Biogas Guidebook
for Small- to Medium-Scale Industrial Biogas Plants in South Africa

forestry, fisheries & the environment
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Contents

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Our apologies, if we have excluded and individual or an organisation.

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Acronyms

AD	Anaerobic digestion
BMP	Bio-methane potential
CHP	Combined heat and power
CNG	Compressed natural gas
COC	Certificate of compliance
COD	Chemical oxygen demand
CSTR	Continuously stirred tank reactor
DM	Dry matter
FiT	Feed-in tariffs
HDPE	High density polyethylene
HRT	Hydraulic retention time
ICP	Inductively coupled plasma
GUP	Gas upgrading plant
MSW	Municipal solid waste
LNG	Liquefied natural gas
LFG	Landfill gas
O&M	Operation and maintenance
oDM	Organic dry matter
OLR	Organic loading rate
POW	Pure organic waste
PP	Polypropylene
ppm	Parts per million
PVC	Polyvinyl chloride
SRT	Solid retention time
TS	Total solids
VFA	Volatile fatty acid
VOC	Volatile organic compound
VS	Volatile solids
WWTP	Wastewater treatment plant

Glossary

Acidification: Making or becoming acid; converting into an acid. This happens in a digester when acidic molecules are produced at a faster pace than they can be pro-cessed by the bacteria.

Biogas production: The amount of biogas (m^3) produced in a defined period of time (per hour or per day)

Biogas yield: Potential amount of biogas which can be produced from any specific type of feedstock

Bio-methane potential (BMP): A measure of the possible methane yield resulting from digestion of a feedstock

Combined heat and power (CHP): Describes a generator unit that combines the generation of electricity with the capturing of thermal energy. The conversion of chemically bound energy into electrical energy and thermal energy occurs on the basis of an engine linked to a generator.

CSTR: A continuously stirred tank reactor is a conceptual model for a type of reactor. The fundamental assumption is that the entire contents of the reactor is constantly mixed such that all concentrations are homogeneous within. In practice, well-mixed reactors are labelled CSTRs.

Digestate: The effluent of a biogas plant, which remains after the biogas has been extracted

Digester volume: The gross digester volume is the theoretical maximum volume of the digester.

Digester: A vessel where chemical or biological reactions are carried out. Sometimes called tank, reactor of fermenter.

Dry matter: The portion of material that is not water/moisture. It is determined by drying the sample at around 105°C to ensure all water has evaporated. It is measured in tonnes, typically shown as t/a, t/d, or in % of fresh mass (FM).

Energy crop: A plant that is grown and harvested for the production of energy only. An energy crop is not a by-product of other processes like feed or food production.

Feedstock: Biomass or organic waste that is processed in a biogas plant

Fresh mass: Mass of fresh feedstock, including water, which is fed into the digester. It is measured in tonnes, typically shown as t/a, t/d.

HRT: A measure of the average time material is retained in a vessel (e.g. digester), defined as the ratio of vessel volume (m^3) and total feeding rate (m^3/day). The unit is measure of time, e.g. days.

Mesophilic: Refers to a particular temperature range for digestion, namely 38–42°C

Organic dry matter (oDM): Organic components of dry matter (dry matter - raw ash = organic dry matter). Only the organic part (not the ash content) contributes to the generation of biogas. oDM indicates the potential of organic waste substances to contribute to biogas generation. It is measured in kg or tonnes, and sometimes in % of dry matter (DM).

Organic volume load / organic loading rate: Indicates how much organic dry matter per day is fed into the digester of a certain size

Outgassing: The release of gas that was dissolved, trapped, frozen or absorbed in any material.

Raw ash: Mineral content of organic waste (feedstock). To measure raw ash, a sample of feedstock (FM) is taken and mixed, and the water is then vaporized. What remains is referred to as dry matter. If the DM is burned off, raw ash remains.

Renewable resources: A natural resource which replenishes to overcome resource depletion caused by usage and consumption, either through biological reproduction or through other naturally recurring processes

Sewage sludge: By-product of sewage treatment of industrial or municipal wastewater treatment works (WWTW). It is a residual, semi-solid material.

Thermophilic: Temperature range for digestion, namely 52–65°C

Volatile fatty acids: A group of organic acids including acetic acid, propionic acid, butyric acid and valeric acid

Wobbe Index: An indicator for burning characteristics and the interchangeability of fuel gases such as natural gas and bio-methane. It is defined as heating value divided by the square root of the specific gas density.

Chemical compounds

$CaCO_3$	Calcium carbonate
CH_3COOH	Acetic acid
CH_4	Methane
CO_2	Carbon dioxide
$C_2H_3O_2$	Acetate
CO_3^{-2}	Carbonate
$C_4H_8O_2$	Butyric/valvic acid
H_2	Hydrogen molecule
H_2CO_3	Carbonic acid
H_2S	Hydrogen sulphide
H_2SO_3	Sulphuric acid
Fe	Iron
$FeCl_3$	Ferric solution
$Fe(OH)_3$	Iron hydroxide
Mo	Molybdenum
N	Nitrogen
$NaHCO_3$	Sodium bicarbonate
NaOH	Caustic solution
NH_3	Ammonia
NH_4^+	Ammonium
NH_4-N	Ammonium nitrogen
NO_x	Nitrogen oxides NO and NO_2
P	Phosphorus
SO_2	Sulphur dioxide
SO_X	Sulphur oxides
Sn	Tin
Zn	Zinc

Units of measure

In this publication, the International System of Units is used. Some additional units or units that are used often are explained below.

a	annum
d	day
h	hour
J	Joule
kV	kiloVolt
kW	kilowatt
kW_e	kilowatt electrical
kWh	kilowatt hour
kW_{th}	kilowatt thermal
mg/L	milligram per litre
MW	mega watt
MW_e	mega watt electrical
MW_{th}	mega watt thermal
t	tonne (metric tonne)
t/h	tonnes per hour
t/d	tonnes per day
t/a	tonnes per annum
Nm^3	normal cubic metres
ppm	parts per million
% w/w	mass percent
Vol.%	volume percent

1. Purpose

1 The purpose of this guidebook is to promote biogas technology in small, medium and micro enterprises (SMMEs) in South Africa. Advancing the adoption of biogas technologies is in line with the country's drive to promote the development of the renewable energy sector and an inclusive low-carbon economy.

The Biogas Guidebook for Small- to *Medium-Scale Industrial Biogas Plants in South Africa* contains comprehensive information for biogas plant operators and relevant stakeholders, including:

- What is biogas?
- Applications of biogas technology in South Africa
- Feedstock for a biogas plant
- Choosing a site for a biogas plant
- How a biogas plant works
- A scientific toolbox for anaerobic digesters
- Economics of biogas projects
- Planning and implementation of biogas projects.

The purpose of this Guidebook serves to enhance the knowledge base on biogas technology in South Africa.

2. What is biogas?

2

Biogas is a by-product of the anaerobic[1] decomposition of organic matter. This organic matter can include vegetable and animal waste, organic waste from industrial processes (from abattoirs, food canning, fruit juice and dairy production), biowaste from households, wastewater and agricultural crops.

In nature, anaerobic decomposition (scientifically referred to as anaerobic digestion) occurs in swamps and the digestive tracts of cattle.

Biogas[2] is a mixture of mainly two components – methane and carbon dioxide – with small amounts of water, hydrogen, hydrogen sulphide and nitrogen. Methane gas is the most important component, because it can be used as an energy source in a wide range of applications. These include cooking, heating and electricity generation. Methane can also be converted into a transportation fuel.

1 *Anaerobic* refers to a process that occurs in the absence of oxygen.

2 The term *biogas* is sometimes also used to refer to gas from gasification. Gasification works on a different operation principle and is not part of this publication.

Table 1: Typical chemical composition of biogas

	Typical composition (%)
Methane (CH_4)	50–70
Carbon dioxide (CO_2)	30–45
Oxygen (O_2)	2–4
Hydrogen sulphide (H_2S)	0–0.6
Ammonia (NH_3)	0–0.05
Water vapour (H_2O)	1–5
Nitrogen (N_2)	0–5

Biogas technology has many advantages when compared with traditional waste management using landfills and energy derived from fossil fuels. These advantages include:

- It offers an environmentally friendly waste management system, as opposed to landfilling or dumping.
- Biogas acts as a decentralised, storable and renewable energy source.
- It reduces uncontrolled methane and carbon dioxide emissions from organic waste.
- It has a positive impact on climate change mitigation, thereby helping to achieve South Africa's goal to reduce carbon emissions.
- It offers a substitute for fossil fuel imports.
- It enhances rural development through energy security and employment opportunities .
- It offers upskilling opportunities due to the introduction of new technologies.
- It generates natural fertilizer as a by-product, thereby enhancing nutrient recycling.
- It reduces odour emissions from agriculture and landfills.
- It can be used directly for cooking or lighting purposes in rural domestic applications, which avoids the use of burning wood or charcoal, thus minimizing the negative effects that this practice has on health and wellness due to smoke inhalation and the environment (i.e. minimizing deforestation).

2.1 Biogas technology

There is a wide variety of biogas production technologies, and these can be classified into four main categories, as follows:

2.1.1 Commercial biogas plants:

Medium- to large-scale biogas plants range in size from 100 m^3 to greater than 10 000 m^3 , with a similar gas storage capacity. Gas produced is primarily used to generate electricity and heating or is upgraded to bio-methane.

Medium- to large-scale biogas plants can produce between 50 kW_e and 5 MW_e of electricity, depending on the feedstock availability. The planning, construction and operation of commercial biogas plants require experienced contractors and skilled operators to ensure the long-term operational success of such plants.

Figure 2.1: Commercial biogas plant (courtesy of Mark Tiepelt)

2.1.2 Domestic digesters

Small-scale domestic digesters usually have a reactor volume below 50 m^3. The biogas is generally used for cooking, lighting and heating water. It is also possible to use this biogas to run small biogas generators to generate electricity for a couple of hours a day.

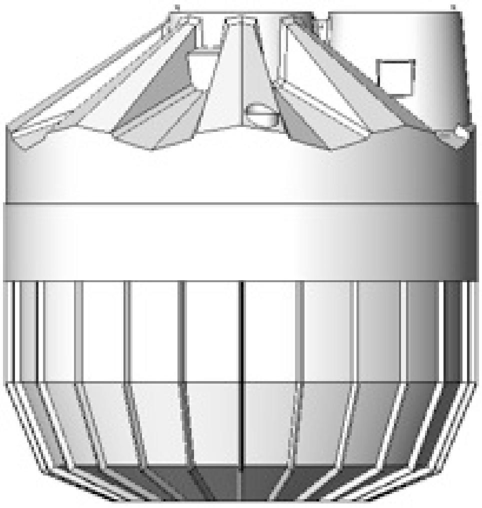

Figure 2.2: AGAMA BiogasPro 6
(courtesy of Agama)

2.1.3 Biogas at wastewater treatment works

Sewage sludge is produced at wastewater treatment works (WWTW) as part of the water treatment process. The sludge contains the solids and bacterial biomass rich in nutrients and organic matter. The benefits of biogas from sewage sludge are widely recognised, and the technology is well established in many countries.

The disposal of sludge is one of the major challenges faced by all WWTW in South Africa. It is easier to sell sludge that has been processed as opposed to raw sludge. Processed sludge is used by the fertilizer industry.

In recent years, a number of WWTW have either upgraded old digester tanks or built new digesters to produce biogas to generate heat and electricity. The first WWTW in SA to refurbish its old digesters, which had been built in the 1980s, was the Diepsloot WWTW of Johannesburg Water, where a 1.2 MW biogas plant was commissioned in 2015.

Figure 2.3: A wastewater treatment works in South Africa (courtesy of Mark Tiepelt)

2.1.4 Landfill gas

Landfill gas (LFG) is biogas produced in a landfill by decomposing waste. This gas is extracted by drilling pipes into the waste and using negative pressure to extract the gas. This waste is typically compacted to increase landfill airspace on a daily basis. Compaction also prevents oxygen from penetrating the waste and encourages the anaerobic microbes to thrive. The gas will gradually build up and be released into the atmosphere if the landfill has not been engineered to capture the gas.

Historically, most landfill sites in South Africa have not been designed or operated to capture landfill gas. Furthermore, landfills in South Africa are not designed for optimal compaction, which hinders the collection of biogas produced, as well as the collection of resultant fertilizer.

Figure 2.4: A South African landfill biogas plant in Ekurhuleni Municipality at the Sebenza waste site (SABIA)

2.2 Biogas in South Africa

Biogas technology in South Africa dates back to 1957, when John Fry installed the first biogas digester on a pig farm, using pig manure, and later started generating electricity.

Since then, South Africa has experienced limited biogas market development. This is due to the following factors:

- Low electricity costs from other sources, such as fossil fuels
- Limited grants or appropriate public sector incentives to support and drive the biogas technology as an alternative renewable energy source
- Lack of local biogas technology providers. [5]

According to the Southern African Biogas Industry Association (SABIA), there are approximately 500 digesters[3] installed in South Africa. Of these digesters, several hundred are small-scale domestic digesters. Figure 2.5 is a map with the location of biogas plants in South Africa.

