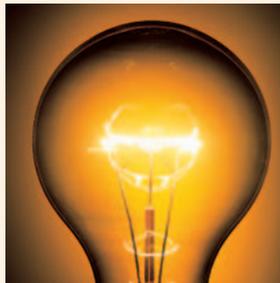




Biogas – an introduction



Federal Ministry
of Food, Agriculture and
Consumer Protection



Published by:

Fachagentur Nachwachsende Rohstoffe e.V. (FNR)

Hofplatz 1 • 18276 Gülzow • Germany

Phone: +49 (0)38 43/69 30-0

Fax: +49 (0)38 43/69 30-102

E-Mail: info@fnr.de

Website: www.fnr.de

With financial support of the Federal Ministry of Food,
Agriculture and Consumer Protection (BMELV)

Text:

Department of Public Relations, FNR

Design and production:

nova-Institut GmbH • www.nova-institut.de

Printing and handling:

Media Cologne Kommunikationsmedien GmbH

www.mediacolonne.de

2nd edition – January 2009

FNR 2009

Contents

Renewable energy from biogas	4
How much energy could be produced from biogas?	5
Renewable raw materials and sustainability	5
What are the environmental benefits of biogas production?	8
How is biogas produced?	8
Which substrates can biogas be made from?	9
How does a biogas plant work?	11
How is biogas utilised?	16
What is the applicable regulatory framework?	20
How does a biogas plant become cost-effective?	22
Further information	23
Useful figures	24
Important process parameters	24

Renewable energy from biogas

There is no disputing the dependency of the industrialised nations on finite resources and the consequences of the use of fossil energy sources can already be discerned. A U-turn can only come about through the increased use of sustainable energy sources. In 2007, renewable energy provided 14.2 % of total electricity consumption and 6.6 % of heating (cf. Fig. 1).

The German Government intends to reduce greenhouse gas emissions substantially by 2020 and to increase renewable energy's share of electricity supply to 30 % and that of heat production to 14 %. Biogas use can make an important contribution to this. After all, energy from biomass has the advantage that it can be produced in a CO₂-neutral way and used in line with demand.

Energy production through the utilisation of biogas has long been well-known.

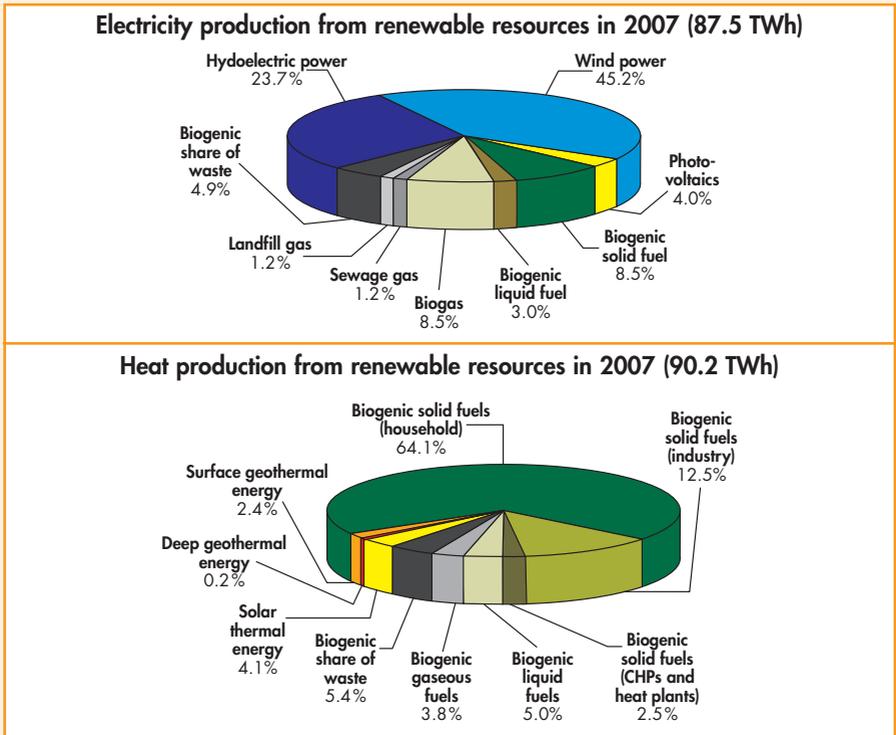


Figure 1: Electricity and heat production from renewable energy sources in Germany in 2007 (Source: Federal Ministry for Environment (BMU), AGEE-Stat, October 2008)

But the biogas technology started its development in the beginning of the 1990s. And there has been enormous growth when the German "Renewable Energy Source Act" came into force in the year 2000. Presently, about 4,000 mainly farm-based biogas plants are installed in Germany for energy production (see Fig. 2).

How much energy could be produced from biogas?

The biogas, sewage and landfill gas potential in Germany is approximately 23 – 24 billion m³/year. This gives a theoretically available annual energy source potential of 417 petajoules (PJ/a). The largest contribution, roughly 85 %, comes from the potential biogas produc-

tion in the agricultural sector. In relation to the total primary energy consumption of 13,878 PJ in Germany in 2007, this would represent a share of about 3 %.

Renewable raw materials and sustainability

Fossil energy sources are running low and in order to spare them and halt climate change, we will have to gradually switch to renewable energy over the coming decades. Bioenergy, which is already the largest contributor among regenerative energy sources in Germany with about 70 % of the total, will continue to play a central role in the future. Renewable raw materials are already of great importance in the materials sector too. A fundamental prerequisite for the

