as a fuel alternative although it may not be able to replace the full amount of current fuel used? • Will the use of biogas as fuel be accepted if the price is the same or even higher than the current fuel used?	Interview
Social acceptance of digestate use	• Do individuals accept the use of digestate as fertilizer, considering that, although high in nutrient content, it may also contain pathogens? • Does the community (product consumers) accept products that have been fertilized with digestate?	Interview
Legislation	• Does any legislation/policy prevent the implementation operation of anaerobic digestion? • Does any legislation/policy prevent the use of biogas or digestate?	Literature review

5. Waste feedstocks for biogas

5. 1. Suitability of waste feedstocks

Waste biomass processed with anaerobic digestion is called “substrate” or “feedstock”. Only organic, biodegradable wastes can be processed by anaerobic digestion, and such organic waste may cover a broad spectrum of waste types. To determine if an organic waste source is suitable for AD, it is important to check the feedstock’s key characteristics. The TET-Biogas Excel contains a list of feedstocks with their characteristics (*Sheet 2 - Feedstock Database*).

Total solids and volatile solids

Each type of organic waste feedstock will show a different biogas potential depending on its specific composition and water content. All waste feedstocks contain a share of water and dry matter. Of this dry matter content, typically referred to as “Total Solids” (TS), it is only the organic biodegradable fraction that contributes to biogas production. This organic dry matter, also called “Volatile Solids” (VS), is an important parameter commonly used to characterise the feedstock. Generally, the VS of suitable biowaste feedstocks ranges from 70% to more than 95% of the TS. Feedstocks with less than 60% VS content are rarely considered suitable feedstocks for anaerobic digestion as the undegradable fraction will accumulate in the active bioreactor, reducing active bioreactor volume and requiring frequent desludging. It is, therefore, important that materials that are not organic or not easily biodegradable are removed from the waste before it is fed into the active bioreactor. This can be achieved by waste segregation at the point of waste generation or by sorting the organic waste before feeding it to the active bioreactor. It is important to note that woody waste (waste with high lignin, wood and carbon content) as a single feedstock in a biogas unit will generate low amounts of biogas as the bacteria have difficulties breaking down such lignin-rich substances. Other examples of unsuitable materials that are often found mixed with organic wastes from households, restaurants, markets, or public spaces are non-biodegradable materials, such as single-use plastic materials (bags, foil, cups, etc.), sand, stones or bones, or else materials which degrade very slowly, such as wood cardboard, corn husks, nut husks, or cooking oils. These should be separated from the organic waste.

The TET-Biogas Excel tool shows examples of different feedstocks and their average biogas yields (*Sheet 2 - Feedstock Database*).

The TET-Biogas Excel tool contains a default list of feedstocks for processing by anaerobic digestion. The list includes typical levels of Total Solids and Volatile Solids. It calculates the respective average expected biogas production rates for each feedstock, as well as for feedstock mixtures based on previous studies and literature.

5. 2. Availability of waste feedstocks

The availability of a specific organic waste stream for AD needs careful evaluation and will depend on:

- the overall amounts of waste generated in the area of consideration
- the seasonal variation of these amounts
- the purity of the waste stream (i.e. contamination by non-biodegradable waste materials)
- the existing waste practices and (re)use of suitable waste materials

Table 2 below summarises the specific questions to answer and suggests methods on how to obtain these answers. Detailed questionnaires are available in **Annex 1** and **Annex 2**.

Table 2: *Feedstock availability assessment - key questions & methods*

Elements		Questions	Methods
General	**Waste source**	Who generates organic waste? (e.g. households, public places, markets, restaurants, animal husbandry, agricultural plots, small food or beverage businesses)	• Interview • Observation
	Waste type	What type of organic waste is produced and by whom? (e.g. branches and leaves, food leftovers, kitchen waste (fruit and vegetable peels), animal manure, human faeces, human urine, crop residue, etc.)	• Interview • Observation
Availability	**Quantity**	How much organic waste (by type) is produced and by whom, per day/week or month?	• Interview • Measurement (**Annex 2**)
	Seasonal variability	How varied is the waste production throughout the year (e.g. during the rainy season, etc.)?	• Interview • Measurement (**Annex 2**)
	Purity	How clean is the waste (e.g. single type of waste or mixed with other waste types)?	• Interview • Observation
	Current (re)use/ Competition	Who already uses the waste and for what purpose (e.g. given to animals, own composting, insect farming, etc.), and what are they currently doing (e.g. paying) to obtain this waste?	• Interview • Observation

A regular and reliable supply of waste and feeding of the feedstock into the digester, according to the digester design, is essential. The biogas system is a biological process where the bacteria need constant food. On one hand, the methanogenic bacteria will starve and die if the biogas system is not fed regularly. Then, the biogas system will have to be restarted, which would slow the procedure. On the other hand, suddenly increasing the waste amounts fed to the digester will also threaten the existing bacteria as this will cause a drop in the pH (acidification) which kills methanogenic bacteria.

Manual sorting of solid waste is inevitable to ensure that impurities in the feedstock to an AD facility are removed, as this may lead to clogging of inlet pipes, reduced biogas yield, frequent desludging of the active bioreactor, and lower quality and acceptability of the digestate.

The purity of organic waste materials is highly dependent on the practices of the waste producers and the collection system. Therefore, it is important to engage and involve the waste producers to ensure that the suitable organic waste remains separate from other waste materials and, if needed, is collected separately. This is called “waste segregation at source” and involves actions by the waste producers to keep and store certain waste materials (in this case, specific organic waste) separately from other waste until separate collection and/or processing. This implies the use of separate bins for the different waste fractions and a separate collection of the segregated fraction. Although a separate collection of segregated waste may increase waste collection and transport costs and complexity, well-segregated organic waste increases the purity and quality of the feedstock, reduces the need for sorting before the waste is fed into the AD digester, making it an important cost factor.

5. 3. Accessibility and transport of organic waste

The logistics of collection of the waste materials is of key importance and the following questions must be answered:

- How easy is it to collect the waste materials for AD processing?
- How much staff would be needed?
- Which collection & transport equipment is needed?
- How much would it cost?

Collecting small amounts of waste generated at many locations is more costly and complex than collecting large amounts in a few locations. Therefore, assessing the accessibility of suitable organic waste materials comprises the questions listed in **Table 3**.