Wider issues of bioenergy potential in South Africa are addressed in a report by *Bioenergy Atlas for South Africa*. [6]

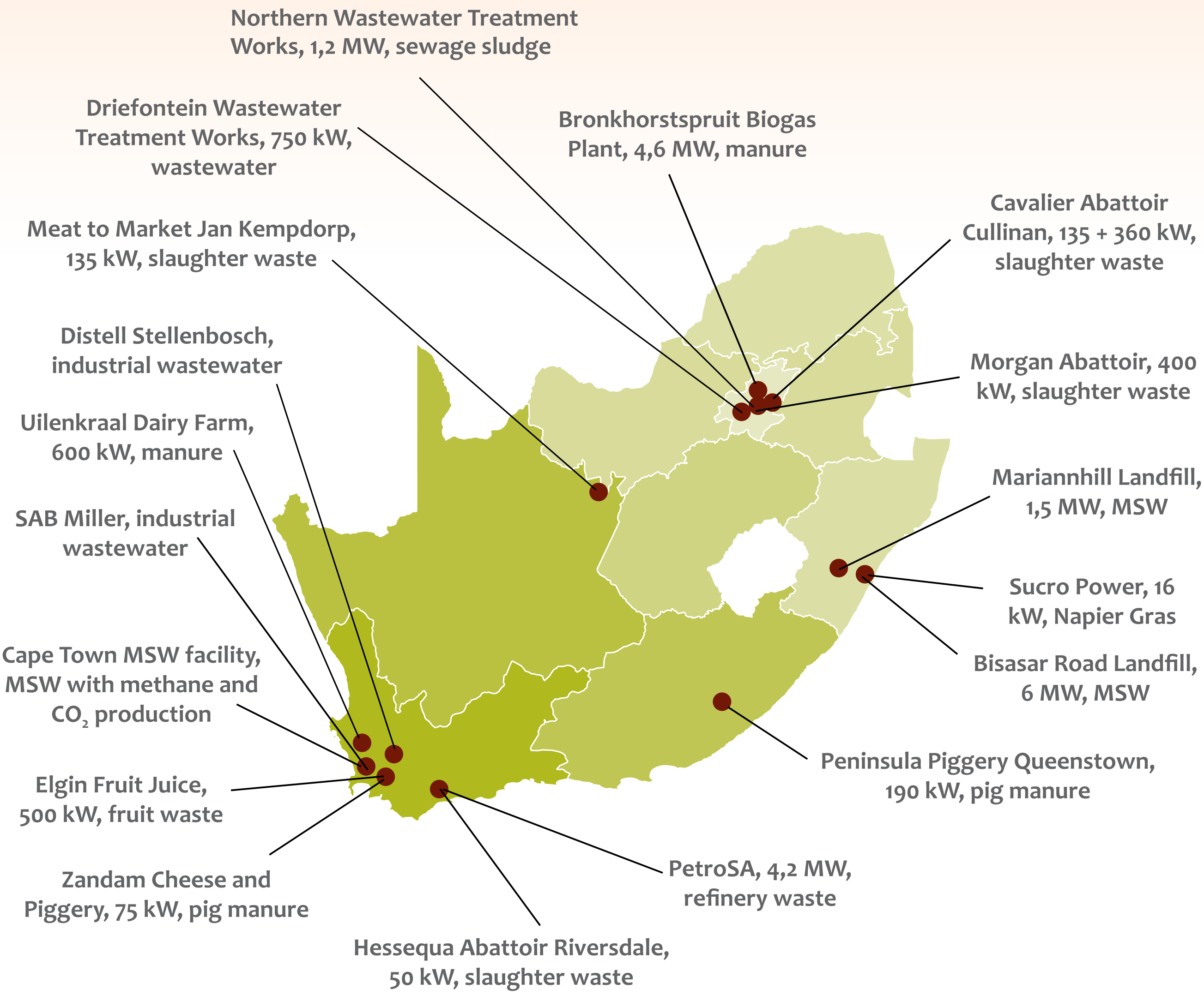

Figure 2.5: Map of selected biogas digesters installed in South Africa (SABIA). For updates, see the **SABIA Map**.

A report by GreenCape offered a Business Case for Biogas from Solid Waste in the Western Cape (29/11/2017). The report indicated that there were 21 biogas plants operating in the Western Cape in 2017. With electricity prices in Europe approximately double the electricity prices in South Africa at the time, GreenCape concluded that the failure of various projects was primarily due to unfavourable cost-benefit ratios:

- Financial viability of biogas facilities is highly site-specific, and generally the business case is strong only under particular conditions.
- Those situations with larger volumes of organic waste (either on-site or by acting as a waste service provider), higher waste disposal costs, higher energy use on-site or in close proximity, and the ability to derive income from various sources (accepting different waste streams and selling multiple by-products) are most likely to be financially viable.

2.2.1 Biogas case studies in South Africa

This section provides an overview of select number of case studies in South Africa.

Case study 1: New Horizens Waste to Energy – Athlone, Cape Town

The more than R400 million New Horizons Waste to Energy biogas plant opened in Athlone, Cape Town, in January 2017. As the highest cost biogas project in South Africa, the plant aimed to digest 500 tonnes per day of organic household, municipal and industrial waste from across Cape Town and produce bio-methane.

The plant offered 80 full-time and more than 100 indirect jobs in the City of Cape Town. Regretfully, the New Horizons Waste to Energy biogas plant no longer operates (2020) and the new plant owner is looking for partners to restart it soon.

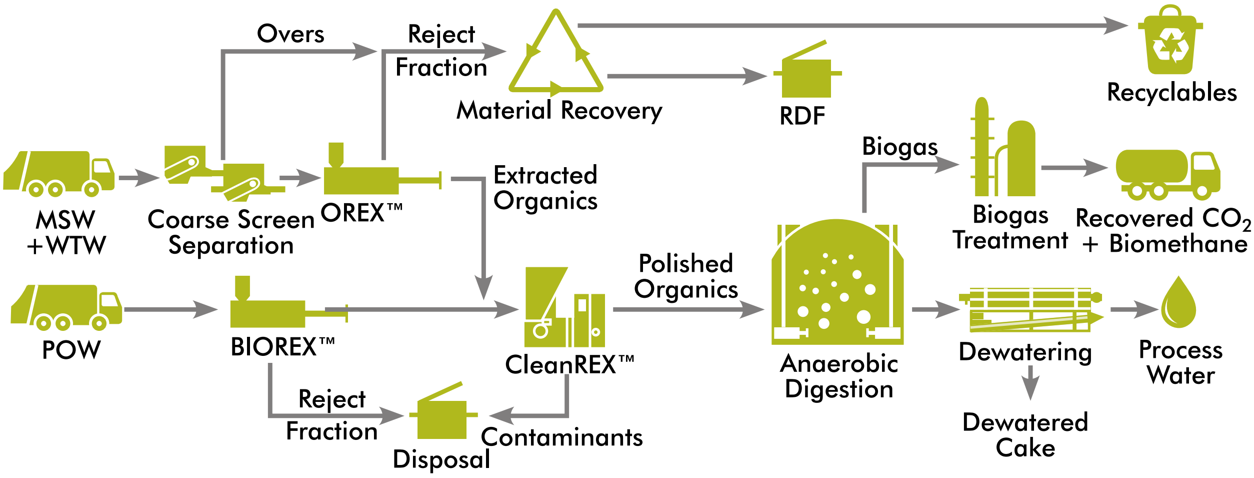

Figure 2.6: Flow diagram showing overall process of New Horizons Waste to Energy (Anaergia)

Figure 2.7: New Horizons Waste to Energy plant (Anaergia) in Athlone, Cape Town

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Case study 2: Bronkhorstspruit biogas project

Bio2Watt operates the Beefcor Bronkhorstspruit Feedlot biogas project. The project cost R150 million and started operations in April 2015.

The plant utilises 120 000 tonnes of feedstock a year, the bulk being manure, with additional supplements from the abattoir along with food wastes. Challenges were experienced relating to the quality of the feedstock, which contained high volumes of soil that displaced the volume in the digester tanks.

The Bronkhorstspruit plant has a generating capacity of 4.6 MW, although it was originally designed for 8MW. The plant supplies electricity via wheeling agreements with Eskom and the City of Tshwane to the BMW Rosslyn Plant, roughly 60 km from the site. The biogas plant supplies roughly 25–30% of BMW's electricity demand.

Case study 3: Zandam Piggery biogas plant – Durbanville, Cape Town

Situated 18 km east of Durbanville in the Western Cape, the Zandam Farm biogas plant is a R9.2 million agricultural biogas project. The feedstock is from 6 650 pigs that produce around 22 tonnes of manure per day, which is fed into the digester.

This plant demonstrates the potential for small-scale commercial biogas in an agricultural setting where the entire output is consumed on-site. The plant produces biogas combusted in on-site CHPs to supplement the farm's electricity demand. The estimated output is 41m³/h of biogas, converted to 75 kW of electricity, however is currently not operational.

Figure 2.8: Zandam Farm plant (Anaergia)

3. Applications of biogas

Biogas can be used for cooking, producing electricity, heating or cooling, or it can be upgraded to bio-methane. This chapter provides an overview of the most important applications of biogas.

It is important to note that biogas needs to be cleaned and pre-treated before it can be used in the various aforementioned applications. This is to protect the machinery and equipment from chemical or mechanical deterioration[4]. For information on biogas pre-treatment, see Section 4.2.

4 When using biogas for cooking in domestic biogas plants, the gas is often not pre-treated.

3.1 Electricity production

The major use of biogas is to generate electricity, either for own use or to feed into the public electricity grid (as a licensed independent power producer). Site selection is important, particularly if the intention is to feed into the grid, as access to transformers or substations becomes a critical factor.

Biogas is an energy carrier and can be stored. Biogas can therefore be used to generate electricity that can be produced specifically during periods of peak demand, or as standby during load-shedding or any other power outage. A biogas plant can deliver a reliable electricity supply for energy-scarce regions.

The generation of electricity can be achieved using an engine and an electrical generator (typically called a genset). These engines can operate using biogas as a fuel, but require adjustments to account for biogas's lower heating value when compared with LPG or natural gas. In this process, less than 40% of the energy contained in the biogas is converted into electricity. The rest is converted to heat, which is normally released into the atmosphere.

3.2 Combined heat and power (CHP)

A heat recovery system can be added to capture this heat energy in the form of hot water at approximately 85°C. A system that includes a genset and a heat recovery system is generally known as a CHP (combined heat and power) unit.

A CHP unit has the potential to capture more of the energy contained in the biogas when compared with a genset. The efficiency of typical CHP units varies and is mainly related to the size of the CHP unit.

Typical efficiency percentages measured in practice over a long period (e.g. 12 years) are as follows:

Energy output	Electrical efficiency	Thermal efficiency
50 kW_e sized CHP:	33%	55%
200 kW_e sized CHP:	36%	50%
1 000 kW_e sized CHP:	38%	40%

A CHP unit comes at a higher cost compared with a genset. This investment will depend on the ability to use the extra heat energy. In commercial biogas plants, 25% of this heat energy could be used to increase the temperature in the anaerobic digester. This increases the microbial activity and biogas yield. The rest of the heat could be used to heat water or for space heating. There is no widespread use of space heating in South Africa, so applications for CHP are limited.

Figure 3.1: A South African landfill biogas plant in Ekurhuleni Municipality at the Sebenza waste site (SABIA)

3.3 Biogas burner/boiler

Biogas can be used in a boiler or burner for direct heat/steam generation (in this case, there is no electricity production). The range of applications includes:

- Heat for the biogas process itself
- Process heat in food processing plants (e.g. milk- and juice-producing industry – pasteurization)
- Steam production
- Drying of materials.

Currently, there are burners available on the market to use specifically with biogas. Boilers that are usually fuelled with natural gas can also be adapted to operate with biogas.

For biogas use in burners, the gas should meet the following technical requirements:

- Dry gas (relative humidity below 60%)
- Particle-free
- Methane content of at least 50%
- Constant gas pressure
- Specified limits on H_2S content followed to avoid corrosion and limit SO_X emissions.

3.4 Bio-methane

Biogas can be upgraded to bio-methane, which can be used as a sustainable alternative to natural gas. To upgrade biogas to bio-methane quality requires the separation of methane (CH_4) and carbon dioxide (CO_2) and the removal of hydrogen sulphide (H_2S) and oxygen (O_2). The CO_2 separated from biogas to create bio-methane can be used to produce dry ice and other food-grade CO_2 applications.

Table 2 shows the difference in composition for biogas and bio-methane. Bio-methane has a heating value of 9.97 kWh/m³. [5]

5 As comparison, natural gas has heating value of 10–14 kWh/m3 (depending on the quality), and LPG has a heating value of 12.8 kWh/kg and a density of 0.54–0.60 kg/l.

Table 2: Typical chemical composition of biogas and bio-methane

	Composition (%)	
Biogas	Bio-methane (natural gas quality)	
Methane (CH_4)	50–70	> 97
Carbon dioxide (CO_2)	30–45	< 3
Oxygen (O_2)	2–4	< 0.5
Hydrogen sulphide (H_2S)	0–0.6	< 0.0005

There are several upgrading technologies available on the market, including the following:

- Membrane separation
- Scrubbing technologies (absorption methods)
  - Water scrubbing
  - Physical scrubbing
  - Chemical scrubbing
- Pressure swing adsorption (PSA)
- Cryogenic treatment.

When upgrading biogas to bio-methane, emissions of methane into the environment must be kept to a minimum as Methane is a greenhouse gas emission and the uncontrolled emissions of methane in atmosphere must be avoided.

3.4.1 Use of bio-methane

Bio-methane can be used for all applications where natural gas or LPG is usually used, subject to calibration of the appliance.

3.4.1.1 Household cooking

Bio-methane in gas cylinders can be used as an alternative to wood or electricity for household cooking.

3.4.1.2 Transport sector

It is possible to run vehicles using compressed bio-methane as an alternative to compressed natural gas (CNG) or liquefied natural gas (LNG). Bio-methane can be used in all engines running on natural gas.

The use of bio-methane as a fuel for transportation vehicles may enhance the environmentally-friendliness of the transport sector. The contribution to GHG emission savings when vehicles use bio-methane reaches 90%, when compared to a conventional petroleum-fuelled vehicle.

South Africa has potential to use bio-methane in the transport sector, already having some experience, especially in public transportation. In 2014, CNG Holdings opened a public filling station in Langlaagte, Johannesburg, which also includes a training facility. During the first quarter of that year, some 300 natural gas vehicles were on the roads, including company cars, taxis and minibuses.[7]

3.4.1.3 Bio-methane as a raw material in the chemical industry

Bio-methane can be used in all kinds of applications to replace the use of natural gas. In South Africa, Sasol uses natural gas to produce liquid fuels (diesel, petrol and jet fuel) and wax via the Fischer-Tropsch process[6]. Bio-methane can be used for the same purpose. However, the chemical industry has specific guidelines on quality.

6 The Fischer-Tropsch process involves the conversion of carbon monoxide and hydrogen to long-chain hydrocarbons such as fuels (diesel, petrol and jet fuel), waxes and various chemicals. Methane from biogas can be converted to carbon monoxide and hydrogen via a process called reforming and fed into a Fischer-Tropsch reactor.

3.4.2 Bio-methane storage

Bio-methane can be stored and transported in pressurized vessels (tanks or cylinders). This is known as compressed natural gas (CNG) or liquefied natural gas (LNG). These cylinders are typically pressurized to 200–250 bar. Lower pressures of 50–70 bar can be used, which requires less electricity for compression, but less bio-methane can be stored in the same volume.

Some recommendations for safe biogas/bio-methane use in pressure cylinders are as follows:

- Legal requirements (e.g. handling of pressure cylinders, gas quality, etc.) must be followed.
- The gas must be dried (removal of H_2O), as water promotes corrosion, for example when H_2S or CO_2 are solved and acids result.
- H_2S must be reduced, as H_2S is extremely toxic for human health and is also highly corrosive.
- The biogas should be free of siloxanes and particles.
- Cylinders should be connected by an authorised person.
- Cylinders must be controlled regularly to check that they are mechanically sound. This aspect is of utmost importance because little fissures often cannot be seen by the naked eye and could lead to dangerous explosions.

More detailed reference is available on the Biogas Standards SANS 1753-1 and 1753-2 (link to GCS and/or SABS).

3.5 Fertilizer production

Anaerobic digestion produces two main products – biogas and digestate. Digestate is the sludge material that is not turned into biogas. It can be used as a high-quality organic fertilizer, rich in humus and nutrients. The digestate can either be sold as an organic fertilizer or, if it contains a high level of impurities or heavy metals, it can be used as an energy source through appropriate technologies.