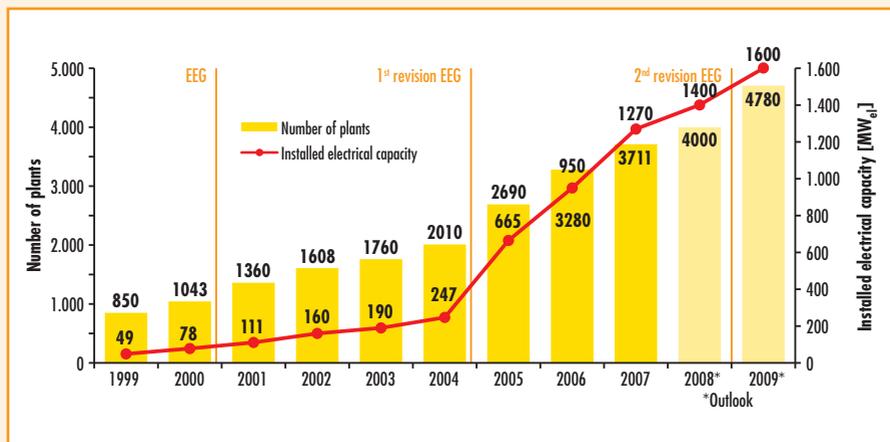


Figure 2: Number of biogas plants with their total installed electrical capacity in Germany (Source: Federal Ministry for Environment (BMU), 2008; German Biogas Association, 2008; provided FNR)

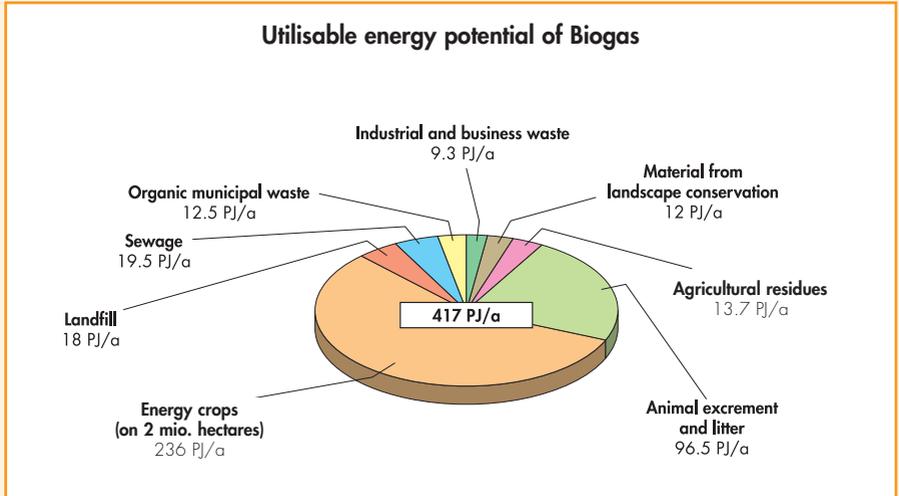


Figure 3: Utilisable energy potential (Hartmann/Kaltsschmitt, 2002, reworked by FNR)

increased utilisation of plant raw materials and energy sources is however that they are produced and used sustainably. Sustainability, as defined in the 1987 Brundtland Report, means meeting the needs of the present generation without compromising the ability of future generations to meet their own needs¹). Sustainability therefore has an environmental, an economic and a social dimension. When applied to renewable raw materials, this means that their utilisation needs to strike a balance between what is economically necessary, such as high and guaranteed biomass yields, and what nature can be expected to tolerate. The social component refers among other things to people's working conditions, new income opportunities and a share of value-added processes. There are many different approaches to su-

tainable production in European agriculture and forestry. One of the Federal Ministry of Agriculture's (BMELV) main funding domains is to test these approaches through research projects and to further develop them. Some of the strategies that are being pursued are:

- Increasing the species diversity used in energy crop production;
- Breeding new varieties;
- New production methods using lower doses of pesticides and fertilisers as well as year-round vegetative cover on fields;
- The use of especially efficient conversion processes;
- The recycling of residues as fertiliser.

The BMELV's task is to fund research in an appropriate and consistent manner so as to develop the most suitable me-

thods for a sustainable energy and raw material industry. It will then require the whole of society to put these methods into practice: it is business and consumers who have to integrate these new processes and products into their daily lives.

Agricultural markets have long been globalised. The needs for bioenergy and renewable raw materials are thus increasingly satisfied by international markets and this cannot help but have an impact on questions of sustainability. In the tropics, there are different problems than in Europe, as areas of rainforest are cleared to grow food, feed and energy crops such as oil palm and soya, the workforce is exploited and indigenous peoples are displaced. A pilot project for a certification system, funded by the BMELV, intends to remedy this situation. Its aim is, as a first step, to authorise only biomass with a certificate of sustainability to be used in the production of biofuels. Later, such certificates will be applied to all possible methods of using agricultural raw materials so as to avoid displacement effects. The certification project, which is now beginning a two-year test phase, is thus also a suitable instrument to test the sustainability requirements of draft Federal and EU-wide laws.²⁾

After all, the situation in Southern countries is exactly the same as in the North: bioenergy can be as much a threat as an opportunity for the ecosystems and people who live there. If in the South, for example, small farmers can be established as biomass producers and the large

areas of uncultivated land can be taken back into production for energy crops, then the advantages outweigh the disadvantages. Extremely drought-resistant plants such as jatropha (also called "physic nut") offer possibilities to revegetate desert-like areas.

In the North, new varieties of energy crops and new production methods can ensure greater diversity and sustainability. What is more, in rural areas, bioenergy is a first-rate instrument for structural development: it offers new sources of income, new economic configurations and greater independence to regions that are presently often some of the more structurally disadvantaged, problem areas.

Paths towards a sustainable, renewable society do exist. It is now a question of choosing them and developing them not

1) In 1983, the World Commission on Environment and Development (Brundtland Commission) chaired by the former Norwegian Prime Minister Gro Harlem Brundtland used the term "sustainability", which originally came from forestry, for the first time in a development context. This definition is quoted from the Brundtland Commission's final report "Our Common Future" (also known as the Brundtland Report) from 1987.

2) Draft sustainability directive by the German Federal Government (2007), which prescribes that only sustainably produced biofuels may be considered for the quotas (Biofuel Quota Act), as well as draft guidelines from the European Commission to promote renewable energy (2008).

only economically but also environmentally and socially. The BMELV is making its contribution by funding research and raising awareness.

What are the environmental benefits of biogas production?

The most important contribution of biogas technology to environmental protection is that it avoids additional carbon dioxide (CO₂) emissions compared with fossil energy sources. Producing energy from biogas is largely CO₂-neutral, i.e. the CO₂ released by burning biogas was previously removed from the atmosphere during the generation of biomass through photosynthesis.

