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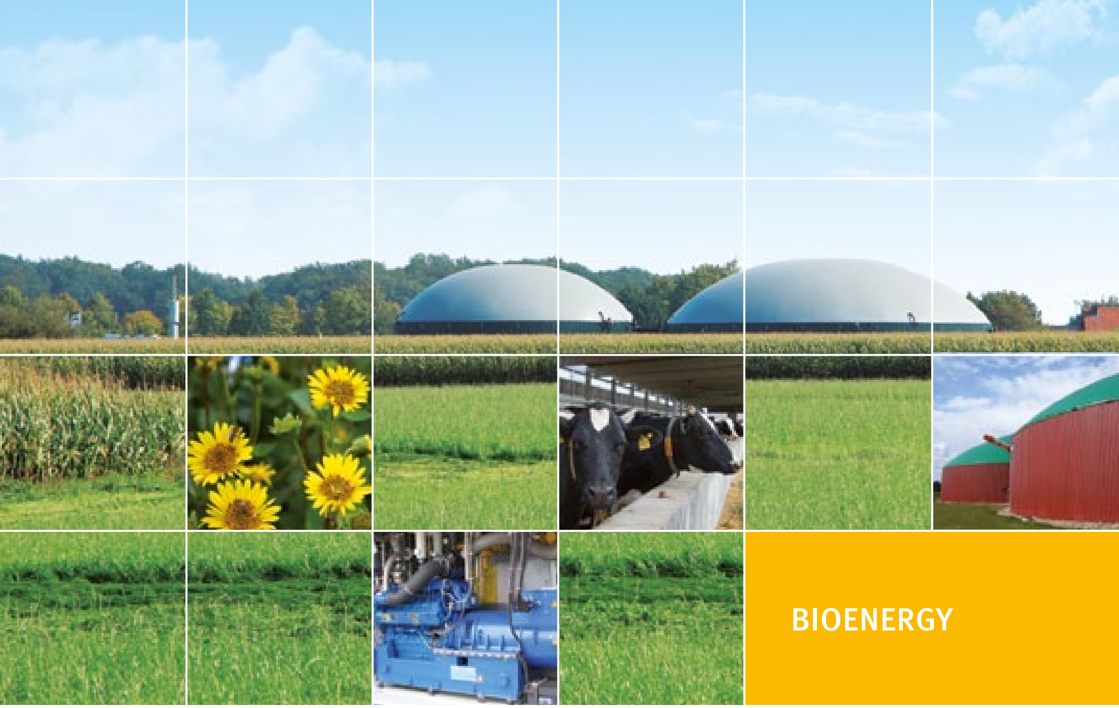
BIOGAS

an introduction



BIOENERGY

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CONTENTS

1 RENEWABLE ENERGY FROM BIOGAS

In order to conserve the dwindling reserves of fossil-based energy sources and to halt climate change, it is necessary to switch to renewable energies step by step over the next decades.

Thus the German Government has set itself the goal of ensuring a modern, environmentally friendly, sustainable and safe supply of energy by means of expanding renewable energies. This goal is integrated into the energy and climate policies of the European Union. The EU has set the following goals for 2020:

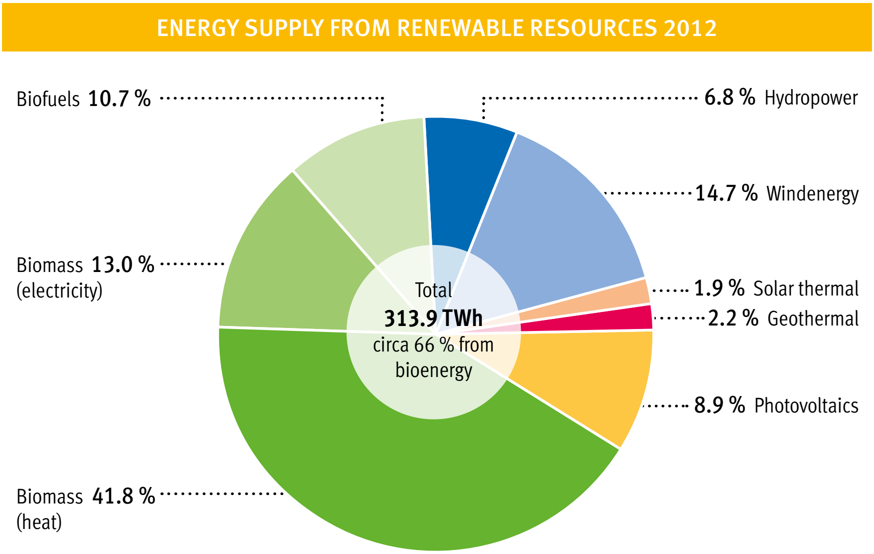
- to lower emissions of greenhouse gases by at least 20 %,
- to reduce energy consumption by 20 % by means of better energy efficiency and
- to cover 20 % of our energy needs by renewable energies.