Digestate is, in most cases, applied directly in its liquid form (containing 5% to 15% dry matter), similarly to the way animal slurry is, or in a semi-solid form (containing 10% to 30% dry matter) like peat or compost. There are several techniques that can be applied to upgrade the digestate. These include composting, drying, pelletizing and granulating.

In South Africa, organic farming is an established practice. Operating an anaerobic digester close to an organic farm offers synergies for high-value crops and fertilizer cost savings.

It is important to make sure that digestate is not simply dumped or pumped into a river, because it contains a substantial amount of nutrients (especially nitrogen) which should not flow uncontrolled into the environment. If this digestate is not sold as an organic fertilizer, it needs to be properly and carefully disposed of (according to South African regulations). This can significantly increase the costs of a biogas plant operation.

3.6 Wastewater treatment

Anaerobic digestion can be a part of a wastewater treatment plant. In wastewater treatment plants, sewage sludge is separated from water. Sewage sludge can be used as a feedstock for an anaerobic digester to produce biogas.

Digestate can be used as a fertilizer; however, there might be impurities and heavy metals in sewage sludge, so chemical analysis is necessary before the digestate is converted to an organic fertilizer.

3.7 Process water from breweries and sugar mills

The food processing industry can use anaerobic digesters to treat their process water. In breweries and sugar mills, anaerobic digestion offers the opportunity to reduce organic matter present in the wastewater and produce energy which can be used in the process.

3.8 Biogas technology for society

Biogas plants provide a host of benefits to society. They can be used to produce organic fertilizer and are important aspects of wastewater treatment.

3.8.1 Odour reduction

The specific molecules which are responsible for emitting bad odours are usually organic (called volatile fatty acids (VFA)). The anaerobic digestion process converts these organic molecules into biogas, which effectively eliminates the bad odours.

3.8.2 Compliance with international climate pledges

South Africa is a signatory to the United Nations Framework Convention on Climate Change (UNFCCC). In 2009, South Africa's international pledge was a reduction to 34% below business-as-usual (BAU) emissions by 2020 and to 42% below BAU by 2025.

In the framework of the Paris Agreement reached in 2015, South Africa then committed itself to a National Determined Contribution (NDC) to reduce emissions. The 2025 target in the NDC corresponds to the same 2025 emissions target from the previous pledge. Nonetheless, this new target provides more clarity by specifying an intended emissions range through to 2030, including when emissions will peak.

3.8.3 Environmental protection and sustainability

Biogas is a renewable energy, and the production of biogas can help to reduce greenhouse gas (GHG) emissions in several ways:

- **Replacing fossil fuels**
  Biogas substitutes fossil fuels in the production of energy, avoiding CO_2 emissions.
- **Avoiding methane emissions**
  When organic material is amassed (like manure or landfill sites), methane emissions occur. Methane has a greenhouse gas potential which is about a factor 25 times higher than carbon dioxide. As long as biogas plants are well designed (so no methane escapes from the system) and biogas is utilized, methane emissions can be avoided.
- **Carbon neutrality**
  Biogas from agricultural waste contributes to carbon-neutral energy generation. During the growing process, plants extract carbon dioxide from the atmosphere and store it in the plant in the form of carbon-containing molecules. After combustion, approximately the same amount of carbon dioxide which was originally extracted from the atmosphere, is emitted, resulting effectively in a carbon-neutral process.
- **Fertilizer production**
  Digestate (the effluent of a biogas plant) is a good-quality fertilizer.

Bioenergy Atlas estimates the biogas potential from domestic and commercial waste in South Africa to be about 1 400 MW_e. [6] Assuming 7 500 operating hours per year, this amounts to 10 500 GWh_e. By producing this amount of energy, 10 500 million tonnes of CO_2 equivalent could be reduced. Furthermore, considering the emissions taking place at the landfills, some 300 g of CO_2 equivalent per KWh_e [6] could be avoided.

3.8.4 Employment opportunities

Biogas technology has the potential to make a positive contribution towards employment opportunities. The South African biogas industry employs approximately 1 700 people, according to an extensive study conducted in 2016. [8]

As the industry grows, the potential for employment opportunities increases and covers all skill levels (unskilled, skilled, semi-skilled and highly skilled). Conservative estimations for the growth of South Africa's biogas industry forecast the number of jobs rising to approximately 59 000 full-time equivalents (FTE) by 2030. More optimistic forecasts estimate the number of jobs to be at 88 000 FTE by 2030 [8] . It is noteworthy that the jobs created can be located in rural and urban areas, depending on the type of biogas plant as well as on the activities carried out in the various phases of a biogas project. [6] With the advent of COVID-19, some of these predictions may change significantly.

The study, however, also states that one obstacle in the way of tapping the envisaged growth potential fully, is the lack of certification standards in the South African biogas industry, which could lead to a lack of trained/skilled labour with certification: “With a lack of biogas standards, the certification skills gap remains at 100%, supplemented by practical/self-taught experience and passion for the industry”. [8]

In response to a need for biogas standards, UNIDO has developed SANS 1753-1 and SANS 1753-2, which focus on safety aspects. Further engagement with the industry will ensure the creation of standards related to quality and other management issues. These will be a valuable resource for operations and maintenance technicians.

4. Feedstock for a biogas plant

4.1 What feedstock do you need?

The types of feedstock that can be used in the anaerobic digestion process are as follows: [9]

- Animal by-products
- Vegetable by-products
- Biowaste from households
- Industrial and commercial waste
- Energy crops
- Wastewater.

Ongoing collaborations with institutes of higher education will add valuable contextual knowledge about the possibilities for diverse sources of biogas feedstock.

4.1.1 Animal by-products

Animal by-products consist mainly of liquid and solid manure, but also include abattoir waste (cattle, pig, poultry) and fat separator contents.

- Manure is probably the most common feedstock in biogas plants, as it is readily available and easy to digest. The composition of manure makes it an ideal substance for the AD process. The most common types of manure are from cattle (dairy as well as feedlot), pigs and poultry[7]. [10] Diluting the manure with water during collection will decrease the biogas yield.
- Abattoir waste has high biogas yield potential, but a sanitization (pasteurization) step is necessary to rule out the presence of pathogens in the digestate.
- Fat, oil and grease from canteen kitchens and restaurants are a valuable feedstock for biogas plants. Collection of this feedstock is a challenge.

4.1.2 Vegetable by-products

Vegetable by-products that are not marketable or suitable for animal fodder (e.g. due to their low quality, the presence of diseases or pest infestation) can be used as feedstock in a biogas plant.

7 The use of poultry droppings is challenging, due to its high ammonium content, which can inhibit the biological process. This type of feedstock should be combined with other low-ammonium-containing feedstocks or diluted with water.

These include: wheat straw, maize, residues from maize cleaning, rejected potatoes, crop residues, rice husk flour, grass silage, cactus, apples, apricots, pears, peaches, grapes, mangoes, guavas, pineapples, strawberries, plums, oranges, lemons/limes and grapefruits.

Large quantities of vegetable waste are also produced by vegetable processing plants. The digestate from these feedstocks is generally suitable as organic fertilizer and can be directly applied without any further treatment. [10]

4.1.3 Industrial and commercial waste

Organic residues from food, beverage (breweries and wineries) or feed production can be designated as **industrial and commercial waste**. These include residues from fruit processing (citrus pulp, pomace, potato pulp, oilseed cake), from the sugar industry (sugarcane distillery vinasse, sugarcane press cake, sugarcane bagasse), from the dairy industry (casein, whey, milk sugar, unskimmed milk, waste milk) and from the beverage industry (spent grain, apple and grape pomace). [10]

Biogas plants operating on these types of feedstock typically have the advantage of normally being located in close proximity to industries where there is high demand for energy (electricity and heat). The challenge associated with these plants, however, is around the seasonality of agricultural produce, i.e. no consistent type and quantity of feedstock available throughout the year. This challenge can be overcome by co-digestion of several (or at least two) types of feedstock to even out the seasonality of the supply of feedstock.

4.1.4 Biowaste from households

Biowaste from households refers to the organic fraction of waste produced at household level. Household waste is typically collected by municipalities and referred to as municipal solid waste (MSW), and the organic fraction (OF) thereof as OFMSW. It might also include garden and park waste.

While separated biowaste from households is advantageous due to a high degree of pure organic material that can be anaerobically degraded, it needs to be considered that waste separation is not a common practice in South Africa. However, biowaste from hotels or restaurants has huge potential as feedstock for biogas plants.

4.1.5 Energy crops

Energy crops refer to crops purposely grown for use in biogas plants. Inedible crops such as grass, cactus and sugar sorghum can be used in South Africa. Energy crops normally have higher biogas yields compared with other feedstocks, such as manure and vegetable waste. The use of food crops to produce energy should be done without endangering food security.

South Africa has huge tracts of land not suitable for the cultivation of food or fodder crops. Utilizing this land to grow specific energy crops for biogas could prove to be a viable option for the biogas industry.

4.1.6 Wastewater

Wastewater is treated by municipal Wastewater Treatment Works (WWTW), which separate the sewage sludge from the water. Sewage sludge can be used as a feedstock for biogas plants.

South Africa has many digesters at WWTW all over the country that were built in the 1980s primarily to manage sludge. The digestion process reduces the quantity and improves the quality of the sludge, thus making it easier to manage. In the past, biogas produced from sludge was not used, due to the relatively low cost of electricity.

Most of these digesters, however, have fallen into disrepair over the years. However, recently some larger municipalities have started refurbishing these digesters to produce electricity.

Challenges associated with biogas production at WWTW include the following:

- Low biogas yields of sewage sludge
- Low solid content
- High volumes of sludge
- Presence of toxic contaminants like heavy metals.

4.1.7 Considerations for feedstock

The type of feedstock used in a biogas plant will determine the yield of biogas.

- Water content
  For example, industrial waste that might have too much water and lack structure for composting is excellent feedstock for anaerobic digestion.
- Degradability of the feedstock
  Not every kind of organic material can be degraded in a digester. One of the main limitations of the biogas process is its inability to degrade lignin (a major component of wood). This type of waste should be treated with aerobic degradation (composting).
- Composition of fat, protein and carbohydrate
  Stale bread, for example, has a high proportion of carbohydrates, which provide a high methane output per tonne. Canola, which has a high protein concentration, could lead to increased concentrations of H_2S in the anaerobic digester, which could negatively affect the microorganisms and machinery.
- Presence of soil/sand in the feedstock
  For example, cattle feedlot manure can fill up the digester and progressively reduce the volume of the digester.

Transport costs may be prohibitive if the feedstock is not located close to the biogas plant.

While it is possible to use a broad variety of input material, even slight changes in the type or quality of feedstock may have a crucial impact on the digestion process. Certain feedstocks can negatively impact the microbiology of the process.

4.2 Feedstock preparation

The feedstock or an anaerobic digester should be as "clean" as possible to ensure high yields of biogas as well as high-quality digestate and compost free of contaminants. Impurities need to be removed from the feedstock before the digestion process starts.

- "Clean" feedstock is free of:
- Unsorted domestic biowaste from households
- Plastics, glass, paper, metals or oversized components
- Sand and stones
- Wood and roots
- Pathogens that occur in biowaste or animal by-products.

In some cases, pre-treatment may be necessary.

Gaseous impurities in biogas that require pre-treatment include:

- Hydrogen sulphide
- Water
- Silicon organic compounds (e.g. siloxanes)
- Oxygen
- Ammonia
- Dust, oil and aerosols.

There are various solutions to achieve a clean feedstock, or to manage anaerobic digestion where a clean feedstock is not possible.

4.2.1 Removal of pathogens

It is possible to remove pathogens at various stages in the process. Removal of pathogens can be achieved by:

- Adding a pasteurization unit and heating up the material to over 70°C for an hour prior to, or after, the anaerobic digestion process
- Using thermophilic digestion at temperatures greater than 50°C within the anaerobic digester
- Composting the digestate in piles at temperatures over 60°C
- Treating the anaerobic digester with lime.

4.2.2 Removal of physical contaminants

Physical contaminants such as plastic, large pieces of wood, metals and oversized objects can be removed in the following ways:

- Waste pickers can be used to sort mixed biowaste from households.
- Sieving the feedstock can remove large objects.
- Breaking glass with presses can help to extract organic material from packaging.
- Air separation techniques can blow plastics out of the feed.
- Magnets or eddy current separators can remove ferrous and non-ferrous metals.
- Hydro-mechanical treatment can be used for waste in liquid form or broken down into small particles and mixed with water.
- Sink-float separation can separate heavy materials like stones and bones which sink to the bottom of the unit, while light impurities like textiles and plastics float to the surface where they can be removed.
- Pulping waste can break down the feedstock and enable the separation of unwanted materials via sink-float separation.
- Hydrocyclones can remove grit and sand.

In some cases, where the anaerobic digestion step is less sensitive to impurities (normally dry digestion processes), the removal of physical contaminants can also be carried out after the biogas process (e.g. by sieving the compost in rotating drums).

4.2.3 Upgrading the feedstock

After removing contaminants, creating a more homogeneous feedstock with a small particle size distribution will improve the biogas digestion. This can be achieved using screw-cutting, milling, crushing or shredding machines.

4.2.4 Feedstock for high-quality digestate

Ensuring the quality of the digestate – its visual cleanliness and absence of contaminants and harmful impurities (e.g. sharp objects) – is paramount when it comes to marketing the product and fostering public acceptance of biogas technology as a waste treatment option.

To create this kind of clean end product, a combination of both high-quality feedstock that is largely free of impurities and the application of appropriate technologies for treating each kind of impurity, are essential.

5. Choosing a site for your biogas plant

The selection of the location for a biogas plant is of critical importance, and could even influence the economic feasibility of the whole project; therefore, many factors have to be taken into consideration, as described in this chapter.

5.1 Biomass availability

Available feedstock is the most important factor in the decision on the best location of a biogas plant. Quite often, the idea of building a biogas plant arises from abundant amounts of biomass that are produced or stored in one place. Examples are:

- Big farming operations such as dairies, feedlots, pig farms or chicken farms
- Abattoirs
- Markets that have vegetable and fruit waste
- Food processing industries like breweries, sugar factories and fruit processing
- Canteens and restaurants with food waste
- Municipal solid waste processing plants where organic waste is separated
- Agricultural industries that produce plant or forestry waste.

Viability of a biogas project depends on the amount of continuous feedstock supply exceeding 6 000 t/a and being available in one place.

As a rule of thumb, the bigger the biogas plant, the lower the unit cost of energy production. Under certain circumstances, it might be viable to import additional biomass to the proposed site of the biogas plant in order to have a bigger plant. The limiting factor when importing feedstock is the cost and greenhouse emissions associated with transportation.