It is important to note that the storage time of collected biowaste should be as short as possible, especially in hot and humid climates. During storage, organic matter decomposes, resulting in smells and attracting animals (flies, rats, etc.). This is not only unhygienic, but also unpleasant for the waste collection workers. Furthermore, with extended storage (periods between collection), the biogas yield will decrease as waste has already degraded and lost some of its energy value. **A daily or every second day collection is recommended for hot and humid climates.**

Table 3: *Accessibility assessment - key questions & methods*

Elements of Accessibility	Questions	Methods
Location	Where are the large waste generators located (map)? How far away are these from the potential treatment location (if already selected)?	• Map • Observation
Dispersed vs centralised	How much of the waste is generated by a few large waste producers?	• Interview • Observation
Collection	What collection system is in place that collects the waste in general or specifically the organic waste? If there is no current collection system in place, how easy/difficult would it be to set up a collection system? How much staff would be needed, which collection & transport equipment, and how much would it cost?	• Interview • Observation

6. Biogas technology

6. 1. Considerations of scale and space for construction

After inserting feedstock types and amounts into the TET-Biogas Excel, the tool estimates the active digester volume required, based on a hydraulic retention time in the digester of 30 days (*Sheet 1 –Biogas evaluation; 3) Results - Design*).

This total volume of waste feedstock can either be processed in one single digester or in several smaller digesters. A decision on the scale (size and number of digesters) is, therefore, required. This may also depend on what digester sizes are available for purchase. Economies of scale come into play where it is typically cheaper to construct one large unit than many small ones for the same amount of volume. Operating several smaller digesters impacts on the operating procedures as the total amount of feed needs to be split for the several digesters (parallel operation).

The TET-Biogas Excel roughly estimates a lower and a higher value of the space needed (*Sheet 1 - Biogas evaluation; 3) Results - Design*). This estimate includes a space requirement to account for feedstock preparation, inlet, outlet and buffer area. Digestate treatment will also require space. Such additional space requirements will depend on the digestate treatment technology selected.

Options of scale and location of the digester(s) depend on waste sources, suitability and amounts, and should be discussed with the future operators and potential beneficiaries.

What factors should you consider when selecting a site for the biogas plant?

- **Proximity of biogas plant to waste feedstocks:** It is challenging to feed the plant daily if the biogas plant is located far from the waste feed material. As a rule of thumb, treating the waste as close to the source of waste generation is typically more convenient to avoid transport. Therefore, siting the digester close to key waste producers is preferred - if space is available.
- **Space:** The area needed for the installation of the biogas plant is determined by its scale.
- **Biogas use:** Consider where the biogas will be used, as gas transport through piping systems before use should not exceed 100 meters. Storage of gas and transport of gas without pipes significantly increases the complexity and reduces its viability.
- **Digestate demand:** Digestate demand refers to the ability to supply the produced digestate to users cost-effectively (e.g. as bio fertiliser in agriculture). Therefore, strategically positioning the site to handle the digestate and its transport is relevant.
- **Access to other utilities:** The area should have a water supply and electricity.
- **Interaction with the environment:** Site safety should also be considered when positioning the plant. The site location requires consideration of the activities in the area, and fencing is necessary to limit access to unauthorised individuals.
- **Terrain and soil characteristics:** Slope and soil characteristics are relevant when evaluating construction and digging.

6. 2. Biogas technologies and components

6. 2. 1. Selecting biogas technologies

A wide range of biogas digester technologies exists on the market in different sizes, makes and configurations. The selection of technology type will depend on the key objectives of the initiative, but also on the availability of the technology for acquisition or construction in the local context.

- Evaluate suppliers of different biogas technologies and digestate treatment options and previous experiences (successes and failures) of these. Whenever possible, relying on local and national suppliers is recommended, as it can help keep the cost of implementation lower than when using international suppliers and will ease the access to the operation, maintenance and repair know-how.
- Obtain quotes from suppliers for different technologies and sizes. Ask specifically for the space requirements and their support services.

Biogas digester technologies come in many forms and sizes, ranging from 1 m^3 for a small household unit to 10 m^3 for a typical farm plant and more than 1,000 m^3 for a large installation. The main types of technologies for small to medium sized units are fix dome, floating dome and tubular polybag. the technology for large sized biogas digesters is a concrete active bioreactor with balloon gas holder. All these technologies are described further in this section.

Biogas technologies can be classified, according to critical operating parameters and elements of biogas technology design. **This guide focuses on systems classified as “wet and continuous”**, which is the most common setup and considered appropriate for the developing country context and most biowaste feedstocks. A wet system indicates a digester fed with feedstocks with a TS content of 16% or less. This “slurry” (a mixture of solids suspended in liquid, usually water) flows like a liquid and can be pumped if required. Continuous systems are those where new feedstock is added at regular intervals. With a new feedstock entering the digester, an equivalent volume of slurry (digestate) leaves the digester. Thereby, a continuous process of digestion takes place. In this configuration, a biogas plant consists of different technology components (see figures in the next pages):

- An **inlet pipe** through which the feedstock is fed into the digester.
- The active bioreactor is a waterproof closed container (typically of cylindrical form) where the feedstocks are degraded by anaerobic bacteria-producing biogas. In some cases, the active bioreactor might include a **stirring device** to ensure a good mixture of the fresh slurry feedstock with the older slurry. The generated biogas rises through the slurry to the top part of the digester into the gas holder.
- The **gas holder** is where the gas rising from the active bioreactor accumulates, and it is temporarily stored before being extracted for use through pipes with valves.
- The **outlet** is at the exit of the digester, followed by an outlet pipe. This area allows the level of the slurry to compensate depending on gas pressure and is, therefore, also called the expansion chamber.
- In the **digestate treatment unit**, the slurry is treated (e.g. dried/dewatered/composted).

6. 2. 2. Common types of biogas digesters

The most common types of biogas digester technologies are briefly described below. They are categorised as "continuous wet digestion systems". This means they operate with daily input of fresh feedstock ("continuous") into the same active bioreactor volume and are fed with a feedstock with high water content or by adding water. The waste material is a slurry and flows like a fluid material. The active bioreactor is always full (steady state system). In other words when fresh materials enters the active bioreactor, digestate leaves the active bioreactor.

A **fixed-dome** plant (**Figure 3**) includes a cylindrical rigid active bioreactor with a rigid gas-holder dome, a feedstock inlet, and an outlet area also called expansion chamber. The gas produced in the digester is stored in the upper part of the unit (in the gas holder dome). With a closed outlet gas valve, gas pressure inside the dome increases with time, pushing the digestate into the expansion chamber. When the gas valve is open for gas utilisation, gas pressure drops, and a proportional amount of slurry flows back from the expansion chamber into the active bioreactor. Typically, such a biogas unit is constructed underground, protecting the active bioreactor from low temperatures at night and during cold seasons. Given that the gasholder dome undergoes pressure, this system needs experienced and skilled construction to ensure gas tightness. Also, given its underground construction, it should be considered as permanent infrastructure.