On this basis, the medium-term objective is for renewable energies to account for a large share of the energy supply. By 2020, the plan is for their share to rise to at least 35 % of the electricity supply, 14 % of the heat provision and 10 % of fuel consumption. It is also the aim for greenhouse gas emissions to be 40 % lower by 2020 than they were in 1990.

Bioenergy – currently making the greatest contribution of all regenerative energy sources in Germany – will continue to play a central role in the future. After all, biomass is a CO_2-neutral energy source to a large degree. Renewable resources are also increasingly in demand for material use, even though the growth in this area is slower than for energetic use.

Today, at approx. 66 %, biomass is making a crucial contribution to the provision of energy from renewable resources in Germany. In 2012, biogas's share in electricity production from biomass was around 50.2 %. In relation to renewable energies as a whole the share of biogas was 15.1 % of electricity generation, and 7.8 % of the supply of heat (when biowaste fermentation, landfill gas and sewage gas are added, the figure is 20.1 % for electricity and 14.6 % for heat). Biogas and biomass will continue to play an important role in the future. Wood, energy crops, straw and animal excrement provide the potential for producing a very significant part of our energy on a sustainable, environmentally friendly and comparatively low-cost basis.

Biogas produced from biomass takes on a special role among renewable energies: it is suitable for the simultaneous production of electricity and heat, as a fuel and as a natural gas substitute. In addition, it is flexible in use and relatively easy to store. Energy generation from biogas is not subject to fluctuations due to the time of year, the time of day or the weather; it can thus be put into service on a long term basis in securing the basic supply of electricity (the so-called “baseload capacity”), also helping to deal with peak loads. That is why efforts



Electricity and heat from biomass, including sewage gas, landfill gas and biogenic fraction of waste

Source: BMU, AGEE-Stat (March 2013)

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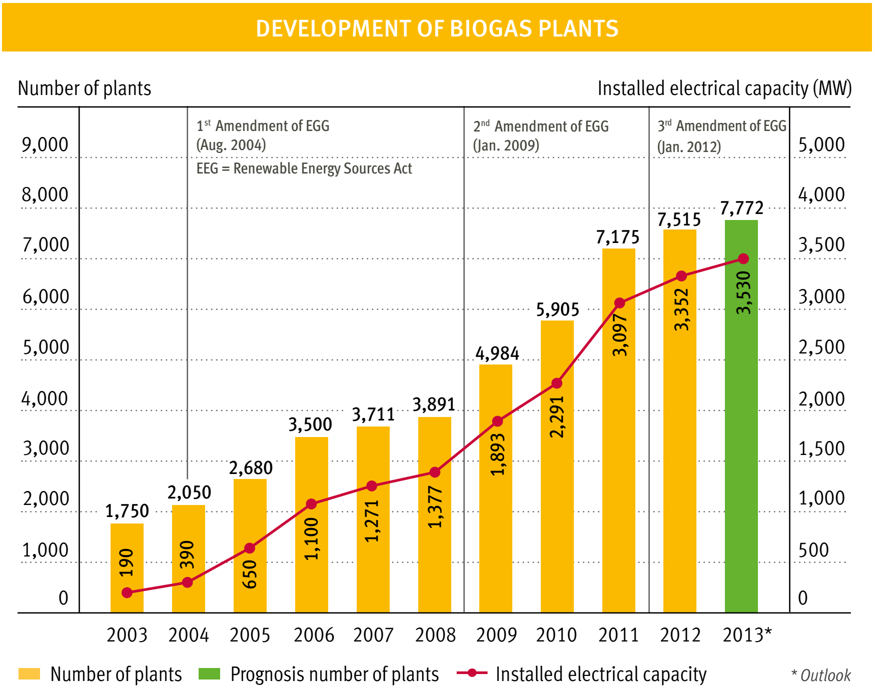
Fig. 1: Significance of bioenergy among renewable energies

are in progress to expand the flexible and demand-oriented production of biogas.