Liquid manure contains a lot of water and consequently has a low energy content, and transportation would typically be limited to a few kilometres. Therefore, the actual energy content of the feedstock plays a crucial role, as a higher transport cost could be justified should the feedstock have a high biogas yield potential, such as with liquids with high fat or oil content.

5.2 Space and available land

The construction of a biogas plant requires adequate space. Small plants need about 600 m^2, while big installations require several thousand square metres. Often, biogas plants are constructed close to an agricultural farm, where the availability of space is not a challenge, whereas space could become a challenge when the plant is developed in an industrial area.

6. How a biogas plant works

6.1 Components of a biogas plant

A typical biogas plant consists of several components, as depicted in Figure 6.1.

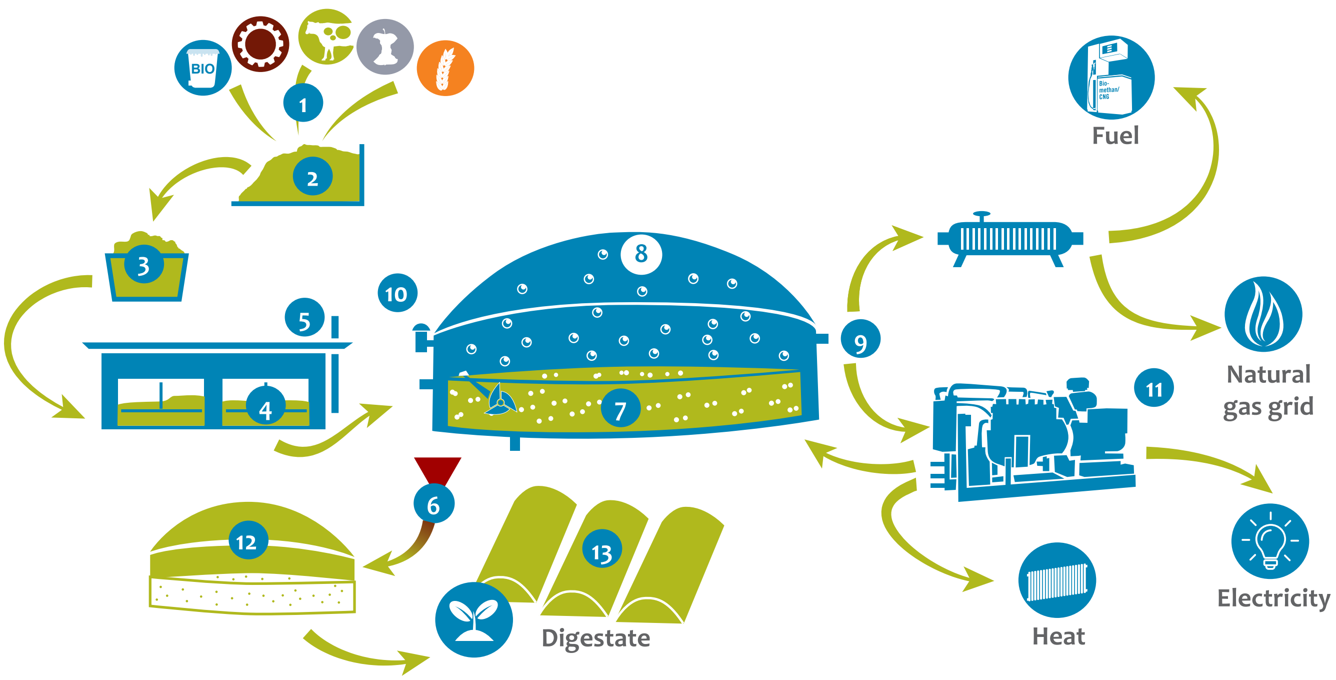


Figure 6.1: Diagram of the components of a biogas plant (Fachverband Biogas e.V.)

These components are as follows:

1. Feedstocks from biowaste, industry, abattoir waste, food waste and agriculture
2. Feedstock delivery holding site
3. Feedstock preparation
4. Feedstock storage
5. Bio-filter to remove potential pollutants
6. Sanitation unit to clean digestate if necessary
7. Anaerobic digester
8. Gas storage
9. Gas cleaning system
10. Safety equipment
11. CHP unit
12. Digestate storage
13. Digestate upgrading.

6.2 Feedstock storage

A typical biogas plant will be fed a couple of times per day with several tonnes of feedstock. Feedstock could, however, be brought in daily, weekly or even annually or seasonally (for agriculturally based feedstock). Several types of storage options are available on the market.

6.2.1 Storage of liquid feedstock

Liquid feedstock, such as diluted manure, can be stored in any type of vessel suitable for the storage of liquids. Such tanks are typically made from concrete, steel or plastic, depending on the type, composition and quantity of feedstock that needs to be stored.

Storage tanks are often equipped with mixers to avoid the formation of sinking layers and to ensure the material remains homogeneous. It is possible that some microbiological activities might, however, start in the storage tank, although on a low level, as storage tanks are not heated.

Tanks are typically covered to avoid methane escaping into the atmosphere – covers also assist in odour control and contribute to safety. The flow of liquid into and out of the storage tanks is typically controlled by pumps.

Figure 6.2: Storage for liquid feedstock (Fachverband Biogas e.V.)

6.2.2 Storage of solid feedstock

Solid feedstock is often stored on open ground next to the biogas plant. Storage areas should be concreted to prevent nutrients from contaminating soil and groundwater. Solid feedstock may also need to be protected from rain, as rainwater could dilute feedstock and lower the average retention time in the digester.

Stored material might start to digest before being fed into the digester. This leads to energy losses and air emissions. To avoid or reduce pre-digester activities, seasonally harvested material can be conserved by covering it with plastic sheeting or turning it into silage.

Figure 6.3: Feedstock preparation through ensilaging attached (courtesy of Mr Vusumzi Mnisi)

6.2.3 Feeding systems

For feeding solid and liquid feedstock into the digester, there is a wide variety of feeding systems available on the market. The general purpose of feeding systems is to ensure that feedstock is transported into the digester with a higher degree of automation, while ensuring safety and minimizing emissions.

6.3 Digester technology

The digester is one of the core elements of a biogas plant. This section gives a brief overview on the digester volume and then focuses on the digester technology. For further information, refer to the Biogas Investment Decision-Making Tool.

6.3.1 Digester volume

The digester is usually filled with liquid feedstock slurry up to a certain design level, and this should ideally be maintained at a constant level.

When calculating the actual volume of feedstock that will fit in the digester, consider the space taken up by installed equipment (mixer, heating systems, etc.) and by sinking layers (stones, sand, etc.) which will effectively reduce the active volume. Additionally, about 20% of the gross volume can be considered as back-up capacity.

It is normal practice to allow 40–80 cm free space above the design liquid level for movement caused by the mixing action and the possible formation of floating layers. The gas pipeline is usually connected to this free space.

The actual construction size of the digester, the gross digester volume, will be composed of the net digester volume, the back-up space and the free space (Figure 6.4).

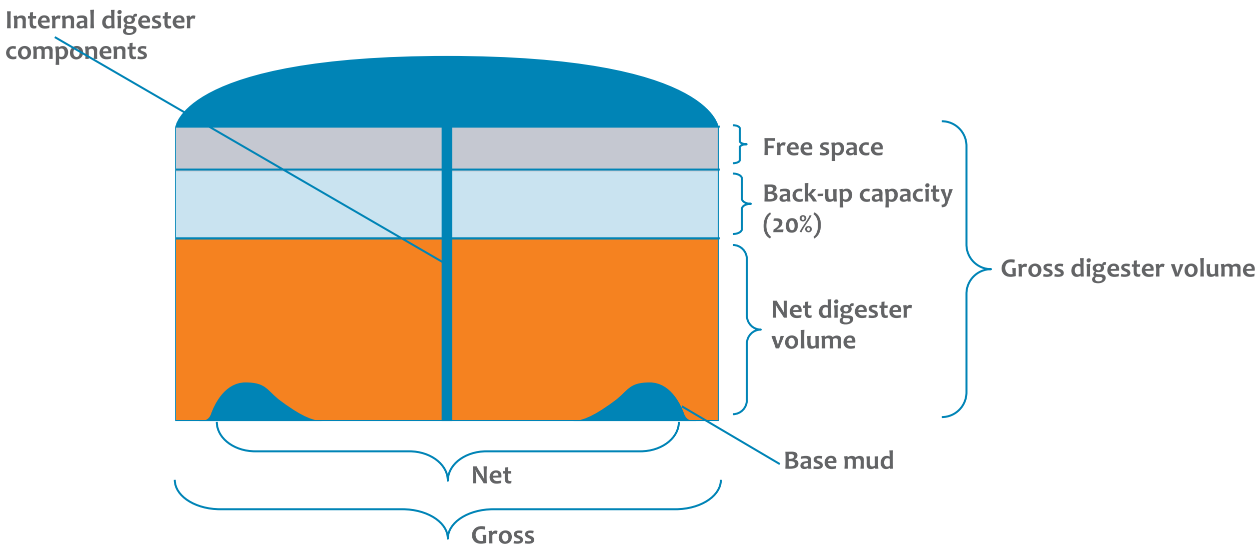
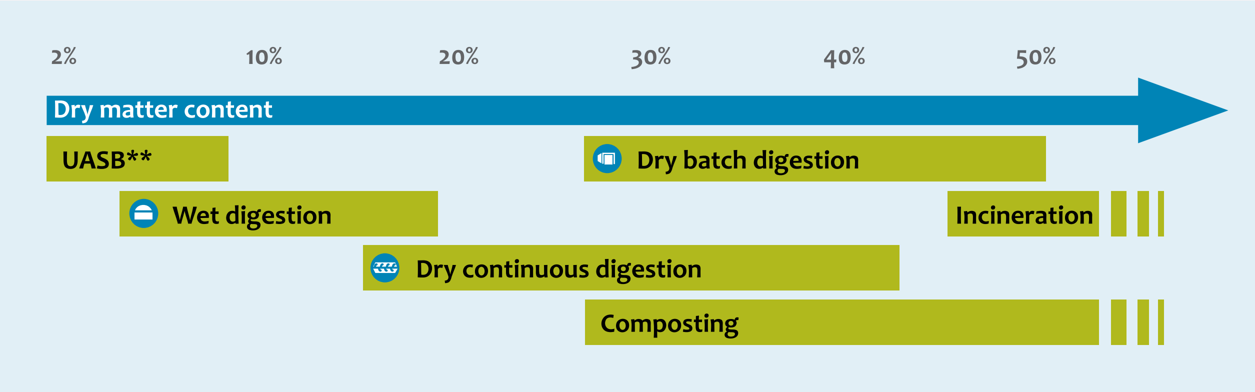


Figure 6.4: Difference between gross and net digester volume

6.3.2 Digester tanks

There are a number of digester designs available on the market, primarily influenced by the characteristics of the feedstock. Figure 6.5 shows the various biogas systems that can be used, depending on the concentration of dry matter in the digester.

Overview of technologies depending on dry matter content for the possible operating mode*



* Almost every type of feedstock can be diluted to the needed dry content of each digester technology.
** UASB: Upflow anaerobic sludge blanket technology is a form of anaerobic digestion designed for materials with high water content (e.g. sewage sludge).
UASB reactors are installed for waste or process water treatment.

Figure 6.5: Overview of digester technologies (Fachverband Biogas e.V.)

6.3.2.1 Wastewater treatment digesters

Starting on the left, upflow anaerobic sludge blanket (UASB) digesters are typically used for wastewater treatment plants and can operate with 2% dry matter and 98% water content.

Highly polluted water is pumped under pressure into the bottom of the reactor where it forms sludge. Biogas is produced in the sludge layer, and the rising gas bubbles mix the sludge without the assistance of any mixing components.

The clean water is extracted from the top of the tank in an area above the sloped walls. The sludge blanket, which is heavy, remains at the bottom of the tank.

The following characteristics apply to UASB biogas plants:

- Mainly used for wastewater or sewage sludge treatment
- pH values between 6.3 and 7.85
- Temperature between 35°C and 42°C.

UASB has the advantages of being able to treat process water with low organic material, being lower maintenance, having an odour-proof design, and having good sludge retention and low space demand. The disadvantages are that it is only suitable for materials with high water content (solid content of 2%), and it has high investment costs and relatively low biogas yields.

6.3.2.2 Wet digesters

Wet digestion refers to the digestion of feedstock that has a dry matter content above 5%, but not more than 20%. It is easier to handle wet feedstock (as opposed to dry feedstock), as it can be easily pumped and mixed. Feedstock that is too dry can be mixed with water or wet digestate to decrease the dry matter content. Liquid manure, on the other hand, can be used directly without dilution.

The continuously stirred tank reactor (CSTR) is the most commonly used tank technology for wet digestion. It is a simple but robust technology that accepts a wide range of possible feedstocks. Almost any sized plant is possible. Biomass inside the digester has to be liquid and pumpable so that it can be mixed with different kinds of mixers.

The following characteristics apply to CSTR:

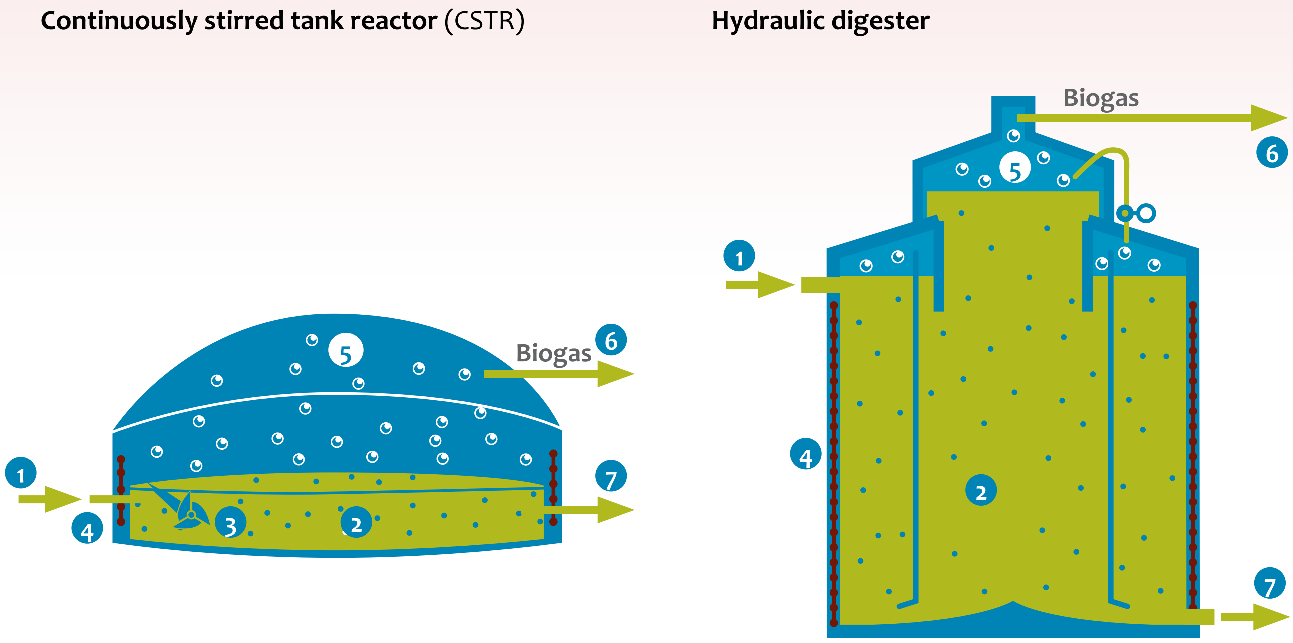
- The material is fed in continuously.
- Suitable feedstocks are animal and vegetable by-products, household waste, industrial and commercial waste and energy crops.
- The dry matter content of the feedstock ranges between 5% and 20%.
- Mixers/agitators are necessary to mix the feedstock.
- The process temperature is mesophilic (35–48°C) or thermophilic (>50°C).
- The process can be single-stage or multi-stage.
- A post-digester and digestate storage usually need to be installed.