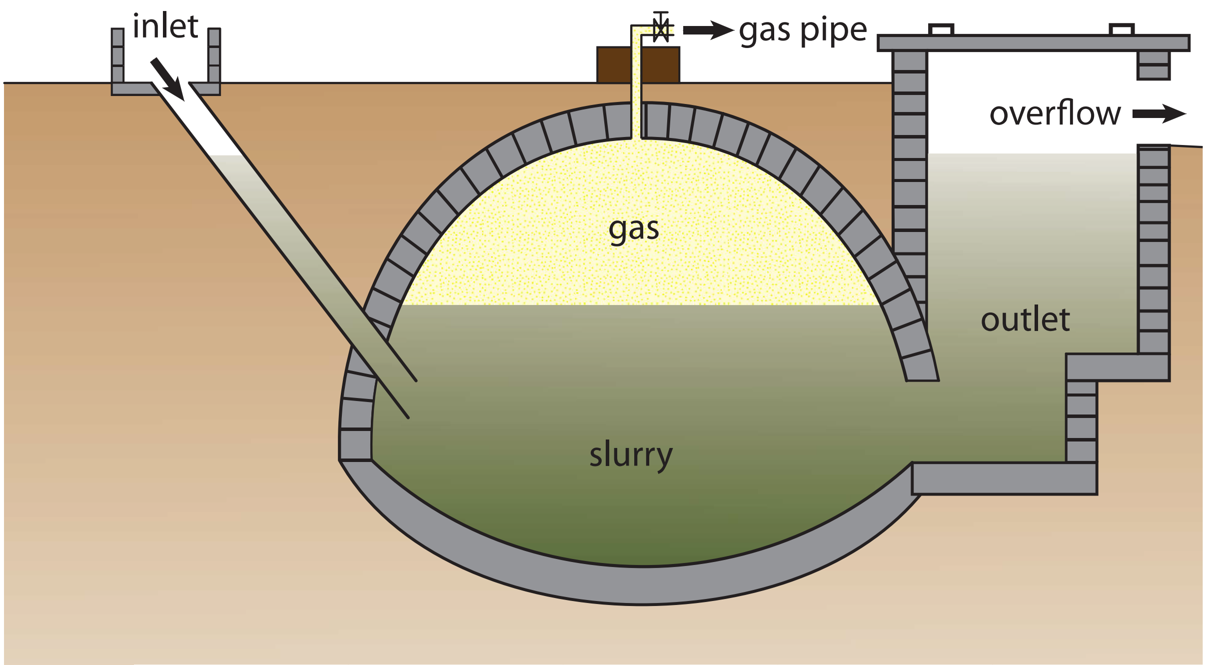

Figure 3: *Fixed-dome plant* ***(source: Vögeli, 2014)***

A **floating-drum** biogas plant (**Figure 4**) consists of a cylindrical active bioreactor and a movable, floating gasholder (drum). The produced gas collects in the gas drum, which rises or falls again, depending on the amount of gas produced and used. The rising and falling drum, thus, provides a helpful visual indicator of the gas production and available gas quantity. The weight of the gas drum creates gas pressure. To increase gas pressure, weights can be added on top of the gasholder.

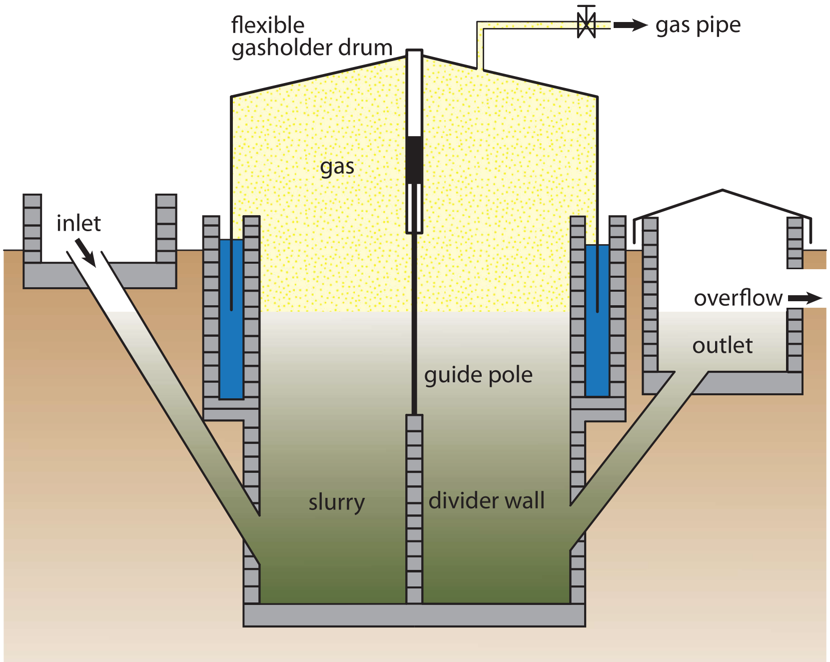

Figure 4: *Floating-drum biogas plant*
(source: Vögeli, 2014)

A **tubular polybag** digester (**Figure 5**) consists of a longitudinal shaped heat-sealed, weather resistant plastic or rubber bag that serves as an active bioreactor and gas holder. The gas is stored in the upper part of the bag, and the inlet and outlet are attached directly to the bag at each end. As a result of the longitudinal shape, no short-circuiting occurs and slurry flows through the biogas unit in a plug-flow manner. Gas pressure can be increased by placing weights on the bag while taking care not to damage it. The benefit of this technology is that it can be constructed at low cost by standardised prefabrication. However, the plastic balloon is quite fragile and susceptible to mechanical damage and has a relatively short life span of 2 – 5 years. To avoid damage to and deterioration of the bag, it is also important to protect the bag from direct solar radiation with a roof. Additionally, it is recommended that a wire-mesh fence protect it against damage by animals.