Energy production from biogas has been a familiar concept for a long time now, but it was not before the early 1990s that it was used in any significant volume. Massive growth followed the coming into force of the Renewable Energy Sources Act (EEG). Development was particularly boosted by the amendments to the EEG made in 2004 and 2009 (Fig. 2).

In Germany the dominant share of biogas is produced by agricultural facilities. At the end of 2012, there were 7,515 biogas plants with an installed electrical capacity of 3,352 MW. Biogas plants in Germany have an average electrical capacity of approx. 420 kW. By way of comparison, average coal-fired power plants have a capacity of approx. 600 MW_{el} and Germany's largest nuclear power plant – Isar 2 – has a capacity of approx. 1,485 MW_{el}. Biogas plants in Germany thereby already replace more than 5 coal-fired power plants or 2 large nuclear power plants, providing proof that many small energy producers can jointly generate an energy quantity that is far from insubstantial. These numbers also make clear that biogas installations rank among the decentralised technologies, like all other



Source: FNR, according to FvB (2013)

Fig. 2: Development in numbers and installed electrical capacity of biogas plants in Germany

power stations producing renewable energy, while the fossil fuels are converted into energy in centralised large power stations.

Yet "green" electricity is not the only form of energy which biogas can produce. By now, there are many successful multi-use models. For example, the energy produced is brought directly to the consumer via gas and heat pipes, whether residential buildings, public facilities such as schools, kindergardens or swimming pools and even commercial and industrial enterprises such as horticultural businesses or manufacturing buildings.

Even those without direct access to energy from biogas can source virtual "green" electricity and "green" heat from energy utility companies – more and more companies are now offering this. Also, numerous natural gas fuel stations are selling biomethane as pure fuel or as a mixed product combined with natural gas.

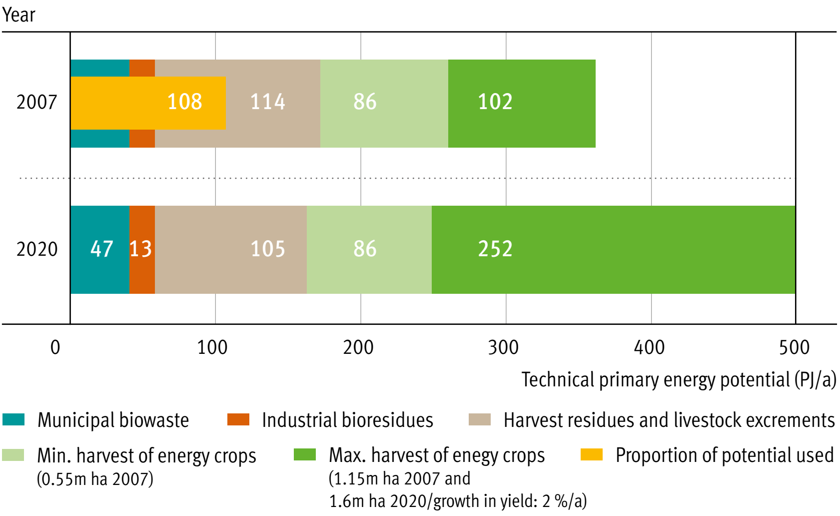
Energy potentials of biogas

Calculations of the biogas potential are dependent on a variety of factors. For example, its potential as agricultural feedstock is dependent on the necessary allocation of a prioritised area for producing food and animal feed, on the regional structure of land cultivation and the economic framework conditions. Biogas production from waste material and residues is likewise influenced by a variety of factors.

Fig. 3 indicates the technical potential offered by biogas from various sources. For 2020, the technical primary energy potential amounts to around 500 PJ, of which the agricultural sector has the largest share of approx. 88 %.

The available potential can be accessed via agriculture, as this is where the largest share is to be found. This is indeed already being made possible to a growing extent, by further enhancing efficiency in electricity production and in the provision of heat, by optimising anaerobic digestion biology and installation engineering, as well as by expanding the use of harvest residues and livestock excrements, in addition to progress in cultivating energy crops.