A hydraulic digester can also be used for wet digestion, and works without mixing. This digester works on the principle of pressure. Wet feedstock is fed into the tank, raising the level of liquid in the digester, which puts pressure on the gas layer, pushing the biogas out of the tank (see Figure 6.6).

The following characteristics apply to the hydraulic digester:

- The material is fed in continuously.
- Suitable feedstocks are animal and vegetable by-products, household waste, industrial and commercial waste and energy crops.
- The dry matter content of the feedstock ranges from 8% to 16%.
- No agitators are required, and there are no moving parts in the reactor.
- Mixing and feedstock discharge are driven by biogas produced by the digester.

The process temperature is mesophilic (35–48°C) or thermophilic (>50°C).



1 Input 2 Biomass 3 Agitator 4 Heating system 5 Biogas storage 6 Biogas utilisation 7 Output

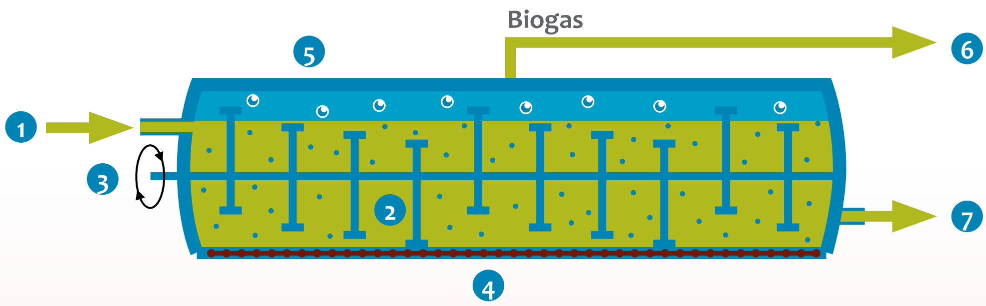
Figure 6.6: CSTR and hydraulic digester (Fachverband Biogas e.V.)

6.3.2.3 Dry digesters

Dry continuous digestion is the digestion of feedstock with higher dry matter content in a continuous process. A plug flow digester is typically used.

The concept that underpins the **plug flow digester** is that the biomass is slowly transported (horizontally or vertically) from the inlet to the outlet. Ideally, all feedstock will spend equal amounts of time in the digester. This requires optimal processing conditions and robust mixing technology.

Plug flow reactor



1 Input
2 Biomass
3 Agitator
4 Heating system
5 Biogas storage
6 Biogas utilisation
7 Output

Figure 6.7: Plug flow digester (Fachverband Biogas e.V.)

The following characteristics apply to the plug flow digesters:

- The material is fed in continuously.
- Suitable types of feedstock are animal and vegetable by-products, household waste, industrial and commercial waste and energy crops.
- The dry matter content of the feedstock ranges from 15% to 45%.
- The digester can operate either horizontally or vertically.
- Agitators operate along or across the flow of material (although vertical flow systems operate without agitators).
- A high reactor load is possible.
- Reactor volume is usually limited to between 1 000 and 2 000 m^3 because of the strong radial forces involved that affect mixing ability; however, a number of reactors can be operated side by side.
- The process temperature is mainly thermophilic (>50°C)[8].

For drier feedstock, a dry batch anaerobic digester (garage system) can be used. During dry batch digestion, biomass is processed in batches that remain in the digester for a defined amount of time.

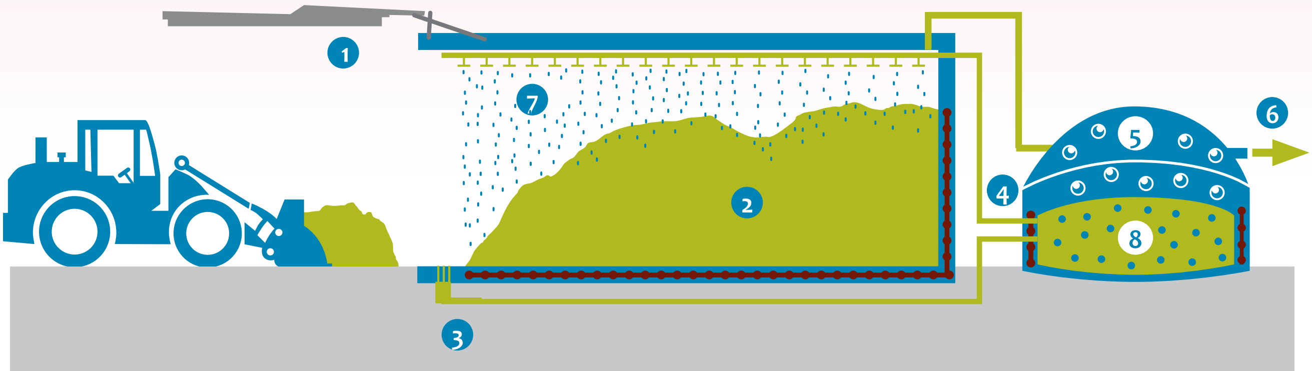
Afterwards, the digester is emptied and refilled with the next batch. New incoming feedstock is mixed with digestate from the previous process or from another reactor and is left to digest inside the digester. Leaching liquids that are drained from the batch digester are recirculated to improve contact between the biomass, acids and bacteria.

The following characteristics apply to dry batch digesters:

- The feedstock is added in batches.
- Biomass usually needs to be moved in and out of the unit using a front-end loader.
- Suitable feedstocks will need to be stackable and thus contain a large amount of structural material, e.g. animal and vegetable by-products, household waste, industrial and commercial waste and energy crops.
- The dry matter content of feedstock must be higher than 30%.
- There are no moving components in the digester, making the digester robust.
- Operations are reliable, and maintenance costs are low.
- A percolation liquid system ensures optimal water content.
- The process temperature is mesophilic (35–48°C).

8 Because of the high investment, it is necessary to use the digester volume in the most efficient way. The thermophilic (>50°C) process has the highest efficiency.

6.3.2.4 Garage systems



1 Gastight door
2 Biomass
3 Drainage system for percolation liquid
4 Heating system
5 Biogas storage
6 Biogas utilisation
7 Percolation liquid distribution
8 Percolation liquid storage tank

Figure 6.8: Illustration of a garage system (Fachverband Biogas e.V.)

6.3.3 Mixers

Mixers or agitators play an important role in a biogas plant. They are used to ensure even distribution of feedstock and microorganisms throughout the digester. Mixers also ensure good heat distribution and help avoid sinking and floating layers. Finally, they help to agitate the gas bubbles out of the liquid.

There are many types of mixers available – mechanical, hydraulic and pneumatic.

6.3.4 Heating systems

A constant temperature inside the digester is of utmost importance for efficient biogas production, as it guarantees ideal living conditions for the bacteria. It is possible to use by-product heat from combined heat and power (CHP) to heat the digester. If no CHP is available, the heat can be supplied by a biogas burner, solar radiant heat (solar collectors) and other heat sources.

Typically, hot water is circulated through pipes installed all around the inner digester walls. These pipes can be of different materials, such as plastic, stainless steel or carbon steel.

Figure 6.9: Heating system showing pipes containing hot water on the inner digester walls (Anaergia)

6.4 Biogas cleaning

Biogas, once produced, needs to be cleaned of various impurities, including the following:

- Hydrogen sulphide
- Water vapour
- Silicon-organic compounds
- Oxygen
- Ammonia.

Hydrogen sulphide (H_2S) is produced in greater quantities when using feedstock containing high amounts of sulphur. There is a wide range of H_2S concentrations in biogas, from below 50 ppm to above 10 000 ppm.

H_2S also has corrosive properties that could severely damage equipment if not removed or reduced to acceptable levels. Typically, H_2S should be reduced to less than 200 ppm in state-of-the-art equipment.

H_2S is also toxic to human beings. H_2S further oxidises during combustion to form sulphur dioxide (SO_2), which is an environmental pollutant. The release of sulphur dioxide into the atmosphere must therefore be kept to a minimum.

Consequently, biogas must be subjected to a desulphurisation process before further processing and use.

Biogas is naturally saturated with water vapour inside the digester and, if not removed, has the potential to damage equipment due to corrosion. To avoid corrosion and other negative effects during subsequent gas treatment, it is necessary to dry the biogas.

Traces of ammonia can also be found in biogas. Because it is highly water-soluble, it can be reduced by the water removal process.

Silicon-organic compounds (e.g. siloxanes) occur mainly in sewage treatment plants. Possible sources include the feedstock (especially those feedstocks coming from waste streams), residues from cosmetics, detergents and anti-foam agents containing silicones, which are used in the digester.

Oxygen can also compromise the biogas process. Although biogas generation in the digester takes place in the absence of oxygen, levels of 0.5% are low enough not to affect the biogas process.

Biogas must additionally be free from impurities such as dust, oil and aerosols. Filters used in gas technology are installed for this purpose.

6.5 Gas storage

Biogas will be produced continuously (24 hours per day, 365 days per year), but the rate of biogas production can vary (cubic metres of biogas per hour) over time. Additionally, every biogas plant has standstill periods due to maintenance.

To accommodate for these fluctuations, provision is made for gas storage.

Storage facilities must be:

- Gas-tight
- Resistant to pressure
- Resistant to UV radiation
- Resistant to temperature variations and changing weather conditions
- Resistant to external effects like strong wind.

Gas storage facilities typically operate at standard atmospheric pressure. Storage facilities should also be equipped with an over-pressure and under-pressure protection system.

The storage volume is selected based on space availability, budget and the need for flexible operation.

Figure 6.10: Digester with foil roof for gas storage (Anaergia)

6.6 Gas flare

Methane produced in the biogas production process is harmful to the environment. It has a greenhouse gas (GHG) potential which is 25 times higher than that of carbon dioxide. Therefore, the produced methane must not be emitted into the atmosphere.

Although biogas production is continuous, the utilization of the biogas might not be, for example during times of maintenance. Biogas plants should be equipped with a gas flare to burn methane and convert it into carbon dioxide, which is less harmful to the environment.

Figure 6.11: Gas flare of a biogas plant (Anaergia)

6.7 Measurement, control and regulation technologies

As it is important to control the digestion process, many measuring devices for biogas plants have been developed.

Gas analyser

This shows the composition of the biogas and the presence of the following components:

- Methane (CH_4) is the most valuable component and contains the biogas energy.
- Carbon dioxide (CO_2) is important to measure, as it indicates the stability of the biological process.
- Oxygen (O_2) indicates if leakages in the gas system have occurred. If above 1%, the operator should do a leak test.
- Hydrogen sulphide (H_2S) is a toxic and corrosive gas. In general, the concentration of H_2S should be as low as possible. Typical limits for CHP operation are in the range of 50–200 ppm.
- Hydrogen (H_2) can be measured for process optimization.

Flow meter

This measures the volume rate of the biogas production, typically in m^3/h. This value shows whether the biological process is stable. If this value drops, the living conditions for the microorganisms are not optimal anymore, and measures to stabilise the process should be implemented.

Additionally, the biogas production rate indicates whether the whole biogas plant is operating in an efficient manner and is according to what is expected from the feedstock used.

7. Getting it right: A toolbox for success

Biogas technology converts organic material into methane gas and other gases. This occurs through a complex sequence of reactions that occur during the decomposition of organic matter.

In the face of challenges, this chapter will offer a guide to the scientific principles of anaerobic digestion, and help with technical troubleshooting.

7.1 Four phases of anaerobic digestion

The decomposition of organic matter can be divided into four different phases: hydrolysis, acidogenesis, acetogenesis and methanogenesis, as follows:

- **Hydrolysis:** Complex long-chain molecules such as carbohydrates, proteins and fats are broken down by microorganisms into smaller molecules such as amino acids, sugars and fatty acids.
- **Acidogenesis:** The intermediate products formed in the first step are further degraded to form lower fatty acids and other carboxylic acids, such as butyric acid and propionic acid. In addition, hydrogen, carbon dioxide and acetic acid are produced, and are the basic elements for the subsequent production of methane.
- **Acetogenesis:** Lower fatty acids are broken down into acetic acid by acetogenic microorganisms.
- **Methanogenesis:** During this phase, archaea – the oldest forms of life on earth, also called methanogenic bacteria – produce methane by converting either acetic acid or hydrogen and carbon dioxide into methane.

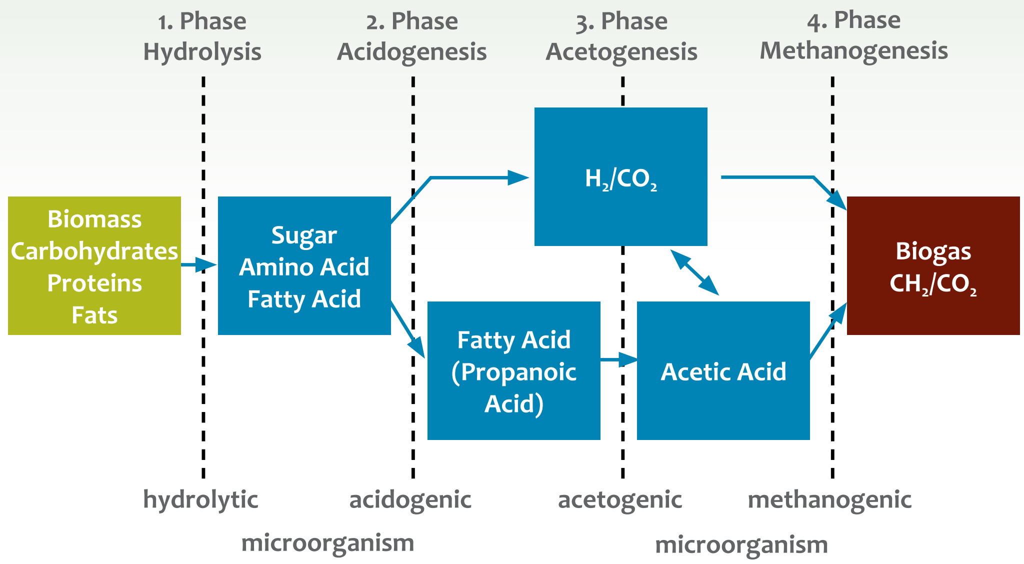


Figure 7.1: Process description of the degradation process of biomass inside the digester [1]

7.2 Microorganisms in your digester

There are many types of microorganisms that assist the breakdown of feedstock in the digester.