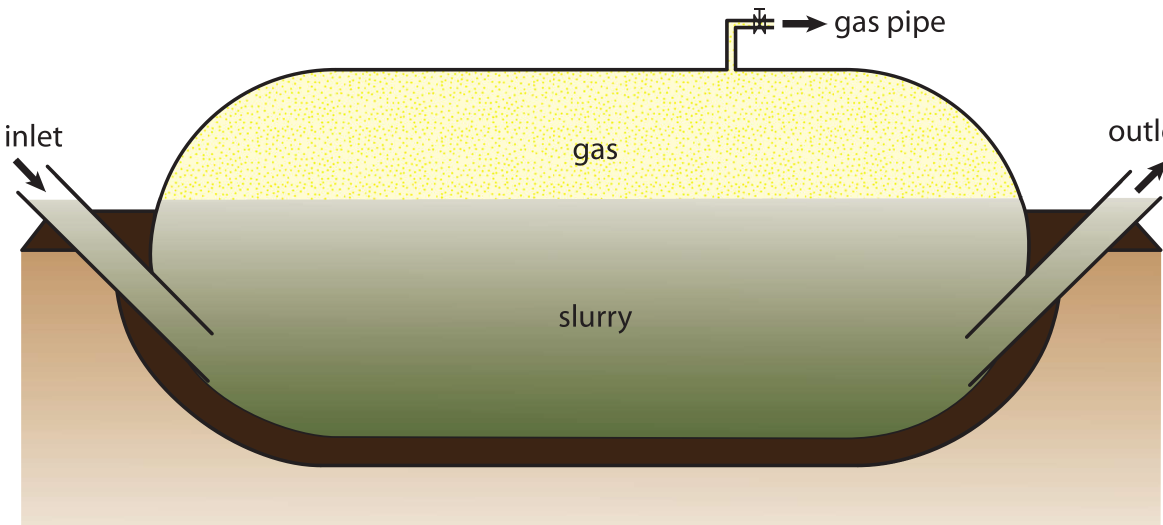

Figure 5: *Tubular polybag digester* ***(source: Vögeli, 2014)***

Concrete digesters with balloon gasholders (**Figure 6**) are typically used for large scale systems, although the technologies described above can also be used for large units. Concrete and balloon designs are typically above-ground and have different units serving different purposes. With this technology, mixing pits are often an additional component. These allow feedstocks to be mixed and homogenised before they are fed into the digester. The mixing pits are equipped with propellers for mixing and/or chopping the feedstock and often a pump is used to transport the feedstock into the digester. The active bioreactor itself is made of concrete or steel and often insulated. Large active bioreactors are almost always stirred by slow rotating paddles, rotors, or injected biogas. The gas holder is usually made of flexible material. It can be placed either directly above the active bioreactor to act as a balloon plant or in a separate 'gas-bag'.

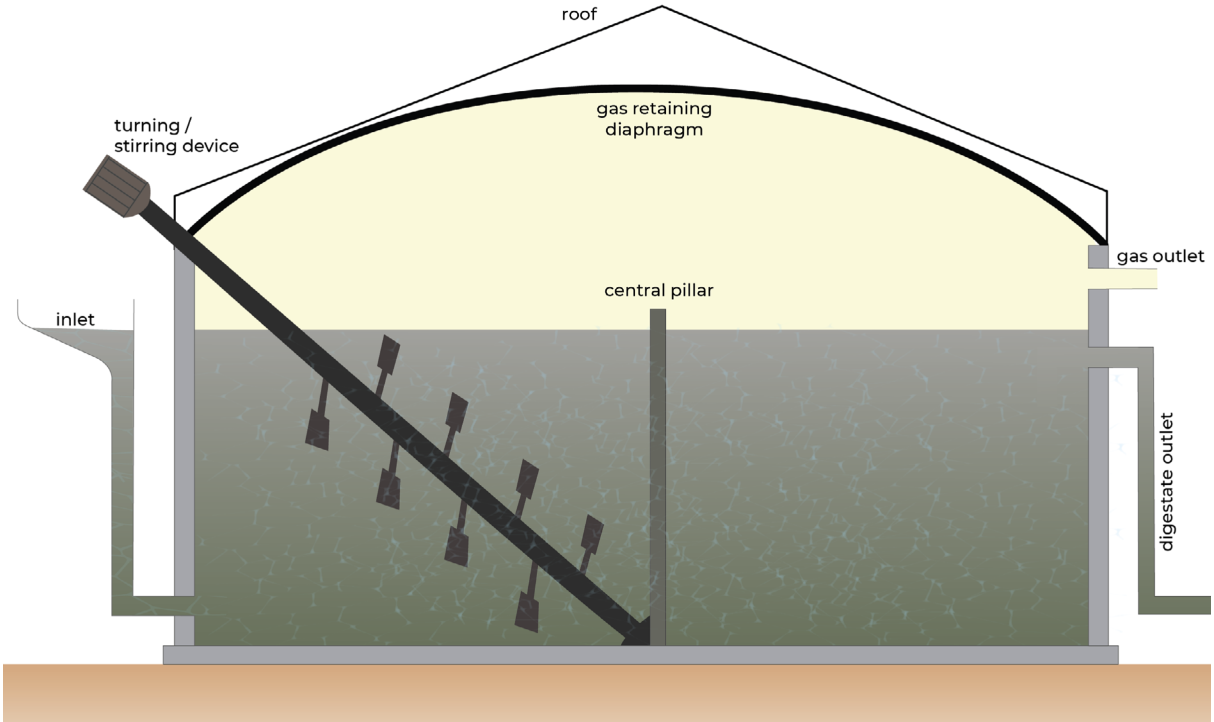

Figure 6: *Concrete digesters with balloon gasholders*

6. 2. 3. Selecting pipes

Biogas is extracted through pipes and valves. The piping system connects the biogas unit with the gas appliances. Galvanised steel (G.I.) pipes, polyvinyl chloride (PVC) pipes, or polyethylene (PE) plastic pipes are the ones most commonly used for this purpose. It is important that these pipes are gas impermeable (gas-tight).

The necessary pipe diameter depends on the required flow rate of biogas through the pipe and the distance between the biogas digester and gas appliances. Long distances and high flow rates lead to a decrease in 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.I. pipes show higher pressure losses than PVC pipes. **Table 4** gives an overview of values for appropriate pipe diameters for a specified length and flow rate, where the pressure losses will not exceed 5 mbar. Flow rate can be calculated by amount of gas produced per day (in m^3) as derived from the TET-Biogas Excel and divided by the number of hours of gas use in hours (h).