TECHNICAL PRIMARY ENERGY POTENTIAL FOR BIOGAS



Source: IE, DBFZ (2009)

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Fig. 3: Technical primary energy potential for biogas in Germany

2 ECOLOGY AND SUSTAINABILITY

Sustainable production and use are basic requirements for increasing the use of plant-based raw materials and energy. Sustainability, as defined in the Brundtland Report of 1987, means that the present generation satisfies its needs without endangering the ability of future generations to meet their respective needs. Thus sustainability has an environmental, economic and social dimension. Applying this to renewable resources, means finding a balance between what is necessary in economic terms – for example high and secure biomass yields – and what we can reasonably expect from our natural environment. Among other aspects, the social component relates to the working conditions of the people involved, new income opportunities, and participation in value creation processes.

There are many approaches aimed at an even more sustainable mode of production of renewable resources. One of the main research areas of the Federal Ministry of Food, Agriculture and Consumer Protection (BMELV) is to test these approaches in research projects and to further develop them. The strategies being pursued include the following:

- increasing the biodiversity in the process of cultivating energy crops,
- breeding of new plant varieties,
- new methods of cultivation, involving reduced use of pesticides and fertiliser, as well as fields with year-round vegetative cover,
- the use of particularly efficient conversion processes,
- models of cascading use, involving renewable resources first being used as a material and then used as an energy source, and
- the re-use of the residual materials as fertiliser.

The role of BMELV is to find suitable methods for sustainable management of energy supply and natural resources, through appropriate and coordinated research funding. When subsequently transferring these methods into practice society as a whole has to engage: it is the business community and consumers who must integrate the new processes and products into their everyday lives.

The principle of sustainability also applies to the biogas sector. Production and use of biogas entail environmental, economic and social advantages. Yet biogas can only be available as an energy source in the long-term if the sustainability criteria are met.

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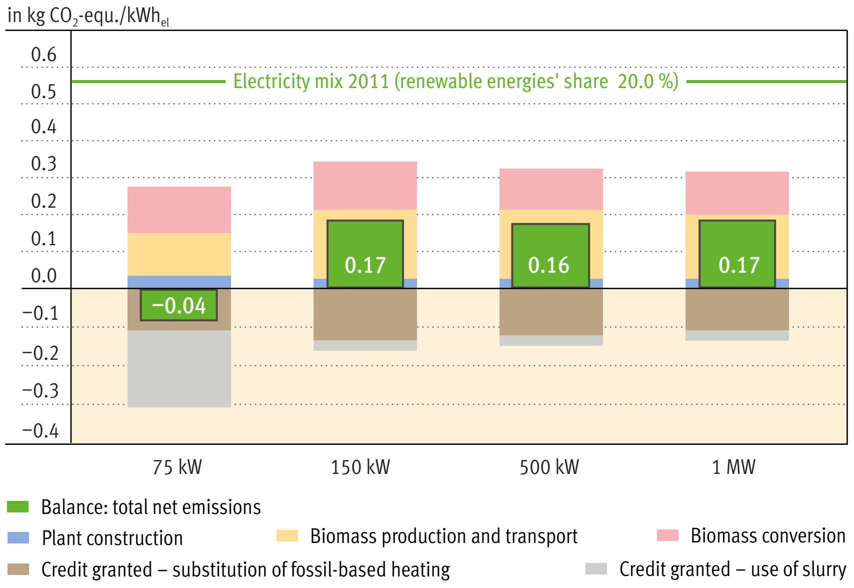
[1] *In 1983 the Global Commission for the Environment and Development, set up by the United Nations (the Brundtland Commission) and chaired by the former Norwegian Prime Minister Gro Harlem Brundtland, used the term "sustainability" for the first time in a development-policy context, a term originating from the forestry sector. The stated definition comes from the Final Document of the Brundtland Commission "Our Common Future" (also known as the Brundtland Report) from 1987.*

Biogas's most important impact on reducing the burden on the environment is the avoidance of CO_2 emissions, compared to fossil-based energy sources. To a large extent, production of energy from biogas is CO_2-neutral, meaning that CO_2 released when the biogas is burned was previously withdrawn from the atmosphere when the biomass was formed.

The greatest potential for CO_2 savings lies with the use of a large portion of slurry and manure as input substrates. This is because, in contrast to energy crops planted specifically for the use in biogas plants, slurry and manure as well as other residual material do not require further energy to produce it. For energy crops, this energy expenditure must be deducted from the CO_2-neutral energy yield of the installation, because at present it is mostly still fossil-based energy that is used when growing crops (e. g. as tractor fuel). The anaerobic digestion of slurry and manure also reduces methane emissions: these would otherwise escape uncontrolled and they are substantially more harmful to the environment than CO_2.