The fermentation of manure also reduces emissions of methane, a gas that has an effect on the climate and would otherwise escape uncontrolled from raw liquid manure with far more damaging effects for the climate than CO₂. New research suggests that emissions of laughing gas – which also has an effect on the climate – can also be reduced by fermentation. Moreover, fermentation reduces the development of odours during liquid manure storage and spreading since the odours contained in the liquid manure are broken down and neutralised during the fermentation process. In addition, fermentation improves the quality of manure as pathogens and weed seeds are killed and nutrients made more available for plants, enabling the manure to be applied in a more tar-

geted fashion as a substitute for inorganic fertilisers.

How is biogas produced?

Biogas occurs widely in nature. Biogas forms wherever organic material accrues under exclusion of oxygen (called anaerobic digestion), e.g. in bogs, on the bottom of lakes or in ruminants' stomachs. The organic matter is almost entirely converted into biogas in these conditions. The actual process by which biogas forms involves the complex interaction of various microorganisms and takes place in basically four separate phases (cf. Fig. 4).

The first stage of decomposition in methane producing fermentation is the liquefaction phase, which splits long-chain organic compounds (e.g. fats, carbohydrates) into simpler organic compounds (e.g. amino acids, fatty acids, sugars) through bacterial action.

The products of hydrolysis are subsequently metabolised in the acidification phase (acidogenesis) by acidogenic bacteria and broken down into short-chain fatty acids (e.g. acetic, propionic and butyric acid). Acetate, hydrogen and carbon dioxide are also created and act as initial products for methane formation.

In the acetic acid phase (acetogenesis), the organic acids and alcohols are broken down into acetic acid, hydrogen and carbon dioxide. These products act as a substrate for methanogenic microorganisms. In the fourth and finale phase, during

which methane is formed (methanogenesis), the products from the previous phases are converted into methane by methanogenic microorganisms (archaea). The end product of fermentation is the combustible biogas that is mainly composed as follows:

- 50 – 75 % methane (CH₄)
- 25 – 45 % carbon dioxide (CO₂)
- 2 – 7 % water (H₂O)
- < 2 % oxygen (O₂)
- < 2 % nitrogen (N₂)
- < 1 % ammonia (NH₃)
- < 1 % hydrogen sulphide (H₂S).

The energy content of the biogas is directly dependent on the methane content. The higher the content of substances such as fats and starch that are easy to break down in the fermented mass, the greater the gas yield. One cubic metre (m³) of methane has an energy content of about ten kilowatt hours (9.97 kWh). E.g. if the biogas contains 60 % methane, then the energy value of one cubic metre of biogas is about six kilowatt hours. In this case, the heating value of one cubic metre of biogas is roughly 0.6 litres of heating oil.

Which substrates can biogas be made from?

Many kinds of organic substrate can be used to produce biogas. In farm-based plants, it is mainly animal excrement that is used (e.g. cattle and pig liquid manure) as the basic substrate. Other organic materials can also be fermented for biogas to increase the biogas production.

Plants that are grown for energy production are known as energy crops. With their help, new biomass can be made available year after year to produce electricity, heat and fuel. Energy crops can also be grown on set-aside. A market for biogas substrates from renewable raw materials is already emerging in Germany and use of these substrates is progressively increasing. Renewable raw materials include cereal crops, grass, maize, millet, sunflower and many others.

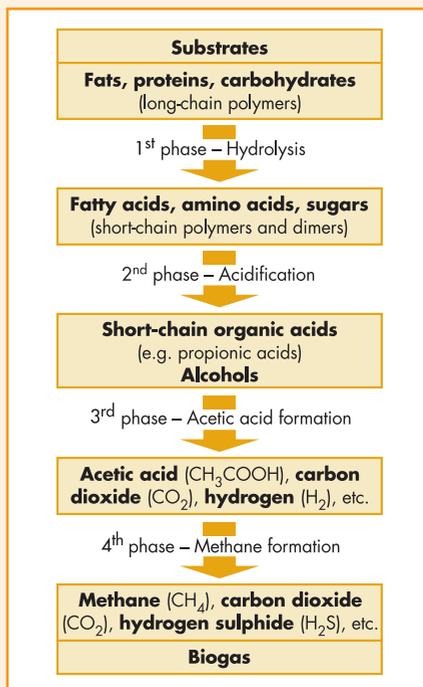


Figure 4: Simplified diagram of how organic matter is broken down during biogas production

Along with renewable raw materials, non-agricultural substrates are also suitable for producing biogas, such as residues from the food industry (e.g. pomace, distiller's wash, grease separator residues), vegetable waste from wholesale markets, food waste or grass clippings and organic waste from municipal waste disposal. The fermentation of residues material (called co-fermentation) provides a possibility of closing the cycle and dealing with them in a way that produces few emissions and is hygienic.

Fig. 5 shows the comparative biogas yields of various substrates (in relation to their fresh mass) with their average methane content.

The substrate used in biogas plants across Germany is composed of about 41 %

animal excrement, 10 % organic waste, 2 % industrial and agricultural residues and 47 % renewable raw materials (BMU 2008).

Fermentation inhibitor

The anaerobic digestion is very susceptible to disturbances. These can either be due to technical reasons or to inhibitors. Inhibitors, even in small quantities, can have a negative effect on bacteria and therefore on the process of decomposition. They enter the fermenter either with the substrate itself or alternatively stem from intermediate products of individual stages in decomposition.