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

Table 4: Values for appropriate pipe diameters for specified length and flow rate

Flowrate (m^3/h)	G.I. pipe length (m)			PVC pipe length (m)		
	20 m	60 m	100 m	20 m	60 m	100 m
0.5	½”	½”	¾”	½”	½”	½”
1.0	¾”	¾”	¾”	½”	¾”	¾”
1.5	¾”	¾”	1”	½”	¾”	¾”
2.0	¾”	1”	1”	¾”	¾”	1”

6. 2. 4. Including water traps in the piping

Due to temperature changes, **the moisture-saturated biogas will inevitably form condensation water in the piping system**. Ideally, the piping system should be laid out to allow a free flow of condensation water back into the digester. The inclination should not be less than 1%. If depressions in the piping system cannot be avoided, one or several water traps have to be installed at the lowest point of the depressions. 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. Automatic traps have the advantage that emptying - easily forgotten - is unnecessary. If they dry up or blow empty, they may cause heavy and extended gas losses.

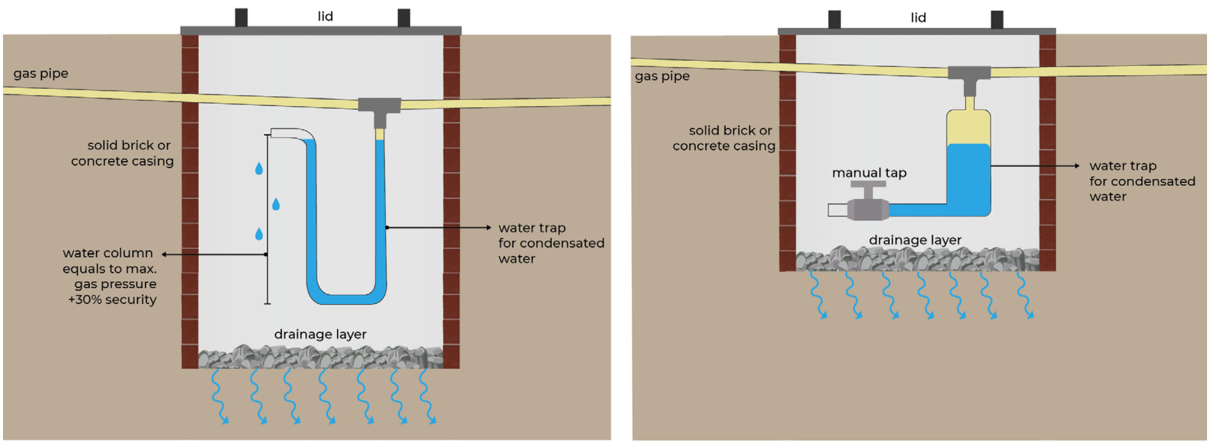

Figure 7: Automatic and manual water traps

6. 2. 5. Selecting valves

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 generally used for water pipes are not suitable**. Any water valves used must first be checked for gas-tightness, and they have to be greased regularly. 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. Cleaning and maintenance work can be carried out with shutoff valves without closing the main gas valve.

7. Producing biogas

7. 1. Preparing waste feedstocks for biogas

Most of the feedstock requires some preparation before digestion. This includes:

- Sorting (if not already done at source)
- Reducing particle size
- Mixing different feedstocks

Sorting: Even with waste segregation at the source, some non-biodegradable materials, such as metals, plastic and glass, may still be in the waste collection for anaerobic digestion. This can cause disturbances in the feedstock flow, it may clog pipes and can remain as noxious matter in the digestate. The feedstock should also be free of such impurities as grit and sand, as these will precipitate in the active bioreactor and reduce the volume available for treatment.

Particle size: Reducing the particle size of the feedstock is important to avoid blockage of the inlet pipe and to increase the ease of degradation. Generally, feedstock particle sizes with a diameter of max. 5 cm are recommended, although the ideal size also depends on the diameter of the inlet pipe. This can be achieved with a manual or mechanical shredder.

Mixture: Feedstock type and quality influences biogas production. The quality is expressed by TS content and VS content, as well as by the relationship between the amount of Carbon and Nitrogen in the organic materials, called the C:N ratio. Optimal C:N ratios in anaerobic digesters are between 16 and 35. Mixing different feedstocks and adding water to the mixture is a way to control the C:N ratio and the TS content.

The TET-Biogas Excel contains a default list of feedstocks and allows for evaluating how a mixture of feedstocks affects biogas yield. The average values of Carbon and Nitrogen are provided for each feedstock listed. The TET also informs about the need for additional water in the mixture.

When you enter each type of feedstock and amount in individual rows as feedstock input in the TET-Biogas Excel (Sheet 1 - TET Biogas; 1) Feedstock Input). The tool will then show if the waste type (or combination of waste types) are suitable for biogas processing with regard to water content and C:N ratio (Sheet 1 - TET Biogas; 2) Mixture Suitability Check).

7. 2. Operation and maintenance

The efficiency of the anaerobic process is affected by the waste type (or mixture of types) and other operational parameters. The operational parameters determine how well the microorganisms grow and, therefore, how well they produce biogas. Operation tasks involve continuously monitoring and controlling these parameters in order to ensure the optimal gas productivity of the digester.

7. 2. 1. Starting the biogas digester

The start-up process of a biogas digester consists of introducing the methanogenic bacteria into their new environment and allowing them to grow so that they operate efficiently with your feedstock to produce biogas. This is the inoculation phase.

The easiest way to start up an active bioreactor is to fill it up with the digestate of another biogas digester. Then, start by adding cow manure until you notice biogas production. Thereafter, you can add increasing amounts of your normal feedstock.

Alternatively, cow manure can be conditioned (optimally 1:1 ratio with water) for a week before filling this into the active bioreactor filled with water. Typically, the minimum cow dung required for good inoculation amounts to 10% of the total feedstock input. In general, the more cow dung used for inoculation, the better. When you notice biogas production, you can gradually start adding some “normal” feedstock to the active bioreactor. Starting with small amounts and progressively increasing the daily feeding load will assist in achieving a balanced microorganism population.

7. 2. 2. Operational parameters

Loading Rate

The loading rate is the amount that is fed into the active bioreactor volume in a given time. However, as it is only the amount of organic matter fed into the active bioreactor that contributes to the biogas production, the Organic Loading Rate (OLR) is used as an operational parameter. The OLR represents the organic feedstock quantity introduced into the active bioreactor volume in a given time and the unit is kilogram of VS per m^3 of active bioreactor volume and day.

Overloading the active bioreactor with feedstock can result in acidification and system failure. On the other hand, underloading will lead to low biogas production. Lack of feeding for extended periods of time (weeks) may even lead to the die-off of the methanogenic bacteria. After that, the system will need to be “rebooted”, requiring an inoculation step, as when starting a biogas digester. Studies show that in non-stirred biogas systems, which are predominant in developing countries, the optimum OLR is around 2 kg VS per m^3 active bioreactor volume and day.