GREENHOUSE GAS EMISSIONS OF BIOGAS PLANTS COMPARED TO THE OVERALL GERMAN ELECTRICITY MIX



Source: KTBL (2011)

Fig. 4: Greenhouse gas emissions – emissions of biogas plants compared to the overall German electricity mix

Recent studies indicate that the anaerobic digestion process also reduces the emission of laughing gas (nitrous oxide), another gas with an impact on the climate. Anaerobic digestion likewise reduces the development of smell during the storage and the distribution of slurry onto soil, because in the anaerobic digestion process the substances causing the smell are to some degree decomposed and neutralised.

A list of the environmental advantages should also include the utilisation and reduction of waste: this is because producing energy from biowaste sourced from organic waste bins and from sewage is not only an excellent way of generating electricity or heat; the digestate can also be used as fertiliser after being processed accordingly. Concepts that are particularly advantageous are those which use almost all of the available energy.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Service work at a biogas plant

Independence from energy imports certainly also merits mention as an important component in sustainability. Like Germany, most other European countries are dependent on these imports. With the targeted expansion of renewable energy systems, we attain an increasing independence and stability in our energy supply.

In economic terms, the decentralised basis of energy production from biogas is significant for the strengthening of rural areas. This leads not only to improved income for farmers but also entails follow-on investments that leads to value creation in the areas involved.

Renewable energy also provides new jobs. In Germany alone, the Renewables industry employed almost 380,000 people in 2012, of which 50,000 work in the biogas sector. And the numbers are still on the rise, because this relatively new economic sector participates both in the domestic market and in the growing export market. By now, German companies are the world market leader in the biogas industry.

3 MULTIPLE OPTIONS FOR USE

Biogas offers a diversity of options for use, e. g. the decentralised production of electricity and heat, the distribution via heat networks, the feed-in of upgraded biogas into the natural gas grid and its follwing use as a natural gas substitute for energy, as fuel or in the chemical industry. Independently of the use selected, the objective is to make the energy utilisation as efficient as possible.

3.1 Electricity and heat

At present, the bulk of the biogas produced in Germany is converted into electricity in close proximity of the biogas production facility. Thanks to the remuneration for feeding biogas-sourced electricity into the power grid, according to the Renewable Energy Sources Act (EEG), production of electricity and heat (combined heat and power production – CHP) in CHP units currently takes first place among the uses of biogas. In principle, CHP units consist of a combustion

VARIOUS UTILISATION OF BIOGAS

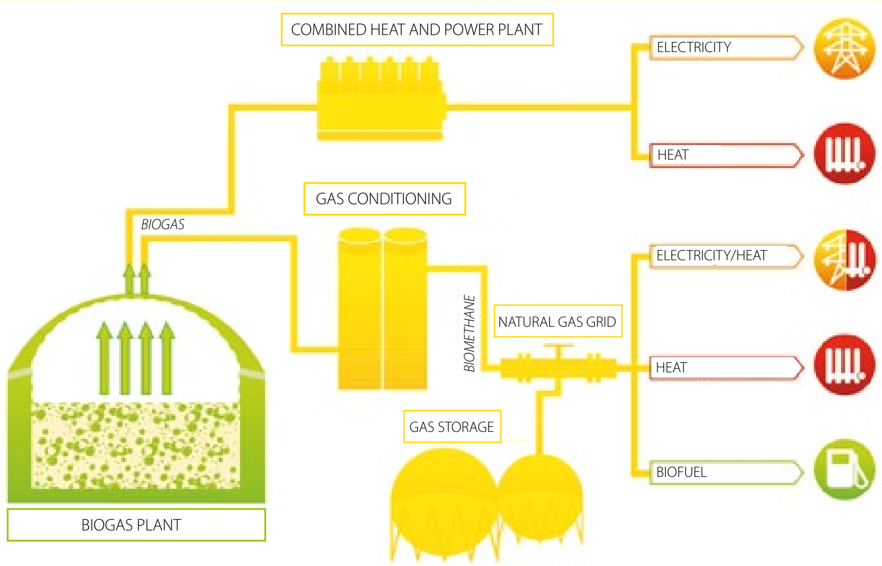


Fig. 5: Various options for using biogas

engine fuelled by biogas, driving a generator used for producing electrical energy.

For this, several kinds of engine constructions and combustion processes are available. In particular, it is gas spark ignition engines and pilot ignition engines that are used. However, electricity can also be generated from Stirling engines, micro gas turbines or fuel cells.