For example, adding excessive amounts of substrate to the fermenter can inhibit the fermentation process because, in principle, the presence of an excess con-

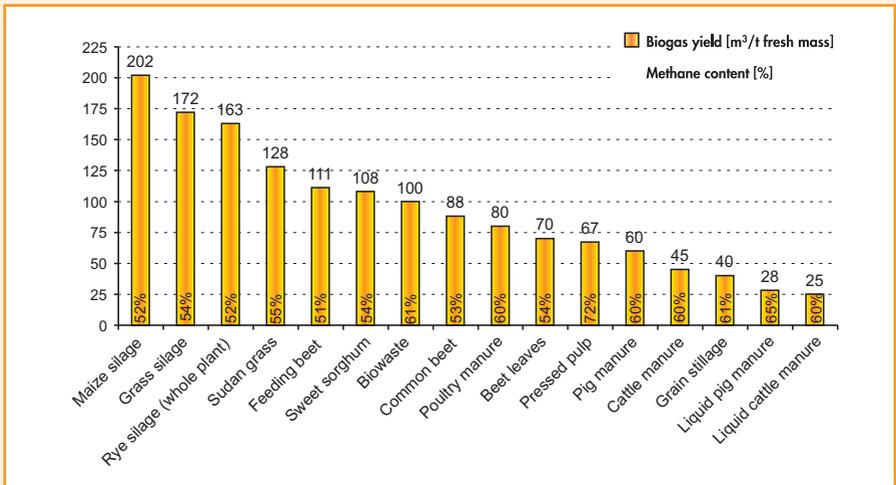


Figure 5: Biogas yield and methane content of various substrates (Source: Handreichung Biogas, FNR, 2006; Energiepflanzen, KTBL, 2006)

centration of any ingredient in a substrate can have a harmful effect on the bacteria.

There are however also substances that are not conducive to the production of biogas. If present in too high a concentration, these can be toxic to bacteria since microorganisms even have a certain tolerance towards these substances. This is particularly true for disinfectants and detergents, antibiotics, solvents, herbicides, salts or heavy metals, even small quantities of which can inhibit the fermentation process.

Hydrogen sulphide, on the other hand, is a product of the fermentation process that can be poisonous to cells in solution and can also hinder the process of decomposition. Sulphur is nevertheless an essential trace element and therefore an important mineral compound for methanogenic bacteria. Too high a concentration of ammonia can also inhibit methane production, which is why poultry droppings and occasionally pig liquid manure are diluted or mixed with co-substrates that have a low nitrogen content.

How does a biogas plant work?

Farm biogas plants generally consist of a liquid manure store, a feed-in unit for solid substances, a digester where the actual fermentation takes place and a digestate storage tank for the fermented biomass. Depending on the type

of substrate, co-fermentation plants may also require a receiving pit, disintegration, the removal of contraries and pasteurisation. The gas produced for utilisation then continues towards gasholders, gas cleaning and its respective uses.

Substrate-bearing components

The liquid manure store is used for intermediate storage of liquid manure as a fermentation substrate. Solid substrates require a suitable metering device. These must be large enough to even out variations in the amount of substrate available. If co-substrates are being used in the plant, then additional buildings may be required to receive and treat the substrates depending on the latter's properties. Along with disintegration, the removal of contraries is especially important for the process to be able run smoothly as well as for the quality of the digestate.

When substrates that could potentially spread diseases, such as organic waste, animal processing and food waste among others, are co-fermented, the substrate receiving area and substrate processing area have to be kept separate by maintaining an unclean and a clean side. Furthermore, pasteurisation equipment is required to heat the substrate up to 70°C for a minimum of 60 minutes. This prevents pathogens that represent a health risk from persisting in the substrate.

The digester or reactor, the heart of a biogas plant, is supplied with fermentation

substrate from the liquid manure store. Depending on how the substrate flows into the fermenter, these can be divided into:

- continuous and
- discontinuous plants.

In the *discontinuous biogas process*, also known as batch process, the fermenter is completely filled with fresh substrate and hermetically closed. The substrate remains in the container until the end of the selected retention time without no substrate added or removed. The fermenter is then emptied and filled with new substrate. Gas production begins slowly after filling and subsides again after the maximum value has been reached. Discontinuous feeding is the process most widely used for dry fermentation (see page 15).

Continuous processes are characterised by regular feeding of the digester. The digester also acts as a digester storage tank in which the substrate is kept until it is spread. The disadvantage is the high energy consumption necessary to heat the large reactor room; the advantages are the low investment cost and the use of biogas from secondary fermentation. Semi-continuous fermentation is the most widely used process in Germany. The substrate is pumped into the digester several times daily from the holding tank/liquid manure store. A quantity of fresh substrate equivalent to that added to the fermenter is expelled or removed into a downstream fermenter. This results in fairly regular gas – and therefore electricity – production. When the retention time has elapsed, the fermentation sub-

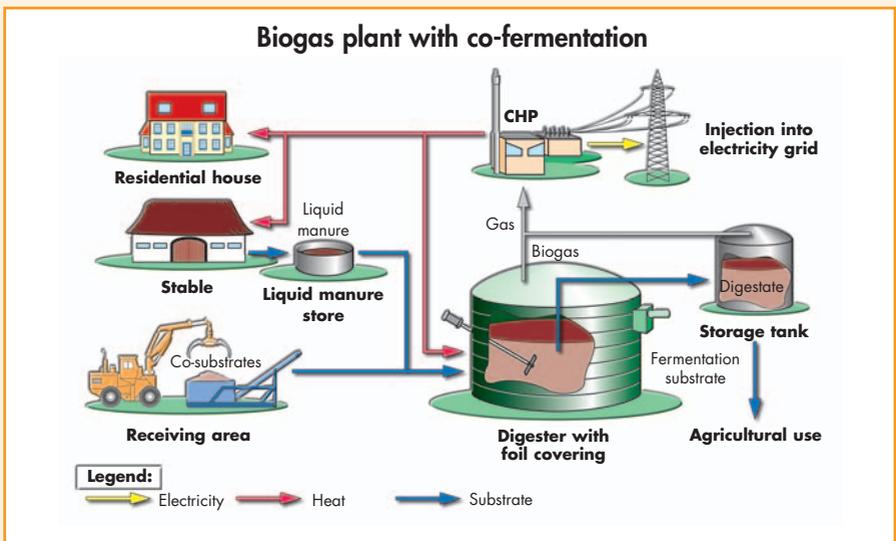


Figure 6: Scheme of processes in a farm-based biogas plant using co-substrates

strate is introduced into the covered digestate storage tank.