Based on the amount of feedstock type and water entered in the TET-Biogas Excel, the tool suggests a digester size (Sheet 1-TET Biogas; 3) Results). This calculation ensures a suitable ORL.

Hydraulic Retention Time

The Hydraulic Retention Time (HRT) quantifies the time the amount of material (feedstock and water) fed daily into the active bioreactor remains in the digester. HRT is calculated by dividing the active bioreactor volume with the volume of material (feedstock and water) fed to the digester per day. Recommended HRT range from 10 to 40 days, and the average is 30 days. This means that the volume of the biogas active bioreactor must be able to contain the amount of 30 days of material (feedstock and water). Lower HRT do not give the bacteria enough time to degrade the feedstock and achieve good biogas production. High HRT allows the bacteria to complete degradation and generate high biogas production. However, this would require a large active bioreactor volume and, therefore, a larger space and higher costs.

Based on the amount of feedstock type and water entered in the TET-Biogas Excel, the tool suggests a digester size (Sheet 1 - TET Biogas; 3) Results) which is based on a HRT of 30 days.

Temperature

For our purposes the most relevant temperature range for the performance of anaerobic bacteria is between 30 – 40°C (optimum temperature 37°C) at which mesophilic microbial communities thrive. At ambient temperatures below 15°C, the anaerobic digestion process does not satisfactorily work. Not only is the mean ambient temperature an important parameter for the AD process, but significant temperature variations, such as those between day and night, or seasonal variations, can also adversely affect the performance of an AD system. Digesters built underground help to minimise these changes by using the temperature buffer capacity of the soil.

7. 2. 3. Operation and maintenance tasks

Proper operation and maintenance of the different technical components of the biogas plant are essential to achieve and maintain high levels of gas production and to ensure efficient and long-term performance. A well designed biogas digester should only require minimum daily care. It is, however, important that the operators are provided with proper training and clear instructions to understand the required tasks and their importance. It is useful to develop and implement an operational plan that includes a clear allocation of responsibilities, a task schedule, and control mechanisms to check if duties have been conducted properly.

Daily activities

- Daily delivery of feedstocks should be measured by weight with scales or by volume using containers with a predefined volume and checked visually for impurities (e.g. inorganic materials, such as glass, metals, plastics, etc.) that should be removed by sorting.
- The feedstocks need to be prepared consistently, i.e. particle size of all feedstocks must be reduced to 3 – 5 cm.
- If available and necessary, different specific feedstocks should be mixed to obtain a suitable C/N ratio and moisture content. Check in the TET-Biogas excel tool if needed.
- Moisture content can be increased by adding water. You can estimate how much is required with the TET-Biogas excel tool.
- The plant should be fed every day with a feedstock or a mixture of feedstocks to provide bacteria with constant feeding to achieve stable gas production.
- There is also the option to improve mixing and inoculation within the reactor by taking some of the digestate outflow and feeding this back into the digester through the inlet. This results in a passive mixing process also called “recirculation”. It not only improves the mixing of fresh feedstock with bacteria-rich digestate, but also helps to flush the inlet pipe.

Weekly to monthly activities

- The appearance and odour of the digested slurry need to be checked regularly. If well digested, the effluent should not have an acidic odour. If the pH measurement of the digestate is below 5.5, feeding has to be stopped and only started again once the pH has stabilised with a gradual increase of the feeding rate.
- Condensed water in the gas pipes should be removed on a weekly to monthly basis to ensure that the biogas can pass through the gas pipe. See Section 6.2.2 for more information.
- The gas pipe from the digester, valves, fittings, appliances and gas storage balloons must be checked for leaks. Similarly, gas pipes and joints of the biogas stove need to be checked to ensure they are still gas-tight when valves are closed. Leaks can be detected either by smell, as biogas contains small amounts of hydrogen sulphide, which smells like rotten eggs, or by smearing some liquid detergent onto the place where leakages could be expected. If leaks are present, bubbles will be observed at those locations.
- Leakages have to be repaired immediately with sealant.
- If the biogas is meant to be used as cooking fuel, the biogas stoves need to be cleaned regularly. Food particles and dust must be removed to avoid clogging the biogas stoves’ air intake holes.
- Grease should be applied to all movable parts of the biogas stove.

Annual activities

- Conduct a pressure-test with pipes and valves. Do this by connecting a gas pressure meter (0 – 160 mbar) between the digester valve and the kitchen valve. With the closed kitchen valve, open the digester valve and observe pressure rise up to at least 100 mbar, then close the digester valve again. Wait 10 minutes and observe the pressure meter. If the pressure decreases by more than 5 mbar, use detergent and water to detect and fix the leaks.
- Check the gas tightness of the dome (pressure-test). Open the digester valve while the kitchen valve remains closed. Operate the digester, but do not use any gas for several days, and observe the increase in pressure. If the pressure never rises up to the maximum design pressure (i.e. the pressure at which the slurry level in the compensation chamber reaches the overflow point), the dome is probably not gas-tight and needs to be checked and repaired.
- Check for blockage of the inlet pipe. Depending on the design, the inlet pipes can be unblocked either with a long plastic tube or wooden stick at the feeding point or at the inspection chambers (if available).
- Observe the slurry level in the compensation chamber. The level should be high in the morning as the gas is produced overnight and lower during the day when the gas is consumed.
- Control the biogas stove and check the flame:
    - Elongated yellowish flames indicate incomplete combustion (meaning unwanted CO and CH_4 emissions in the kitchen); therefore, the oxygen intake needs to be better regulated at the stove inlet to let more air into the system.
    - Flame lifts off: this indicates excessive pressure (either the diameter of the gas injector is too big or the valve is too wide open, stoves often have a design pressure in the range of 8 to 16 mbar, so higher pressure needs to be avoided).
    - Flame extinguishes: this indicates little gas flow or low gas pressure. This may be due to a corroded or blocked injector which must then be repaired.
    - Flame is small: which indicates a low gas flow rate, resulting from a blocked gas pipe (blocked by slurry or water) or gas leakage in the system.
    - Flame is big: this indicates excessive fuel supply. Burner holes may be corroded or too big, or the injector diameter is too big.
    - Thick reddish or fluttering flame or flame too small: this indicates a low flow rate (blocked gas piping by slurry or water).
- For floating dome biogas technology: For metal floating drum digesters, the gasholder drum needs to be removed and the inside annually repainted with anticorrosive paint.
- Remove the accumulated sludge on the bottom of the digester. The frequency of desludging depends on many parameters, but if properly designed and operated, sludge emptying should only be necessary every 5 – 10 years. If all the above measures have been performed, but the gas production is still deficient, it may be that over the years, the active bioreactor volume has decreased because of accumulated sludge on the bottom of the digester. In this case, the sludge must be removed with a pump from the bottom of the digester.