The five most common microorganisms have different growth rates (see Table 3). Acid-forming organisms have a relatively short reproductive time. Methanogenic bacteria grow slower and have a slower metabolism.

Table 3: Generation times of organisms involved in the biogas process

Type of organism	Name	Generation time (days)
Acid-forming organisms	Bacteroides	< 1
	Clostridia	1.5
	Acetogenic bacteria	3.5
Methanogenic bacteria	Methanosarcina	5–15
	Methanococcus	~ 10

The time taken to produce biogas is influenced by the concentration of the micro-organisms, the quality of the feedstock, mixing, particle size and temperature. Sugars and starches degrade quickly, while woody biomass is slower to break down.

7.2.1 Balancing the environment for microorganisms

Balancing the environment to favour the growth of all these microorganisms is important. Each of these microorganisms thrives under different conditions (pH, temperature and feedstock composition).

The optimal living conditions of the various microbial strains differ considerably. In practice, a biogas plant cannot provide optimal conditions for all organisms, but needs to find a compromise which is suitable for all. Several influencing factors are as follows:

- **Amount of oxygen:** Microorganisms involved in hydrolysis are partially to low oxygen; however, microorganisms involved in the other three phases thrive in strictly anaerobic environments.
- **Mixing:** Efficient mixing will ensure that microbes have constant access to their source of food. Mixing also maintains consistent temperature. However, excessive mixing can have a negative effect on microbe communities.
- **pH:** Microorganisms thrive under specific pH levels.
  - Microbes in the hydrolysis phase thrive under acidic pH levels of 5–6. However, they are able to survive when the pH rises.
  - Microbes in the methanogenesis phase favour more neutral environments with a pH of 6.6–8. These microbes are ineffective at a higher or lower pH.
  - To accommodate most microbes, the ideal pH should be maintained between 7 and 8 in the digester.'

Feedstock has a significant effect on the pH of an anaerobic digestion system. If the digester is fed with too much material that is easy to break down (like sugars and starches), the bacteria which perform the first stage of digestion will grow quickly, resulting in a build-up of organic acids which drop the pH.

- **Buffer systems:** This is a chemical system that can prevent the pH from dropping too low. However, care must be taken when using buffer systems, as they can get saturated if too many acids are generated, which can cause further issues in the digester.
- **Volatile fatty acids:** The amount of volatile fatty acids (formic acid, acetic acid, propionic acid, butyric acid and valeric acid) in the anaerobic digester at any given time gives an indication of the speed of degradation in the first three phases (hydrolysis, acidogenesis and acetogenesis), as opposed to the fourth stage (methanogenesis). Volatile fatty acids are commonly measured in Acetic Acid Equivalent (AcEq), which needs to be < 2 000 mg/l to ensure a stable digestion process. This value should never exceed 4 000 mg/l.
- **Feedstock particle size:** The particle size of the feedstock has a direct effect on how well microbes can perform their task – the smaller the particle size, the quicker the microbes can digest them.

- **Ratios of nitrogen, carbon, phosphorus and sulphur:** The amount of nitrogen, carbon, phosphorus and sulphur in the feed needs to be balanced for good biogas operation. The carbon-nitrogen ratio can be influenced by the addition of feedstock high in carbon (veld grass) or high in nitrogen (i.e. canola, dried chicken manure, abattoir waste).
- **Micronutrients:** Microorganisms also require micronutrients such as sodium, potassium, magnesium, iron, nickel, cobalt, molybdenum, tungsten, selenium, zinc and calcium for optimal performance.
- **Microbial inhibitors:** Inhibitors like heavy metals, ammonia and hydrogen sulphide slow down the anaerobic digestion process. In small quantities, they decrease the rate of digestion. In large quantities, they can create a toxic environment which stops digestion.
- **Light:** Light can inhibit digestion, thus should be prevented from entering the digester.

7.2.2 Single-tank digester

Normally, biogas plants are set up as one-stage systems, where all the phases occur in a single tank.

Advantages: It has lower investment costs, and the organisms live in close synergy.

Disadvantages: Optimal conditions are a challenge, with so many different types of microorganisms. Also, biogas yields may be lower.

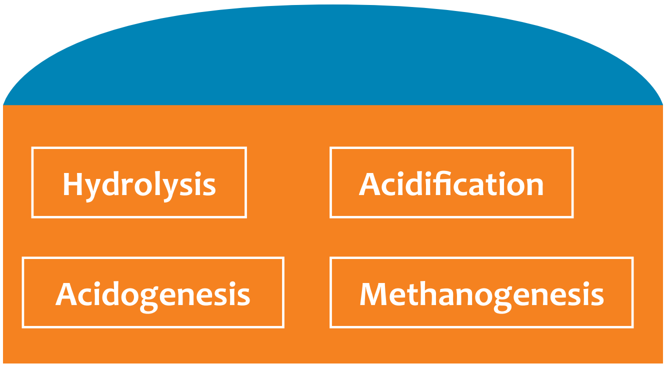


Figure 7.2: Phases in a one-stage process biogas plant

7.2.3 Multi-tank digester

Certain feedstocks, such as fats and cereals, experience increased hydrolysis, which may cause the pH or acidity in a single-tank digester to increase. This could have negative effects on certain microorganisms. In these cases, a multi-stage digester system can be used. This allows different bacteria to work in their optimal environments.

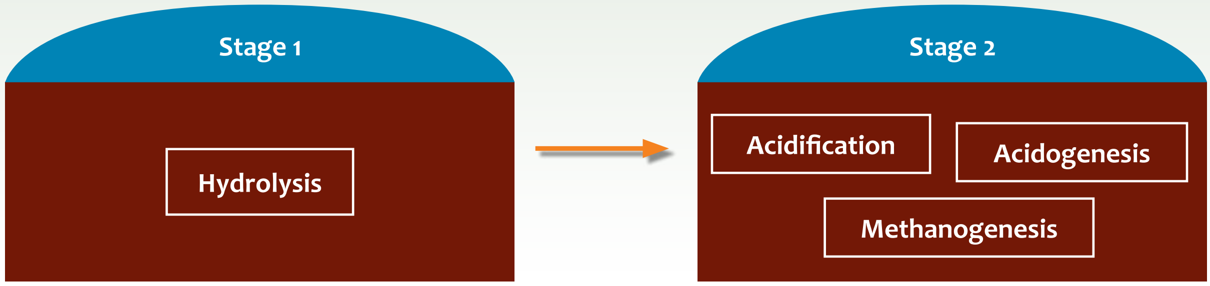


Figure 7.3: Phases in a multi-stage process biogas plant

In a two-stage system, the hydrolysis stage of the biological process happens in a separate tank, which allows for pH, temperature and retention time to be optimised for each stage.

In practice, the first-stage digester would be a smaller tank compared with the second-stage digester.

Advantage: Higher biogas yields

Disadvantage: Additional investment required

7.3 Role of temperature

The efficiency of the biogas process is directly influenced by temperature and therefore requires careful consideration when designing a biogas plant. Typically, AD operates within the following different temperature ranges:

- Psychrophilic (< 25°C): not relevant for commercial biogas plants in practice
- Mesophilic (35–48°C): most common/optimal temperature
- Thermophilic (> 50°C): fastest degradation, but more difficult to control.

In general, the following may be observed:

- The higher the temperature, the faster the growth rate of the microorganisms. The higher the growth rate, the higher the activity and digestion of the feedstock.
- With faster digestion, lower HRT and less digester volume are needed. This means reduced investment costs and less energy needed to mix the process.
- If a digester is operated without being heated, it will operate at ambient temperature only. Although this reduces cost, it also results in much lower biogas production.
- Most industrial biogas plants operate at mesophilic temperatures (about 37–45°C). The microorganisms are well adapted to this temperature range, because it is comparable to the inside of the digestive tract of cattle and pigs.

- Thermophilic operation offers the fastest growth, but the process will be more sensitive and will therefore require more accurate process monitoring as well as experienced operators, because the biogas can become more contaminated with hydrogen sulphide and ammonia.
- High temperatures are able to destroy potential pathogens in the feedstock.

Irrespective of which operating temperature range is chosen, it is important to ensure that a constant temperature is maintained. Quick temperature fluctuations may lead to reduced microbiological activity and consequently lower gas yields.

Temperature differences of +/-1–2°C are described as tolerable and without problems. Generally, mesophilic processes can accommodate temperature fluctuations better than thermophilic processes can.

7.4 Hydraulic retention time

Hydraulic retention time (HRT) is the average time the feedstock stays inside the digester. Different feedstocks require different retention times. Hydraulic retention time is calculated using the following formula:

The hydraulic retention time is a ratio of the size of the digester and the amount

$$\textbf{Hydraulic Retention Time} = \frac{\textbf{Capacity of the digester}\ (\mathbf{m^3})}{\textbf{Daily feedstock volume flow}\ (\frac{\mathbf{m^3}}{\mathbf{d}})}$$

of feedstock. The feedstock determines the hydraulic retention time.

The typical HRT needed for different feedstocks is:

Feedstock:	HRT:
Liquid cattle manure	≥ 20 days
Pig dung and straw	≥ 40 days
Energy crops	≥ 50 days

7.5 Energy calculation

The planning of a biogas plant usually starts with the calculation of the potential biogas production and, therefore, the energy yield calculation. This can be done as follows:

$$Available\ feedstock\ \left(\frac{tonnes}{a}\right) \times biogas\ yield\ \left(\frac{m^3}{tonnes}\right) = biogas\ production\ (\frac{m^3}{a})$$

$$Biogas\ production\ \left(\frac{m^3}{a}\right) \times methane\ content\ (in\ \%) = methane\ production\ (\frac{m^3}{a})$$

$$Methane\ production\ \left(\frac{m^3}{a}\right) \times 9.97\ \frac{kWh}{m^3}\ (lower\ heating\ value\ of\ methane) = theoretical\ energy\ production\ (\frac{kWh}{a})$$

$$Theoretical\ energy\ production\ \left(\frac{kWh}{a}\right) \times \eta\ (electrical\ efficiency) \times gas\ utilisation\ factor = annual\ electricity\ production\ (\frac{kWh_e}{a})$$

The guidance provided by applying the equations will give you the biogas production, methane production and theoretical energy production.

7.6 Start of operation

The start-up phase of operation is very sensitive. The existing microorganisms are not yet adapted to the prevailing conditions (feedstock, temperature, synergy with other microorganisms), so the process may be quite unstable during the first few months of operation.

At the start of the process, the amount of feedstock must be increased very slowly. Factors such as pH-value and gas composition can be evaluated daily to ensure a stable process.

Additional aspects to be considered ahead of initiating the start-up phase are listed below:

- Check that all equipment is functioning.
- Check that all safety precautions are in place.
- Check that all components are connected.
- Start with a small amount of material containing bacteria and microorganisms (digestate from another plant or cattle manure).
- Start feeding a low amount of feedstock.
- Monitor the process: gas production, gas quality and pH-value.
- The start-up phase may need several months until full load capacity is reached.

7.7 On-site safety

If biogas plants are not operated safely, they can pose a risk, negatively affecting the environment and human health. For operational standards, refer to SANS 1753-1 and SANS 1753-2.

Additionally, health hazards can still potentially occur at biogas plants, and are divided into four categories:

Explosion and fire hazards, since biogas is a mixture of different gases, the concentration of which may vary depending on the plant in question
Hazardous substances such as biogas itself, processing additives, oils, activated carbon, silage effluent, slurry and wastes
Electrical hazards such as control equipment, CHP units, pumps, agitators and measuring instrumentation
Mechanical hazards such as falling, impact, crushing and cutting

Table 4 details the main components of gaseous materials that can be found in a biogas plant, and their potential hazards.

Table 4: Properties of the gaseous constituents of biogas (Sources: [3] and [4])

	Properties	Hazardous atmosphere	Recommended workplace exposure limit
CO_2	Colourless, odourless gas Heavier than air	8% v/v: danger of asphyxiation	5 500 ppm
NH_3	Colourless and pungent-smelling gas Lighter than air	Above 30–40 ppm: mucous membranes, respiratory tract and eyes become irritated Above 1 000 ppm: breathing difficulties, potentially inducing loss of consciousness	20 ppm
CH_4	Colourless, odourless gas Lighter than air	4.4–16.5%	
H_2S	Highly toxic, colourless gas Heavier than air Smells of rotten eggs	Above 200 ppm: sense of smell deadened and gas no longer perceived Above 700 ppm: danger of respiratory arrest	5 ppm

Explosions and fire hazards occur when three factors apply simultaneously: a flammable substance (like biogas), oxygen (from air) and a source of ignition. If the concentration of biogas in the atmosphere is between 6% and 22% v/v, there is a risk of explosion in the presence of an ignition source (explosive range, explosive atmosphere). In the case of pure methane gas, the explosive range is between 4.4% and 16.5% v/v. The ignition temperature of biogas is 700°C (methane 595°C).

The composition of biogas may vary with regard to the proportions of methane and carbon dioxide, with the result that the explosive range of the gas mixture in the presence of air also varies.

7.7.1 Safety documentation

Safety documentation is a crucial prerequisite for the operation of a biogas plant and has to be constantly kept up to date.

In the event of an accident, it is of vast importance to document the situation exactly as it happened, as investigators into the case, including police, the fire brigade, insurance companies and other stakeholders, will look into safety precautions, alarm chains and countermeasures.

A major accident involving property damage and possibly personal injuries which are not covered by the insurance, would financially endanger and probably halt the whole biogas project. It is therefore of utmost importance for a biogas plant operator to be able to prove that the operation and maintenance plans and procedures, as well as the safety regulations, have been put in place and have been followed at all times.

In accordance with national requirements, the following should be documented:

- Authority to issue directives / line of command: list of persons to contact (both internal and external, e.g. authorities and agencies, including phone numbers)
- Emergency plan (operating instructions for procedures in the event of accident, fire, explosion, spilled substrate, power outage, unauthorised entry, etc.)
- Hazard assessment / explosion protection document
- Operating instructions for the employees
- Instruction manuals from the manufacturer
- Hazardous substances register
- Safety data sheets
- Release/briefing forms
- Maintenance and repair plan (including schedule according to manufacturer's instructions[9])
- Regular tours of inspection and operation diary
- Evidence of recurring tests (electrical tests, tests of work equipment)
- Evidence of initial and recurring training on operation and troubleshooting
- Evidence of initial and recurring safety training
- Up-to-date inventory of facilities and equipment (floor plan for fire-fighting, piping and instrumentation diagram, piping layout plan, etc.)
- Process management matrix
- Fire protection certificate.