There are many different possible models of fermenter (steel or concrete, rectangular or cylindrical, horizontal or vertical). The crucial thing is that the container is gas- and watertight as well as completely opaque. A stirring device ensures that the substrate remains homogeneous as, depending on the primary material, the substrate will have a greater or lesser tendency to separate into a floating layer and a sedimentation layer.

A agitator in the fermenter ensures that the substrate is equally distributed throughout the reactor and that the gas that forms can escape from the sub-

strate. If sedimentation layers form, e.g. when chicken manure or organic waste is fermenting, then they must be regularly removed by suitable dischargers.

As bacteria produce only small quantities of sensible heat through their own “work” and this is insufficient to attain the necessary ambient temperature, the fermenter has to be insulated and externally heated to create the ideal temperature conditions for the bacteria that are necessary for the fermentation process. The fermentation temperature is an important process factor that influences the speed of anaerobic digestion. Essentially two temperature ranges can be distinguished:

- between 32 and 42°C (mesophilic)
- between 50 and 57°C (thermophilic).



Figure 7: A biogas plant with a foil roof acting as an integrated gasholder

Around 85 % of German's farm biogas plants operate in the mesophilic range. Thermophilic fermentation can be an advantage if forms of biomass that are risky from a sanitary point of view are to be fermented or if the aim is to achieve a high throughput in the plant.

One further important parameter is the hydraulic retention time (HRT). This indicates the average time the added substrate remains in the fermenter before being removed. This is calculated from the utilisable volume of the fermenter and the amount of biomass loaded daily.

The aim when operating a biogas plant is to attain the maximum rate of gas production or the complete digestion of the organic matter contained in the substrate. If the organic ingredients are to completely decompose, then one has to reckon with a long retention time for the substrate in the fermenter and therefore ensure that the reactor is of an appropriate size, since some substances are only broken down – if at all – after a considerable length of time. Volume load is also an important operating parameter in this respect. It indicates how many kilogrammes of organic dry matter can be loaded into the fermenter per m³ of volume and unit of time. When it has finished digesting, the substrate goes into the digestate storage tank. This should be covered so as to utilise any further biogas that is produced, as well as preventing emissions and smells. The size of the digestate storage tank is determined by the required storage time which in turn depends on specifications for the

environmentally friendly use of this residue in plant production.

Dry fermentation

Almost without exception, the biogas plants currently operating in Germany are based on the principle of wet fermentation. Yet the use of solid substances (e.g. renewable raw materials) is only possible to a limited extent.

From a biological point of view, it is actually misleading to divide processes strictly into wet or dry fermentation as in both cases the bacteria involved in the fermentation process require a liquid phase to survive. Nevertheless, the fermentation process during dry fermentation does not need a basic liquid substrate. However, "dry fermentation" is of special interest to operations that have no liquid manure nor any other liquid primary substrates at their disposal, but do have enough stackable biomass.

In contrast to wet fermentation, the substrate used in dry fermentation is neither pumpable nor capable of flowing, nor does any constant mixing take place during biogas production. However, as in wet fermentation, the biological fermentation process requires a moist environment. The processes to ferment stackable organic biomass were originally developed to utilise organic waste and residual waste and have now found an application in the agricultural sector. Biomass with a dry matter content of between 20 and 40 % can thus be fermented. The substrates used include so-

lid manure, renewable raw materials (such as silage made from maize, cereal crop or grass) and crop residues (such as straw and cereal debris), as well as green and organic waste.

A wide range of alternative processes are currently being applied and they can basically be subdivided into continuous (e.g. plug-flow fermenter) and discontinuous (e.g. percolation reactor) systems. Dry fermentation processes represent an alternative to the widespread wet fermentation process and have future potential mainly because they make fermentation both technically simpler and possible without liquid manure.

Measurement and control technology

It is well-known that the anaerobic digestion of organic substrates is a highly complex, multi-stage process that is in-

fluenced by a great number of microbiological, chemical and physical factors. Process control therefore requires the recording of various indicators. A further complication for process control is that the individual stages of decomposition take place at very different speeds and the dynamic behaviour of the process thus depends to a great extent on the material composition of the substrates used. Some of the main parameters for operating a biogas plant are:

- The temperature in the fermenter
- The pH value in the fermenter
- The amount of gas produced
- The methane, hydrogen sulphide and oxygen contents during the gas phase
- The VOA/TIC value (ratio of volatile organic acids (VOA) to total inorganic carbon (TIC))
- The ratio of volatile organic acids to total inorganic carbon in the fermenter (VOA/TIC value).

It is also important to have data about the chemical substances in the substrate mix that is used including the quantity of biomass added as well as its dry matter content and organic dry matter content. Due to the serious impact of methane on the climate, plants in Germany producing more than 20 m³ gas/h must have a second gas consumer installation (e.g. a gas burner) or a gas flare which can burn off the biogas if there is a fault in the block heat and power plant. Biogas is inflammable and explosive in mixtures with 6 – 12 % air. The security regulations for farm biogas plants and the relevant comprehensive body of legislation (DIN standards, etc.) must the-



Figure 8: Dry fermentation biogas plant

refore be observed. If these guidelines are respected, then handling biogas presents no greater risk than handling natural gas.

Gas-bearing components

Gasholders are used to smooth out the fluctuations between gas production and gas consumption. For storing gas (low pressure), integrated storage (under an inflated roof on the fermenter) have proved their worth. There is a preference for using cheap, balloon-shaped foil tanks as external gasholders (separate enclosures) (Fig. 9).

Before the gas is used, particles and condensate have to be removed. It is also important to desulphurise the gas to protect the CHP engines from corrosion. An inexpensive desulphurisation process, by which 3 – 5 percent air is added to the

fermenter, has gained acceptance for use in farm biogas plants. If this is correctly managed, removal rates of up to 95 % can be achieved.

How is biogas utilised?

Desulphurised and cleaned biogas can be used in as many different ways as natural gas. One cubic metre of biogas can replace about 0.6 l of heating oil. The most common use of biogas in Germany at the moment is to produce electricity in a combined heat and power plant (CHP). However, biogas is a versatile source of energy, as shown by the following diagram.