7. 3. Models of operation

Who will operate the biogas digester? There is no blueprint answer to this question, as this depends on where the digester is located, the size of the digester, and the biogas system's objective. In all cases, skilled operators are required, and this requires people being educated on biogas processes and operation and, ideally, experience in reacting to the circumstances which can threaten the anaerobic digestion process. It is essential to discuss the options of a management system.

- Who will secure the waste delivery in quantity and quality so that operators can feed the biogas digester?
- How do the tasks of the operator fit into the daily existing "other" work-schedule and how is the operator time remunerated?
- What are the current skills of potential operators and how can these be developed and maintained through a training programme?

Operational models can include on-site trained operators for every digester or a responsible operator who services a number of digesters on a regular daily basis.

Household scale biogas digester: These are typically small in volume and designed for waste produced by one or two families. Usually, this system is operated by a household member who does not receive incentives, but who conducts the activities as there is an interest in the resulting products (gas and/or digestate). The household should be properly trained on operation and maintenance, including handling of the digestate.

Medium-scale biogas digesters: These are usually placed at markets, restaurants or livestock rearing facilities. In these cases, the digester is located at the location where significant amounts of organic waste are produced daily and where gas might also be directly used as a fuel or heat source at the same location. Larger biogas digesters will need more operator time and one or more skilled and dedicated staff members. The operators in such cases are typically salaried, but may also be operating the biogas digester as a side activity or through a community mobilisation approach.

For the small and medium scale set up, the "service" operator model could also be envisaged for monthly and yearly maintenance tasks, which means that skilled and salaried staff be paid to take care of a large number of biogas digesters. This also ensures that they are well operated and functional.

Large scale biogas digesters: These are located at one central point and receive feedstock from many locations and sources, which are transported and delivered by a waste collection service. Here, the typical operator model is through an enterprise approach where skilled staff are employed and manage the facility daily.

8. Further treatment and use of the biogas and digestate

8. 1. Biogas

As described above, most biogas digester technologies already include a gasholder and storage container in their setup. Biogas is best used at the location where it is produced. In low- and middle-income countries, it is most commonly used in stoves, lamps and engines, ideally in biogas stoves. The energy conversion efficiency of using biogas is 55% in stoves, 30% in engines and only 3% in lamps. A biogas lamp is only half as efficient as a kerosene lamp.

Often, the biogas produced may not suffice to cover the total demand, e.g. for cooking. Therefore, provisions must be taken so that biogas can be used with a stove separate from the conventional cooking system. For example, a restaurant may not be able to generate all the biogas needed for their kitchen. Therefore, this restaurant will need to keep their current cooking system and in addition install a biogas stove that is connected to the biogas digester.

Table 5 shows some examples of consumption rates of biogas depending on the equipment used. Direct burning of biogas in stoves is the easiest way of taking advantage of biogas energy for households, restaurants, communal kitchens or commercial production, thereby replacing traditional cooking fuels, such as wood, charcoal or Liquefied Petroleum Gas (LPG).

Table 5: *Consumption rates of different biogas appliances* ***(Kossmann et al., undated)***

Biogas Application	Consumption Rate (L/h)
Household cooking stove	200-450
Gas lamp, equivalent to 60 W bulb	120-150
Biogas/diesel engine per brake horsepower (746 watts)	40
Generation of 1 kWh of electricity with biogas/diesel mixture	700

Gas as direct fuel: Burning biogas in stoves requires a specific biogas stove, which is a relatively simple appliance for direct combustion of biogas. The biogas stove is different from the regular gas stove since biogas is far less compressed. Therefore, air has to mix with biogas at the inlet and the gas burner flame openings need to be wider for better combustion. The biogas might be used for different purposes, such as cooking, roasting (e.g. peanuts), and soap making, etc. It is important to consult with the potential beneficiaries in each context and agree about the use of the biogas at the onset of the project.

Gas converted to electricity: Converting biogas to electricity is complex, expensive, not very efficient, and not feasible for small-scale installations. Each cubic meter (m^3) of biogas contains the equivalent of 6 kWh of heating energy. If biogas is converted to electricity in a biogas powered electric generator, about 2 kWh of useable electricity can be obtained per m^3 biogas (2/3 of the energy content is lost as heat). Such 2 kWh can power 20 light bulbs of 100 W each. In order to continuously operate a 2 kW generator, 24 m^3 of biogas is needed per day, and this would require approximately 240 kg of biowaste per day. Therefore, conversion to electricity is only appropriate for medium to large scale digesters with an abundant daily waste feedstock.

Using gas driven engines or generators to produce electricity from biogas requires additional capital investment for buying the generator (or engine) and for installing and operating biogas cleaning/refinement technology. Biogas cleaning is necessary because when it leaves the digester, it is saturated with water vapour and contains CO_2 and varying quantities of hydrogen sulphide (H_2S). These components in biogas need to be removed when using biogas in generators or engines as water vapour and CO_2 do not have any energy value and hydrogen sulphide (H_2S) is corrosive to metal and is toxic. The main gas cleaning steps involve more complex equipment and skills not explained further here. Such installations will increase the complexity and costs of the system (in capital and operational costs) and severely threaten the financial and operational feasibility and sustainability of biogas systems (see chapter 4.3 of the online book *Anaerobic Digestion of Biowaste in Developing Countries: Practical Information and Case Studies*).

8. 2. Digestate

The digestate is another valuable product derived from the anaerobic treatment process. Commonly, the digestate is a very liquid slurry as most of the volatile solids have been decomposed during digestion and the non-volatile solids have settled to the bottom of the digester. The digestate is rich in nutrients, but may contain pathogens. Given the environmental and pathogenic risks, its application should be restricted to food crops grown above ground (without direct contact to soil) or non-food crops. Proper awareness raising should be done for the people using the digestate on how to use it. It should not be discharged into water bodies before further treatment.

For small AD units where on-site digestate treatment may not be feasible, direct use of the digestate for land application can be envisaged as fertiliser or soil amendment, with the above-mentioned restrictions. Areas with the following characteristics are not suitable for digestate application:

- where the groundwater table is less than 1.5 m from the natural surface
- rocky soils, or soil depth less than 1.5 m
- a slope greater than 1 in 5 (20%)
- seasonally waterlogged or classified as being poorly or very poorly drained
- subject to flooding (the site should not be subject to flooding more frequently than once in 10 years)
- known or potential problems with salinity that any application of digestate may exacerbate
- risk of nutrients being leached from the root zone into groundwater
- bare or no ground cover with no plants or pasture to utilise the nutrient loading.