9 Maintenance contracts with specialist companies are particularly advisable for parts of the plant that are of relevance to safety and need to be regularly calibrated (e.g. gas warning system, gas analyser, gas detector, personal protection monitor, fire detector).

8. Economics of biogas plants

In this chapter, the cost structure of a biogas plant (investment costs, annual capital costs, operation costs), followed by income streams, are further explained. For more information, refer to the Biogas Investment Decision-Making Tool.

A biogas project should be financially viable. What makes a biogas plant financially viable?

- Long-term feedstock supply. Is it free, or is there a purchase price attached?
- Define all revenue streams. Is the energy, biomethane, fertilizer, fuels, heat and/or biogas for burners being sold?
- Digestate management. Are there long-term contracts with farmers who can spread the digestate on their fields as fertilizer?
- Project structure and stakeholders. Is there an experienced project developer on the team?
- Choice of technology. Has the appropriate technology for the specific type of project been selected?
- Location. Is the biogas plant located near a long-term feedstock source and near customers?

Investment in a biogas plant can be motivated by several factors, but not all aspects can be monetized. Aspects which are hard or impossible to monetize, but might give additional reasons to invest in a biogas plant, are:

- Efficient waste management and reduction of organic matter, such as process water in the food industry. A biogas plant helps reduce organic matter, which allows wash water to flow into water bodies or reduces costs for wastewater treatment.
- Duty of care towards environmental protection. In many cases, the motivation to invest in biogas plants is based on the environmental benefits.
- Fertilizer production. Digestate is a valuable liquid fertilizer. Some farms invest in biogas plants mainly to produce fertilizer.
- Odour reduction. Biogas plants reduce odour of waste material.
- Independence from fossil fuels. Many farmers, especially in rural areas, have little access to fossil fuels, which often must be transported a long way.
- Security of supply. In some regions of Africa, the electricity grid is unstable and the supply unreliable. A company producing biogas could potentially rely 100% on energy produced from biogas and provide around 8 000 hours of electricity per year.

8.1 Costs of biogas production

The costs of biogas production can be divided into three categories: investment costs, operational costs and financial costs.

8.1.1 Investment costs

Biogas plants are customized to fit specific situations; therefore, components differ from one plant to another. However, experience shows two tendencies:

- Robust components can make a difference in the long run, providing economic sustainability and lower maintenance costs.
- A biogas plant can be operated for decades, provided it is closely monitored and well maintained.

Therefore, it can be concluded that investing in reliable technology solutions is a key aspect of a successful project.

Investment costs for a biogas plant vary, depending on factors such as:

- **Type of technology:** CSTR, plug-flow reactor, UASB reactor or batch reactor
- **Type of feedstock:**
  - Liquid feedstock can easily be pumped, which may lead to savings on investments in the feedstock preparation stage. On the other hand, costs for feedstock storage will be high, due to the water content of the feedstock which increases its volume and thus the storage capacity needed.
  - If municipal waste is used as feedstock, the investment cost might be higher, as additional equipment for separation and feedstock preparation will be needed.
- **Robust equipment:** It is important to choose robust equipment, specifically with regard to mixers and pumps, as these may require regular maintenance, which may affect downtime. Choose robust equipment to generate electricity to avoid long periods of downtime, which affects revenues.

The experiences in South Africa show that large biogas plants that intend to produce one megawatt of electricity (MWe) may cost in the range of R35 to R45 million.

In general, the relative investment cost (CAPEX plus OPEX) per biogas unit will decrease with an increase in the size of the plant. This is because basic costs apply regardless of the type and size of the plant. Therefore, the larger a plant, the lower the cost per unit of installed capacity.

In the case of individual components (mixers, pumps, etc.), the cost difference for similar equipment might vary as much as 30% (+/-), depending on the plant design. Where possible, locally produced equipment should be procured, as this could provide considerable cost savings.

In the case of larger-scale biogas plants, approximately 10–20% of the total investment should be budgeted as project development costs.

8.1.2 Operational costs (OPEX)

Operational costs of a biogas plant include the following:

- Feedstock costs (if any)
- Material costs, such as water or chemicals
- Labour costs
- Maintenance costs
- Reinvestments
- Business and administrative costs
- Insurance (0.5–2% of investment costs per year).

Operational costs depend on the size of the biogas plant. Anecdotal evidence in South Africa suggests that operational costs can be about R900 000 for a 50 kWe biogas plant, R1.3 million for a 200 kWe plant and R3.7 million for a 1 MWe plant.

8.1.3 Capital expenses (CAPEX)

Capital expenses are influenced by investment costs and the conditions related to the financing of the project. The CAPEX for the South African financial framework would need to take into consideration the following factors:

– Return on debt	Interest rate (foreign capital)
– Return on equity	Interest rate (own capital)
– Tenure (loan)	Lifetime of credit
– Debt / Total capital cost	Percentage of foreign capital
– Resulting WACC	Weighted average of capital costs.

Biogas plants should, however, be considered as long-term investment projects, wherein the capital which is secured for the infrastructure development attracts a low interest rate over the long term.

8.2 Revenue from biogas plant operation

Biogas plants have the possibility of generating various revenue streams. The actual income of these revenue streams cannot be monetized in general terms, as the conditions differ for each project. Potential revenue streams can, however, be explained by means of a general example.

8.2.1 Energy: Electricity and heat

Assume that a biogas plant of 1 MWe with a CHP plant which operates approximately 8 000 hours per year will result in an electricity production of 8 000 000 kWh_{el}. Anecdotal evidence from South Africa suggests that the revenues will be in the range of 0.9–1.6 R/kWh_{el}. If, for example, the monetary value for electricity is 1.5 R/kWh_{el}, the electricity produced has a monetary value of R12 million per year.

Some industries, such as chicken farming, could potentially use the heat produced by CHP units and thus generate additional revenue for the project. If, for instance, a project runs a CHP plant, the engine will produce around 8 000 000 kWhth per year. If only 25% of the amount of heat produced can be sold at 0.5 R/kWh, the revenue from heat could reach R1 million per year.

8.2.2 Fertilizer

Another potential revenue source is the sale of digestate as fertilizer.

All nutrients (like N, P, K, S and elements such as Fe, Zn, Sn, Mo and many more) present in the input material will be retained in the digestate. Material such as manure is already used extensively as fertilizer. By introducing a biogas plant, the amount of nutrients present in the output material remains the same, but it has an improved quality as fertilizer.

The amount of nutrients in the digestate is directly dependent on the type of feedstock.

For example, a 1 MW_e biogas plant would require about 65 000 tonnes of liquid cattle manure feedstock per year. Each tonne of digestate will contain 5.33 kg of total nitrogen, 1.68 kg P_2O_5 and 2.45 kg K_2O. This example will result in 346.45 tonnes of nitrogen, 109.2 tonnes of P_2O_5 and 160 tonnes of K_2O being produced per year.

Assuming the following prices for mineral fertilizer:

- R13 350 per tonne of nitrogen (N)
- R12 680 per tonne of phosphorus oxide (P_2O_5)
- R11 150 per tonne of potassium oxide (K_2O).

the value of nutrients in the digestate is R7 742 000.

The biogas process improves the fertilizing effect of the minerals that were already present in the input material, thus enhancing the value of the digestate as fertilizer.

Digestate cannot be sold as fertilizer if it contains heavy metals or has excessively high levels of mineral salts. Care should be taken to analyse digestate before considering it as a fertilizer.

8.2.3 Carbon credits

A biogas plant also reduces greenhouse gas (GHG) emissions. Therefore, another possible revenue source is the sale of carbon credits.

Biogas production can help to reduce GHG emissions in several ways:

- Open storage of organic material (like manure or residues from industrial production) generates methane emissions. Methane has a GHG potential which is about a factor 25 times higher than that of carbon dioxide. Due to material treatment in the biogas plant, effectively a closed system, and gas utilization (e.g. in a gas engine or boiler), these methane emissions are not released into the atmosphere but are combusted and transformed into carbon dioxide.
- Biogas generation is a nearly carbon-neutral energy generation method ("Zero Carbon Footprint"): during the growth of plants, carbon dioxide from the atmosphere is stored in the plant in the form of carbon-containing molecules (CO_2 reduction). After combustion, about the same amount of carbon dioxide is emitted as was originally extracted from the atmosphere (CO_2-neutral process).
- Due to renewable energy generation, fossil energy carriers can be substituted and, by that, CO_2 emissions avoided. The GHG emissions for electricity production in South Africa are about 1 ton CO_2 per MW electricity produced.
- Digestate (the effluent of a biogas plant) is a good-quality fertilizer.

Methane is a rather aggressive GHG, which is why methane emissions from biogas plants must be prevented or limited. This can be done by ensuring no leaks during operation, covering the digestate storage areas, and installing a flare which burns the produced methane in times when the biogas utilization is not in operation.

The value of carbon certificates depends strongly on the type of market. Currently, the price of European Emission allowances is above 8.5 US$ per tonne CO_2. According to the example given, a CO_2 emission reduction of 8 615 tonnes would result in about 73 000 US$ value of carbon certificates.

In 2019, a carbon tax was introduced in South Africa, which may be potentially beneficial to the biogas industry, given the emission reduction potential of the technology.

8.3 Financing mechanisms and incentives

There are several financing mechanisms and incentives available for the South African market. [11]

The banking sector is in general very risk-averse, and due to the relatively small number of biogas plants developed in South Africa, banks still perceive biogas projects as high-risk investments. With higher risk comes higher interest and more stringent lending conditions. However, there are several options to finance a biogas plant in South Africa.

8.3.1 Financing and funding instruments

The commercial banking sector of South Africa by now has recognized the financing of renewable energy (RE) projects as a business area. South African banks are highly involved in the Risk Mitigation Independent Power Producer Procurement Programme (RMIPPPP). Therefore, it is generally possible for creditworthy companies and enterprises to finance their RE plants via loans from commercial banks. [11]

Additionally, numerous public financing and supporting measures have been introduced to promote the use of renewable energy and the increase of energy efficiency in industry. These measures include financing instruments as well as tax incentives. Funding instruments are accessible for companies established in South Africa. A selection of instruments will be presented in the following paragraphs to give an overview of the local funding mechanisms. [11]

8.3.2 GEEF – The Green Energy Efficiency Fund

The GEEF aims at reducing the energy and CO_2 intensity of South African industry, as well as raising awareness among South African enterprises regarding energy consumption. Specifically, the following aims are targeted:

- Stimulation of investment in the sector of energy efficiency (in industry)
- Support of RE projects for self-sufficiency
- Promotion of competitiveness of South African industry
- Contribution to international climate protection.

To achieve these goals, the GEEF supports projects by enterprises registered and operating in South Africa (with a focus on small and medium enterprises (SMEs)), according to the following conditions:

Eligible types of projects: Investment in energy efficiency leading to a significant reduction of energy consumption (saving: > 20%) and CO_2 emissions, as well as investment in renewable energy for self-sufficiency.

Funding conditions: Credit up to R50 million with a credit period of 15 years, depending on the payback time of investment; the rate is independent of the project and always set to 2% below the base rate.

The GEEF is coordinated by South Africa's Industrial Development Corporation (IDC). The funds of the GEEF originate from, among others, the German KfW Development Bank, which has granted the IDC a loan of over R500 million, and established in 2011.

More information about the GEEF is available on the website of the IDC: Green Energy Efficiency Fund – Industrial Development Corporation .

8.3.3 Environmental tax incentives

South African Revenue Service (SARS) has developed measures to promote investment in renewable energy. These aim to help businesses become more energy-efficient and self-sufficient.

An amendment to section 12B of the Income Tax Act provides for an accelerated depreciation for movable assets used in the production of renewable energy. More specifically, it allows for a depreciation on a 50|30|20 basis over three years in respect of any machinery, plant, implement, utensil or article (referred to as a qualifying asset) owned by the taxpayer. [12]

The following sources of renewable energy are included:

- Wind power
- Solar energy
- Hydropower (gravitational water forces) to produce electricity of not more than 30 megawatts
- Biomass comprising organic waste, landfill gas or plant material.

8.4 Business models for biogas plants

The most viable biogas projects in South Africa are those where the owner of the project is also the owner of the feedstock and all energy produced is used for own consumption. Another viable scenario is where the project manages to secure an off-take for the energy produced by the plant. Additionally, other drivers for the viability of biogas projects are:

- Difficulty in procuring electricity from the national grid.
- Reuse of the waste produced by food processing industries or by abattoirs (rumen, blood), with consequent saving of the disposal costs of hazardous waste.
- Reduction of greenhouse gas emissions due to the introduction of the carbon tax or to the voluntarily policies and strategies adopted by international owned industries in the automotive, food processing sectors and breweries that operates in SA.
- Non availability of CO_2 for industrial use in some regions of the country.

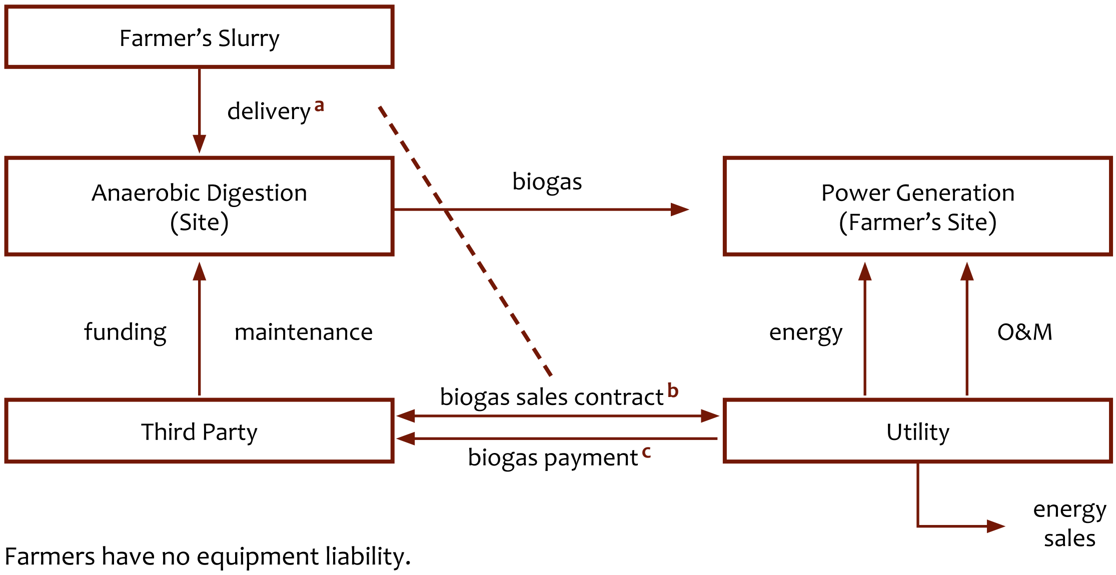
The Asian Development Bank, in their publication about business models for renewable energy, [2] differentiates between two types of business models for renewable energy and energy efficiency projects: a) ownership business models and b) service models.