Utilisation for combined heat and power

Biogas can be used in a CHP to produce electricity and heat. CHPs consist of a combustion engine running on biogas that drives a generator to produce electrical energy (Fig. 10). The surplus heat from cooling and exhaust fumes is used to heat the digester and, if possible, to heat residential houses and other consumers of heat. There are several available engine models and combustion processes. Engines that have been specially developed to run on gas (the Otto engine principle) are used as well as spark ignition units (the diesel engine principle). Gas-Otto engines are capable of burning biogas with a methane content of at least 45 % directly. Spark ignition engines, on the other hand, require ignition oil that may not make up more than



Figure 9: Foil biogas storage tanks in a ventilated loft above a digester

10 % of the fuel capacity supplied to burn the biogas. Moreover, since the beginning of 2007, new plants are no longer authorised to use fossil based igniti-on oils.

When choosing a CHP engine, the focus should be on a high degree of effi-ciency and low proneness to defects. Especially in the case of co-fermentation plants, there can be variations in the quality and the quantity of gas and this can cause damage to the engine. This can be remedied by electronic engine control systems.

A biogas plant can operate particularly economically in situations where a cus-tomer can be found for the surplus heat from the combined heat and power plant. With conventional technology, up to 45 % of the energy contained in bio-gas can be converted into electricity. When the resulting surplus heat is also

used, the overall degree of efficiency (el-ectrical and thermal) can be raised to about 85 %. The surplus heat can be used to heat residential houses, schools or as process heat and replace fossil fuel.

Micro gas turbines

The micro gas turbine represents a new alternative to motor-driven gas utilisati-on that has been favoured up until now. Micro gas turbines or micro turbines are small, fast-running gas turbines with low temperatures and pressures in the combustion chamber and an electrical capacity up to 200 kW.

In gas turbines, compressed air and ad-ded biogas are burned in a combustion chamber. The resulting increase in tem-perature causes the gas to expand be-fore this relaxes again inside the turbine and thus drives the generator so as to produce electricity. Impurities in the bio-

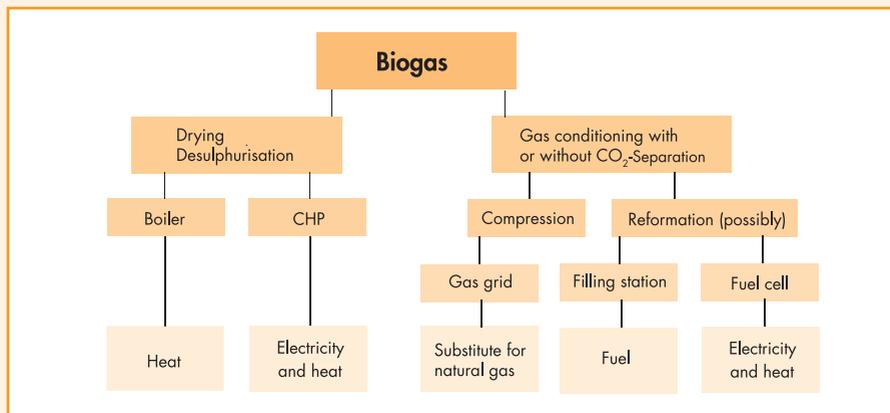


Figure 10: Scheme of the various uses of biogas and stages of its conditioning (Source: ATB (2003), modified)

gas can damage the micro turbine, therefore the gas must be cleaned and dried. Micro gas turbines require a minimum methane content of 35 % in the gas.

The electrical efficiency of micro gas turbines is relatively low at about 28 %. The overall degree of efficiency is about 82 %. As there is continuous combustion with excess air and at low pressures in the combustion chamber, micro gas turbines have considerably lower exhaust emissions than engines. The intervals between maintenance are, at least in the case of micro gas turbines that run on natural gas, far longer than for engines. For the time being though, there is relatively little experience of micro gas turbines in actual use.



Figure 11: Assembling a “hot module” fuel cell

Fuel cells

In order to achieve higher electricity yields, one subject researchers are currently working on, is the use of biogas in fuel cells that are capable of converting the chemical energy from the processed biogas directly into electricity. In a fuel cell, H_2 from the biogas is the “fuel” that reacts with O_2 to give water (H_2O) while producing electrical energy and heat. Biogas has to be conditioned for this by removing the H_2S and increasing the methane concentration.

So far, fuel cells are expensive but they do run quietly and can reach degrees of electrical efficiency of up to 50 percent. Fuel cell technology (with the exception of portable systems) is still being researched and could play a role in the use of biogas in the future.

Biomethane as a natural gas substitute

Alongside its conventional role in electricity and heat production, biogas can also be used as a substitute for natural gas. This requires costly conditioning of the biogas until it has the same quality as natural gas so that it can be fed into the natural gas grid as “biomethane”. This method is a good alternative to the decentralised utilisation in CHP that has been common up to now and is especially interesting for biogas plants that do not have a suitable method of utilising the surplus heat on the site where the biogas is converted into electricity. Biomethane can be transported any distance using the existing gas grid infra-

structure and for example be converted into electricity where the surplus heat is actually needed.

The order of processing steps to obtain the minimum quality required depends mainly on the choice of technology and the obtainable quality of the gas in the

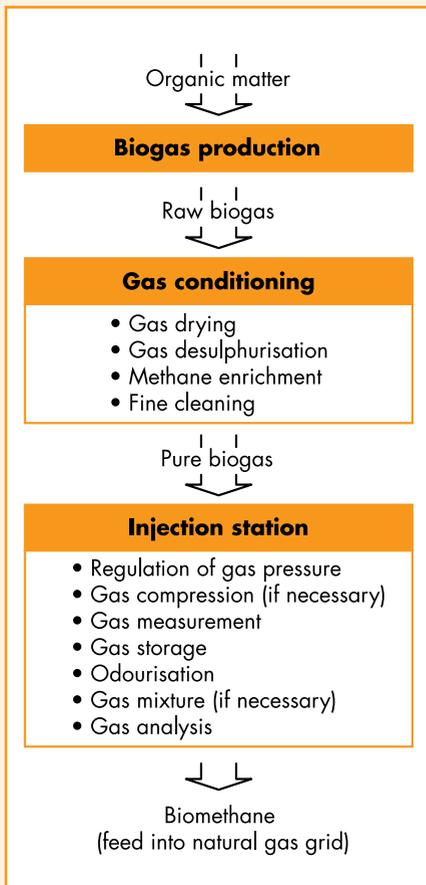


Figure 12: Scheme of the various uses and stages of biogas conditioning

local grid. The main processing step alongside desulphurisation and removing contraries is the methane enrichment of the gas from about 60 % to over 87 %. The biomethane is delivered to the network at injection stations. This is where the composition of the gas is determined and its compatibility with the local network established.