For medium and large scale units, it is recommended to follow the treatment steps of DEWATS systems, which are designed to be low maintenance, reliable, long lasting, and tolerant towards fluctuations in the inflow and operate with minimal electrical energy input (Ulrich et al., 2009). Elements of a DEWATS for treatment of AD digestate include the following:

- Sedimentation of sludge in sedimentation ponds, septic tanks or anaerobic baffled reactors.
- Aerobic/anaerobic treatment of the effluent in constructed wetlands (subsurface flow filters)
- Sludge treatment by composting. High temperatures during the composting process resulting in pathogen deactivation.

9. References

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ANNEX 1 - ASSESSMENT OF FEEDSTOCK AVAILABILITY, ACCESSIBILITY AND SUITABILITY

A: General

1. **Waste source -** Where does the organic waste come from?

- ☐ Households
- ☐ Common spaces
- ☐ Market
- ☐ Restaurants
- ☐ Animal husbandry
- ☐ Agricultural plots
- ☐ Small food businesses
- ☐ Small beverage businesses
- ☐ Other: ______________________________

2. **Waste type** - What type of organic waste is produced?

☐ Food leftovers
☐ Kitchen waste (fruit and vegetable peels)
☐ Branches and leaves ☐ Animal manure Please specify from which animal: _______________
☐ Crop residue Please specify from which crop: _________________
☐ Human faeces
☐ Other: ____

B: Availability

3. **Quantity -** How much organic waste is produced per day/week or month?* (in kg per unit of time or L per unit of time):

____

* If the quantities are unknown, please see how you could measure them in **"Annex 2"**.

4. **Seasonal variability** - Does the waste production vary throughout the year? (e.g. during religious festivals, during the rainy season, etc.)? If yes, specify when (period) and how much it varies.

- ◯ Yes

  When: ____

  How much does it vary (1/2, 2x, 3x, etc.): _____________

- ◯ No

5. **Purity** - Is the waste mostly "pure" (i.e. organic waste only), or is it mixed with other types of waste (e.g. plastic waste)?

- ◯ Pure
- ◯ Mixed: Please specify: _____________________

6. **Current (re)use / Competition** - Is the waste already used for something else? (e.g. given to pigs, composting, etc.)? If yes, does it have a price? If yes, how much?

◯ Yes*

Describe the current (re)use practice: ______________________

Actual price: ______________________

◯ No

* This practice might compete with the AD process!

C: Accessibility

7. **Location** - Where is the waste source located (map)? Is it far away from the potential treatment location?

____

8. **Dispersed vs. centralised** - Is the waste produced in large amounts at a few locations or small amounts in many dispersed locations?

◯ Dispersed

Please specify: ___________________

◯ Centralised

Please specify: ___________________

9. **Collection** - Is there any collection system in place to collect the organic waste? How easy/difficult would it be to set up a collection system?

◯ Yes, the organic waste is currently being collected

◯ No, the organic waste is not currently being collected

Please specify how easy/difficult it would be to set up a collection system:

____

D: Suitability

10. **Feedstock suitability** - Is the waste a suitable feedstock for anaerobic digestion?*

◯ Yes

◯ No

* Use the TET-Biogas Excel to answer this question

11. Social acceptance - Is it socially acceptable in the given context to use biogas from organic waste as cooking fuel?

◯ Yes

◯ No

12. Past experience - Was there any previous negative/positive experience with biogas production which could discourage/favour biogas technology?

◯ Yes, positive experience

Please specify: _____________________________________

◯ Yes, negative experience

Please specify: _____________________________________

◯ No experiences

13. Legal framework - Is there any legislation/policy preventing the use of biogas or digestate?

◯ Yes

Please specify: _____________________________________

◯ No

ANNEX 2 - MEASUREMENT OF FEEDSTOCK QUANTITIES

If no data is available on the quantities of waste produced, some measurements can be performed. The measurement procedure varies depending on the source of waste considered.

A. Household, market, restaurant

Necessary equipment:

- Recording sheet & pen
- Scale (for weighing) or 10L / 20L bucket

  Recommended scale: hanging scale (digital, capacity 50kg, accuracy 0.1 kg)

Measurement period: 7 to 14 days

Procedure: Each day, weigh the organic waste generated on that day.

If no scale is available, you can also evaluate how much the bucket is filled with waste (e.g. ½ of a 10L bucket, ¾ of a 20L bucket, etc.) and later convert it to weight. To convert it to weight, you can use a density of 300 kg/m^3.

Recording sheet

Day	**Weight of waste generated** *If no scale is available, please note the estimated volume of the filled bucket (e.g. ¾, ¼, etc.). Make sure to write down the unit (weight or volume of bucket).*	**Comments** *Please specify if the waste is purely organic or mixed with other types of waste (e.g. plastic waste).* *Also, note the type of waste observed (e.g. fruit and vegetable peels, rice, etc.)*
Day 1		
Day 2		
Day 3		
Day 4		
Day 5		
Day 6		
Day 7		
Day 8		
Day 9		
Day 10		
Day 11		
Day 12		
Day 13		
Day 14		

B. Animal husbandry

To estimate the quantity of manure produced, the values presented in the table below can be used:

Manure type	Amount
Pig/Sow manure	4.5 kg/pig/day
Young pig manure	1 kg/pig/day
Cow manure	50 kg/cow/day
Chicken manure	0.20 kg/chicken/day

C. Human faeces and urine

When evaluating the amount of human faecal waste, it is best to obtain values from pit and/or septic tank sludge emptying. If this is not possible the table below allows for a rough approximation based on literature values.

Organic waste type	Amount
Faeces	0.35 kg/person/day
Urine	1 L/person/day
Pour flush water	4 L/person/day

ACKNOWLEDGEMENTS

Authorship
These guidelines have been developed by the Swiss Federal Institute of Aquatic Science and Technology (Eawag) in collaboration with the Geneva Technical Hub, embedded in UNHCR's Technical Support Section.

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Funding
The Geneva Technical Hub and the backstopping mandate by Eawag are funded by the Swiss Agency for Cooperation and Development (SDC).

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LINKS
- UNHCR WASH
- Geneva Technical Hub

Cover Picture: Yuhei Honda, UNHCR. Tongagara, Zimbabwe.

First edition, March 2024.

GENEVA TECHNICAL HUB | Co-convened by UNHCR The UN Refugee Agency

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