For medium-scale to large-scale renewable energy projects, the ownership model most frequently used is a public-private partnership (PPP). A PPP involves a contract between a public-sector authority and a private party, in which the private party provides a public service (e.g. electricity supply) and assumes a substantial amount of the financial, technical and operating responsibilities. [2]

Typically, a special-purpose vehicle (SPV) is developed to build, maintain and operate the project for a contracted period of time. The SPV enters into a contract with the client (the off-taker) and with subcontractors to build the facility and then operate and maintain it.[2]

A very important factor for biogas projects is a secured feedstock supply agreement (FSA) to guarantee the expected output and the bankability of the project. The feedstock supplier can also be the client for the energy itself. In cases where the energy client is also the feedstock supplier, it is advisable to integrate him into the SPV.

A multiparty ownership model could also be suitable for a biogas project. Figures 8.1 and 8.2 show the aspects of multiparty ownership for a biogas plant.

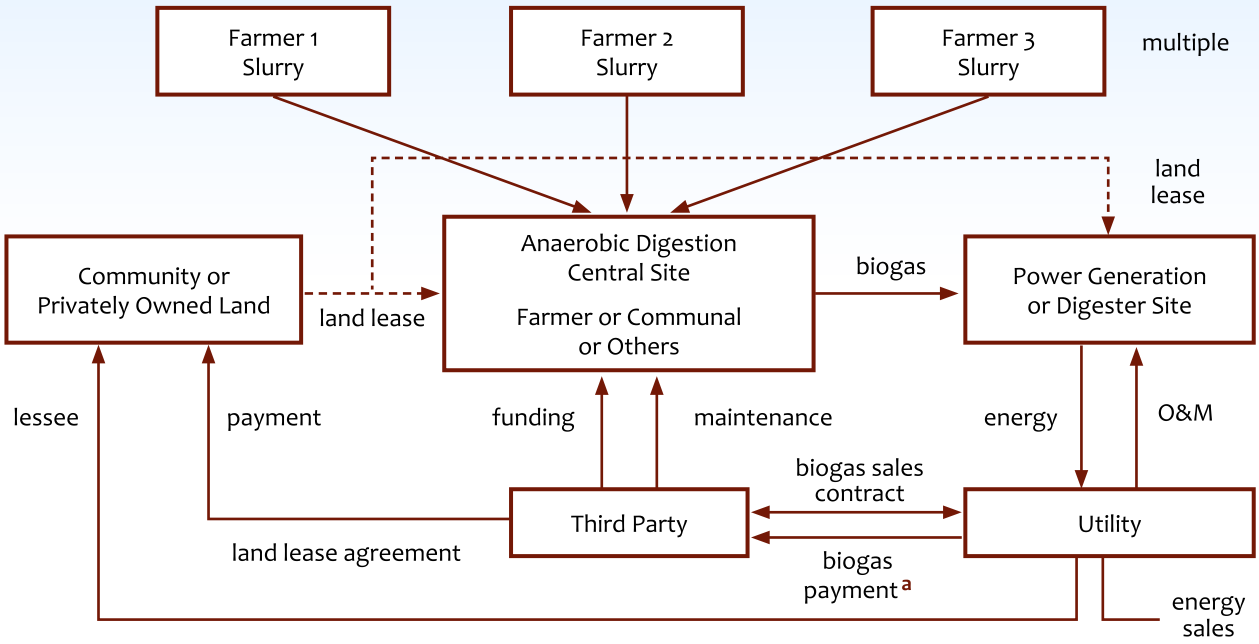


– Farmers have no equipment liability.
– Site-related risk is with third party or utility.

O&M = operation and maintenance

[a] Farmers obliged to deliver slurry and provide land
[b] Most likely equiring tripartitie agreement
[c] To cover debt and interest of digester

Figure 8.1: Multiparty ownership model for a biogas project[2]



- Farmers have no equipment liability.
- Site-related risk is with third party or utility.
- Project may benefit from lease payment/property exemption if on commercial land.

O&M = operation and maintenance

[a] To cover debt and interest of digester

Figure 8.2: Relationship diagram for a community biogas project [2]

Among the various business models, a cooperative or collective action model could be used for a biogas project, especially for community-based projects.

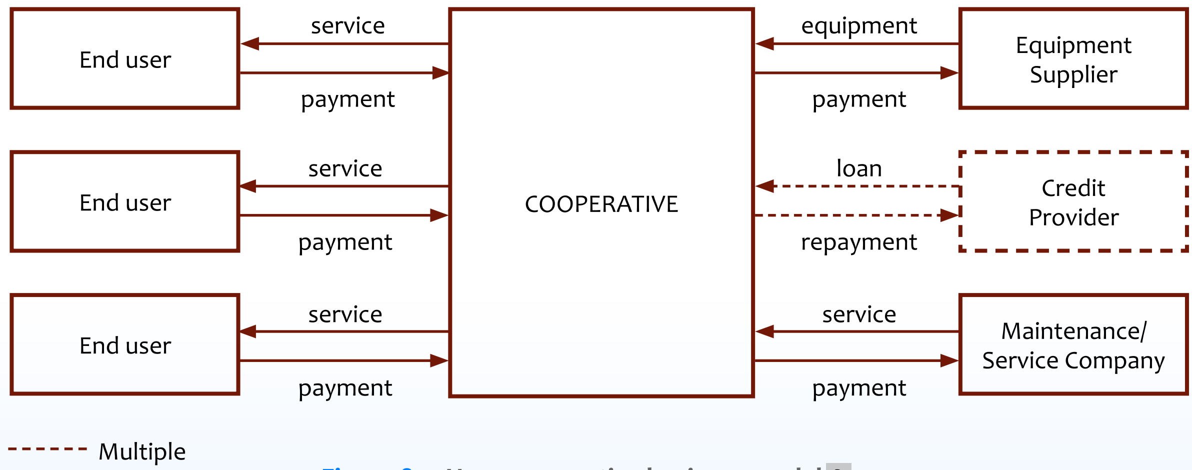


Figure 8.3: User cooperative business model [2]

A collective action model involves the establishment of a non-profit community organization, owned and managed by its members. The community operates the project and is also in charge of the financial management. This model offers a mechanism for governments and NGOs to support renewable energy projects at the local level. Figure 8.3 shows what this model could look like in practice.

9. Planning a biogas plant

Numerous factors need to be considered when planning a biogas plant. These include a feasibility study, due diligence, stakeholder communications, financing, licensing and construction.

9.1 Initial idea for a biogas plant

The first idea of building a biogas plant is usually initiated by either the owner of the feedstock or a biogas project developer.

To assess the suitability of a particular location, the following considerations are important:

- Is there (enough) feedstock available? As described above, the more feedstock available, the better the chances that a biogas plant might be viable. For a commercial biogas plant, at least 6 000 t/a feedstock should be available.
- What kind of income might be generated (electricity, heat, fuel and/or fertilizer)?
- Is there an off-take agreement for the energy produced?
- Is there enough space?
- Are there access roads?
- Is there an electricity connection?
- Is there any requirement for heat?
- Is there agricultural land close by to spray the digestate on the fields?

The first considerations should also include matters like the possibility of creating partnerships with local stakeholders, feedstock providers and the customers of outputs such as electricity/heat.

9.2 Feasibility study

A feasibility study concerns technical and economic factors. At this stage, a biogas expert can be consulted. The result of the feasibility study is a report, describing the main characteristics of the project, which would assist in final decision-making. A report may include:

- Advantages and disadvantages of each technological option
- Rating of the options
- Risk assessment
- Cost analysis.

Based on the feasibility study, further steps of project development can be taken. For bigger projects with higher investment, additional due diligence might be required.

9.3 Stakeholder liaison

Identifying and communicating with all relevant stakeholders is critical to any biogas project in South Africa. The following stakeholders are important to any biogas project.

9.3.1 Local authorities

Contact an Environmental Assessment Practitioner (EAP) familiar with local government regulations. Points to discuss include:

- What approvals are required?
- What conditions need to be complied with in order to get an approval?
- What kind of information is needed?

SABIA assists members through webinars, and the Environmental Assessment Practitioners Association of South Africa will give you details of EAP members in your area.

9.3.2 Communities

Communities or farms near the planned location of the biogas plant can support or block the project. Involve these stakeholders from the beginning. Convene stakeholder meetings and offer sound and realistic information. Communicate the issues and advantages of a proposed biogas plant:

- Employment creation: work on the plant, maintenance, direct and indirect jobs
- Low-cost energy production, e.g. heat
- Organic fertilizer (digestate) for their fields
- Energy independence.

Stakeholders may be wary of potential accidents, e.g. explosions, poisonous gases and environmental damage (digestate flowing into rivers or harming the quality of the soil). They will need honest and humble explanations and replies.

9.4 Finance

In order for a biogas plant to be constructed, it has to prove to be financially viable. Large commercial plants will most likely require considerable funding.

Financing conditions strongly depend on the perceived risks. Reliable technology and professionals experienced in planning are important aspects for banks. Present a realistic business case and economic viability assessment to the bank.

When contacting financing institutions, clarify the following issues:

- Investment
- Finance conditions
- Interest rate of debt
- Return on equity (ROE)
- Return on investment (ROI)
- Ratio equity/debt
- Running time of finance
- Weighted Average Cost of Capital (WACC).

9.5 The law and biogas plants

Since commercial biogas plants are complex facilities, consider all laws, legal issues, permissions and environmental issues during the planning phase.

Biogas consultants and Environmental Assessment Practitioners (EAP) will be aware of these legal and environmental hurdles. This is a checklist to consider:

- Construction
  - Statistics
  - Site selection (e.g. near watercourses or other environmentally sensitive areas)
- Emissions/Pollution
  - To the atmosphere
  - To the soil
  - To water bodies
- Digestate application
- Pasteurization of digestate
- Waste utilization
- Safety
- Energy connection/supply
- Environmental impact assessment needed?

In 2015, the German Development Cooperation Agency published an exhaustive study on the licensing procedures for biogas in South Africa. [13]

The study concluded that various interrelated approvals/licences/permits [13] under numerous Acts have different requirements, processes and time frames.

For example, there are discrepancies between definitions and interpretations, particularly between provincial authorities and the national departments. [13]

Table 5 presents the regulations to be considered when establishing a biogas plant.

Table 5: Regulations to be considered

Name of the licence/ permit	Responsible entities	Approximate time frame	Additional requirements (if any)
Environmental impact assessment (EIA)	Designated provincial department	1.5 years	Specialized studies including but not limited to: Groundwater impact study Surface water impact Heritage / visual impact assessment Air emission impact Biodiversity assessment
Land lease agreement	Land owner (for leases shorter than 10 years) Land owner and Department of Agriculture (for leases longer than 10 years)	6 months	Required if someone else besides the owner of the land plans to build and operate a plant, where maximum duration of agricultural land lease is 10 years. In cases where more time is required, e.g. when the life of the plant is 20 years, an application has to be lodged with the Department of Agriculture for an extension.
Municipal consent of use licence	Responsible municipality	2 years	Granted by municipalities, allows biogas plants to be built and operated
Waste management licence	Department of Forestry, Fisheries and the Environment	Up to 6 months	Application is issued under the National Environmental Management Act of 2008 by the Department of Forestry, Fisheries and the Environment. The licence authorises the storage and processing of animal waste. Must go through an EIA process to obtain the licence.
Water use licence application	Department of Water and Sanitation (DWS)	Up to 2 years	Application issued to the Ministry of Water and Sanitation according to the National Water Act.
Generation licence	National Energy Regulator of South Africa (NERSA)	Up to 6 months	A generation licence from NERSA for projects outside the REIPPP have to get approval from the Department of Energy.
Grid connection and transmission agreements	Eskom	Up to 12 months	Agreements obtained from Eskom if the connection is subcontracted
Wheeling agreement into the national grid	Eskom	6 months	The procedure for this requires that a power purchase agreement is concluded. This is not a clear-cut process in all projects and can still be very costly, cumbersome and time-consuming.
Wheeling agreement with the involved municipality	Involved municipality	2 years	The process of acquiring this is lengthy, as there is no framework in place. This can also only be signed once a PPA has been signed.

10. Biogas plant construction

A biogas plant represents a complex industrial construction process. Choose an interdisciplinary team of experts to guarantee a reliable, stable and safe operation with low maintenance effort and downtime.

Planning of a biogas plant may take months. Project development costs for large biogas plants could be as high as 10% of the investment costs.

The planning of a biogas plant has several steps. In the figure below, some typical phases of this process are shown.

Figure 10.1: Biogas plant planning process

10.1 Managing equipment purchases

Most biogas projects are joint ventures between willing stakeholders.

On very large biogas projects and after the specifications of the biogas plant have been completed, a tender process could be initiated to identify companies who offer complete biogas plants or components. Commonly, there are two ways to organize the purchase of a biogas plant.

- **Turnkey projects:** Appoint a company to deliver the complete biogas plant.
- **Appointment of a project coordinator or consultant:** This individual will organize the purchase of the individual components by working in close cooperation with the owner of the project.

Local contacts and experiences are also important aspects influencing the path you will take.

10.2 Collective action partnerships

In any project that is a collective active partnership, consider these issues:

- Ownership: Settle the percentage participation of the ownership of the biogas project, as it will affect the split of profit share.
- Ownership of land or rental of land
- Feedstock: The quality, quantity and price of feedstock will determine the farmer's stakeholder share in the venture.
- Energy supply contracts: Who will buy your power or heat, and at what price?
- Heat supply contract: If nearby industry is buying your power, you will need documentation in place.
- Suppliers: Make sure that the planner, manufacturer, component supplier and construction team are aware of their fees.
- Operational contract: Who will run the biogas plant operation?
- Maintenance contracts: Do you have CHP plant maintenance in place?
- Digestate: Quantify the cost of fertilizer by offering a long-term contract with local farmers.

10.3 Construction sign-off

Communication and collaboration between experts is important in order to avoid delays and mistakes during construction.

At the end of the construction phase, an inspection of the plant should take place to sign off the construction. Consider these issues:

- Sign off each phase/discipline of work during construction (electrical work, pipework, welding and concrete work).
- Performance tests: Check that all components and emergency equipment works.
- Does it work? Make sure the biogas plant can produce biogas (check gas quality, etc.) and convert the energy (e.g. into electricity) according to the design parameters. The intended performance parameters are usually defined in contracts.
- Get deviations from the planning documented in writing.
- Take contract and guarantee conditions into account.

10.4 Documentation

The biogas plant manufacturer should supply complete documentation to the operator regarding:

- Overall description of the plant
- All construction and technical drawings
- Operation manual for each component
- Manual for whole plant operation, including action for unplanned situations
- Checklists (daily, weekly, monthly, annual).

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