Although this process works, it is only in certain cases the best means of using biogas. For it is not everywhere that there is a connection to the gas grid, that constant demand is guaranteed or that the extra technical expense makes economic sense. This means that injecting biogas into the natural gas grid is interesting above all for large biogas plants, for, as a general rule, it is only in such cases that it is profitable to invest in the necessary conditioning technology.

The main possibilities for utilisation that result from injecting biomethane into the natural gas grid are location-unspecific use for combined heat and power, as well as a substitute for natural gas, among other things for natural gas boilers and natural gas filling stations. Biomethane is widely used as fuel in Switzerland and in Sweden. In Germany, this type of use is still in its infancy. The first German biogas filling station was inaugurated in 2006. In principle, biogas is also suitable as an energy source for fuel cells, Stirling engines and micro gas turbines. It will be several years before the necessary developments lead to their being widely used.

What is the applicable regulatory framework?

Constructing a plant

Depending on the size of the plants in Germany or the type of substrate to be processed, the construction of a biogas plant is subject to construction law or environmental immissions law. A major decision criterion here is the daily throughput of substrate. If this is more than 10 t of non special supervisions waste per day requiring no special supervision per day, the approval procedure must take place according to the Federal Immission Control Act (BImSchG). Information about the approval procedure as well as the necessary documents can be requested from the competent autho-

rities in the Federal States and from the Trade Supervisory Offices.

A biogas plant operator who wishes to use animal by-products other than liquid manure has to meet a comprehensive catalogue of requirements. The provisions of the Ordinance on Biowastes (BioAbfV) only apply to plants in which biowaste is fermented. In principle, any material listed in Biowaste Ordinance may be used in the biogas plant. According to BioAbfV, all digestate to be spread on the ground that contains plant waste must be phytohygienically harmless. According to the Use of Fertilisers Ordinance, materials that are put into circulation must be hygienically harmless.

Fig. 13 shows the various legal specifications that are to be complied with for

Legal specifications	Substrates concerned
Regulations on nutrients	
Ordinance on Fertilisation Use of Fertilisers Ordinance	all substrates all substrates that are not spread on the farm's own land
Regulations on pollutants	
Ordinance on Biowastes	all organic waste that is not subject to the EU Hygiene Directive, digestate using organic waste as co-fermenting agent
Regulations on product hygiene	
EU Hygiene Directive Use of Fertilisers Ordinance Ordinance on Biowastes	substrates of animal origin all substrates that are not spread on the farm's own land all organic waste that is not subject to the EU Hygiene Directive, digestate with organic waste as co-fermenting agent

Figure 13: Legal specifications in Germany

each type of digestate utilisation. If the Use of Fertilisers Ordinance is applied, the legislator places restrictions on the composition of the digestate and the feed material.

Renewable Energy Source Act

The most important legal instrument in Germany to support the production of electricity from renewable sources is the Renewable Energy Source Act (EEG), which first came into action in the year 2000. Since then the EEG has been amended in 2004 and recently in 2008 to cope with the chancing requirements.

The EEG regulates the preferential connection of plants that produce electricity from renewable energy sources and the purchasing, transmission and payment of electricity by the operator of the grid. The EEG defines payment rates for every kilowatt hour of renewable electricity that is fed into the public grid. The basic payments differ according to the type of renewable energy source, the conversion technology and the capacity of the plant.

The level of fees shall be determined according to the share of a plant's capacity which falls between the relevant threshold values. In this case, the capacity of the plant will not be deemed to be its effective electrical capacity, but rather the ratio of the total of the kilowatt hours to be fed in to the grid during the calendar year in question to the total number of full hours for that calendar year. The Table 1 shows the EEG payments for elec-

EEG tariff for the year 2009

	Share of capacity	€cents/kWh
Basic tariff	up to 150 kW _{el}	11.67
	from 150 to 500 kW _{el}	9.18
	from 500 kW _{el} to 5 MW _{el}	8.25
	from 5 MW _{el} to 20 MW _{el}	7.79
Cultivated biomass bonus	up to 150 kW _{el}	7.00
	from 150 to 500 kW _{el}	7.00
	from 500 kW _{el} to 5 MW _{el}	4.00
Manure bonus	up to 150 kW _{el}	4.00
	from 150 to 500 kW _{el}	1.00
Landscape conservation material bonus	up to 500 kW _{el}	2.00
Emission reduction bonus	up to 500 kW _{el}	1.00
Technology bonus	up to 5 MW _{el}	2.00
	– Biomethan production (350 – 700 Nm ³ /h)	1.00
CHP bonus	up to 20 MW _{el}	3.00

Table 1: Payments for electricity from biomass according to the Renewable Energy Source Act 2008

tricity from biogas according to the updated amendment (valid from the January 1st 2009).

The basic payment is subject to an annual depression of 1 % based on the basic rate applicable in the previous year. The EEG guarantees the plant operators fixed tariffs for electricity fed into the grid for a period of 20 years – plus the year it was taken into operation. The fee paid depends on the defined tariff in the year the equipment was installed. The EEG also stipulates an additionally increase in the electricity payments

through various cumulative bonuses that are linked to specific conditions. There are e.g. bonuses for the utilisation of renewable raw materials specifically grown for energy production (biomass bonus), for the external utilisation of the heat produced (combined heat and power) and for the use of innovative technologies such as Stirling engines, fuel cells or upgrading biogas to natural gas quality (biomethane).