When the methane concentration level is at least 45 %, gas spark ignition engines are able to burn the biogas directly. To burn the biogas, pilot ignition engines need an ignition oil in order to initiate the combustion process. For optimised pilot ignition engines, a quantity of 2–4 % ignition oil is sufficient; older installations need up to 10 %. According to the Renewable Energy Sources Act's regulations, since 2007 it is no longer allowed to use fossil-based ignition oil for new installations.

When selecting the CHP unit, care must be taken to ensure high efficiency and a low level of repair requirements. Especially in the case of co-fermentation facilities, there can be fluctuations in the quality and quantity of the biogas: this can cause damage to the motor. To avoid this, electronic engine control systems can be installed. When running a CHP unit, certain framework conditions must be complied with, including in particular the requirements on maintenance intervals and also those governing the building that houses the unit.


CHP unit of a biogas plant

Micro gas turbines are characterised by certain advantages compared to combustion engines, such as the simpler and cheaper use of the produced heat and reduced maintenance requirements. The disadvantages are less efficiency and higher investment costs.

The use of Stirling engines and fuel cells is being developed as well.

Stirling engines (hot gas engines) are not that demanding in terms of gas quality but have an efficiency of only 24–28 %. At present they are only available in low-capacity power ranges (up to 100 kW_{el}).

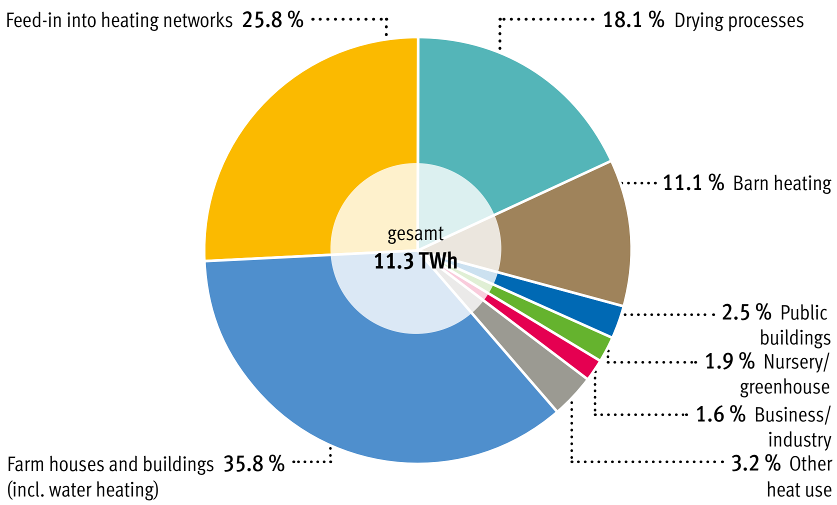
Biogas can also be used in various types of fuel cells. For this purpose, the biogas needs to be conditioned (particularly the removal of sulphur, carbon monoxide and further harmful substances) and transformed (conversion from biogas into hydrogen). The very good efficiency level (up to 50 %) and the almost emission-free mode of operation are currently set against the disadvantages of very high investment costs and the need for further technical developments.

When used in CHP units, the coupled products generated are electricity and heat. In environmental terms and also for efficiency, it is purposeful and necessary to use the heat generated. Accordingly, a suitable heating concept plays a decisive role when planning new installations. Depending on the type of installation and the time of year, around 10–30 % of the waste heat is required for heating the digester. When losses (approx. 15 %) are deducted, 50–60 % are then available for external use.

In recent years, a significantly increased use of heat has been observed. According to the recent EEG monitoring report more than half of the available external heat is already being used. For this purpose, there are various heating concepts in place. The largest share are the heating of farm buildings and connections to district heating networks, through which consumers who live further away are supplied with heat. There are many examples for supply of residential, municipal and commercial facilities with biogas heat. The heat is also used for drying of grain and other agricultural products, wood, or even the digestate. Worth mentioning are also direct pipelines to heat customers, such as greenhouses.

The heat that is generated in the CHP process can also be used to produce additional

HEAT USE FROM BIOGAS PLANTS 2012



Source: DBFZ (2013)

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Fig. 6: Heat use from biogas plants 2012

electricity in the ORC process (organic rankine cycle). In this so-called secondary electricity generation process, the heat vaporises an organic working medium (e.g. silicon oil). The gas produced as a result drives a turbine that subsequently produces electricity by a coupled generator.