In the last four years, the EEG's payment regulations have led to a considerable increase in electricity production from biomass. With the improvement of the payment rates as part of the revision of the EEG in 2004, energy production in farm biogas plants expanded noticeably (Fig. 2) and this is reflected by the quantity of plants. And the second EEG amendment enhances the conditions for biogas e.g. by increasing the basic payment up to 150 kW_{el}, introduce a bonus for greater utilisation of farmyard manure and slurry and landscape conservation materials and also increase the bonus for the use of renewable materials and surplus heat. But is also obligates e.g. to the use of sustainable produced biomasses and to meet certain environmental requirements.

How does a biogas plant become cost-effective?

Reducing investment costs

Building a small biogas plant (under 100 kW_{el}) for renewable raw materials and

liquid manure involves specific investment costs of 5,000 to 3,000 Euros per kW of installed electrical capacity. However, these decrease as plant capacity increases. Larger wet fermentation plants can cost about € 2,500/kW_{el} to purchase. Possibilities for realising economies of scale lie in serial production (industrial prefabrication) for which a prerequisite would be the standardisation of the main plant components and a simplified and optimised process. In contrast to this, plants that are specially designed and built for individual farms and are dependent on individual services result in comparatively high investment costs. But these plants, on the other hand, could operate more effectively, cause they're customised for specific conditions.

Lowering operating costs

Along with substrate costs, which can make up about 50 % of operating costs if renewable raw materials are used, maintenance and repair costs represent a large share of operating costs. Further items are lubricants such as ignition oil for a spark ignition CHP, as well as expenses for laboratory tests and insurance. The costs for maintenance and repairs of CHPs can be minimised by electronic engine control and regulation, especially for variations in the quality and quantity of the gas in co-fermentation operations, i.e. a changing substrate composition. The required daily working time on a biogas plant can – depending on the size of the plant – be between 0.5 and 5 hours.

Further information

Fachagentur Nachwachsende Rohstoffe e.V. (FNR)

Agency for Renewable Resources e.V. (FNR)

FNR "Bioenergy Consulting Service"

E-mail: info@bio-energie.de

Website: www.bio-energie.de

Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV)

Federal Ministry of Food, Agriculture and Consumer Protection (BMELV)

Website: www.bmelv.de

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU)

Federal Ministry for the Environment, Nature Protection and Reactor Security (BMU)

Website: www.erneuerbare-energien.de

Johann Heinrich von Thünen-Institut (vTI)

Federal Research Institute for Rural Areas, Forestry and Fisheries (vTI)

Website: www.vti.bund.de

Kuratorium für Technik und Bauwesen in der Landwirtschaft e. V. (KTBL)

Association for Technology and Structures in Agriculture (KTBL)

Website: www.ktbl.de

Leibniz-Institut für Agrartechnik Potsdam-Bornim e.V. (ATB)

Leibniz Institute for Agricultural Engineering Potsdam-Bornim e.V. (ATB)

Website: www.atb-potsdam.de

Fachverband Biogas e.V.

German Biogas Association e.V.

Website: www.biogas.org

Deutsches BiomasseForschungsZentrum gGmbH (DBFZ)

German Biomass Research Centre gGmbH (DBFZ)

Website: www.dbfz.de

Useful figures

1 m ³ biogas	5.0 – 7.5 kWh _{overall}
1 m ³ biogas	1.5 – 3 kWh _{el}
1 livestock unit (GV)	500 kg of animal body mass
1 ha maize silage	7,800 – 8,300 m ³ biogas
1 m ³ methane (CH ₄)	9.97 kWh
1 kWh	3.6 MJ (3.6 × 10 ⁶ joule)
1 billion kWh	3.6 PJ (3.6 × 10 ¹⁵ joule)
Efficiency rate CHP _{el}	30 – 45 %
Efficiency rate CHP _{th}	35 – 60 %
Efficiency rate CHP _{overall}	85 %
Operating time CHP	7,500 – 8,000 h/a
Specific investment costs	
CHP (gas engine) 150 kW _{el}	900 €/kW _{el}
CHP (gas engine) 250 kW _{el}	740 €/kW _{el}
CHP (gas engine) 500 kW _{el}	560 €/kW _{el}
Biogas plant up to 100 kW _{el}	5,000 – 3,000 €/kW _{el}
Biogas plant from 100 to 350 kW _{el}	3,000 – 2,500 €/kW _{el}
Biogas plant above 350 kW _{el}	≤ 2,500 €/kW _{el}
Labour time per year	3 – 7 h/kW _{el}
Temperature variation in fermenter	≤ ± 2 °C per day
Optimal VOA/TIC range	0.4 – 0.6

(Source: Handreichung Biogas, FNR, 2006; Federal Research Institut for Rural Areas, Forestry and Fisheries (vTI))

Important process parameters

<p>Dry mass (DM) [kg] = fresh mass [kg] – water content [kg]</p>	<p>Required fermenter volume [m³] = substrate added daily [m³/d] • average retention time [d]</p>
<p>Organic dry mass (ODM) [kg] = dry mass [kg] – ash residue [kg]</p>	<p>Hydrolic retention time (HRT) [d] = $\frac{\text{capacity fermenter [m}^3\text{]}}{\text{substrate added [m}^3\text{/d]}}$</p>
<p>Biogas yield [m³] = FM substrate [t] • DM [%] • ODM [%] • yield [m³/t ODM]</p>	<p>Loading rate [kg ODM/m³ • d] = $\frac{\text{ODM added [kg/d]}}{\text{capacity fermenter [m}^3\text{]}}$</p>

Literature

You can find detailed information about the utilisation of renewable raw materials among others in the following FNR publications:









Published by

Fachagentur Nachwachsende Rohstoffe e.V. (FNR)

Hofplatz 1 · 18276 Gülzow · Germany

Website: www.fnr.de

E-Mail: info@fnr.de

FNR Bioenergy Consulting Service

Phone: +49 (0) 38 43/69 30-1 99

Fax: +49 (0) 38 43/69 30-1 02

Website: www.bio-energie.de

E-Mail: info@bio-energie.de

With financial support of the Federal Ministry of Food,
Agriculture and Consumer Protection

Printed with linseed oil-based ink