Via so-called sorption processes, heat can also be converted into cold, which is then (for example) used in dairy operations for cooling milk or in cold storages. This coupling of power, heat and cold is attracting increasing interest and can make a better use of the produced heat in the summer months.

Use of heat from a biogas plant in a greenhouse

Heating grids are limited in case of greater distances between the biogas plant and the user: in such a case, transmission losses are high. Micro gas networks can serve as an alternative. Here the raw biogas goes from the digester to a satellite CHP unit (or respectively to several), positioned directly at the heat user's location. Here also, the enhancement of overall efficiency by an optimum use of the heat has an advantageous and value-creating effect.

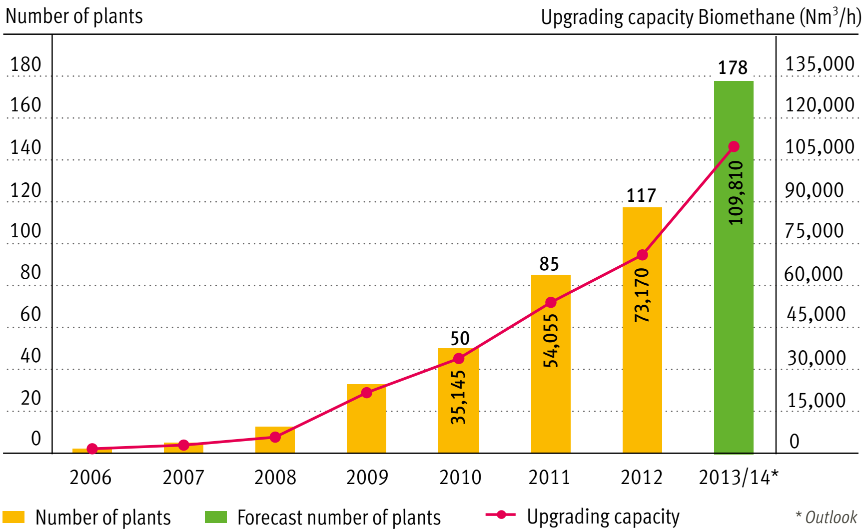
3.2 Biomethane and fuel

In recent years, upgrading biogas and feeding it into the natural gas grid has become an established practice. To be able to use biogas as a substitute for natural gas, it is purified of unwanted constituent elements, the CO_2 is separated to a large degree and thus the methane content is raised. The upgraded biogas, now also called biomethane or also bio natural gas, is then transported via the infrastructure of the natural gas grid. This enables it to be used at any location with a high demand for heat all year round. Biomethane can also be stored in the extensive gas grid, with its underground caverns, thereby helping to ease the burden on electricity grids. This also reduces the requirement to build new power lines. Feeding biomethane into the natural gas grid makes it possible for direct heat utilisation to be decoupled from production (e.g. by gas condensing boilers) or the coupled generation of heat and electricity in gas-powered CHP units with municipal heating networks. The Renewable Energies Heat Act (EEWärmeG) regulates the use of renewable energies for new buildings. To fulfil the statutory requirements, at least 30 % of the heating requirements can be met using biogas (in CHP installations).

Like with the principle of green electricity, the biomethane is fed into the natural gas grid by the plant operator, at the place of production. The end customers then take the biomethane from the grid as an equivalent quantity of natural gas at their location. Private households and commercial customers can use the biomethane in CHP units for generating heat and electricity, solely for generating heat in gas-fired heating boilers, or for gas-powered household equipment. In principle, biomethane can also be used as a substance in the chemical industry, substituting natural gas.

At the end of 2012, 117 biogas-upgrading plants operated in Germany, producing approx. 73,000 cubic metres of biomethane per hour. It is the German Government's goal to substitute 6 billion cubic metres of natural gas annually by biogas in 2020. 2012's total capacity amounts to approx. 10 % of this goal.

BIOGAS PLANTS FOR BIOMETHANE PRODUCTION IN GERMANY



Source: FNR, according to dena (2013)

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Fig. 7: Biogas plants for biomethane production

Biomethane can also be used as a fuel in natural gas vehicles. In Europe, Sweden and Switzerland lead the field in this. Biogas has already been used there for years in cars, buses, trucks and also for railways. Compared to traditional fuels, biomethane is characterised by a very high potential for saving CO_2. Even at admixtures of 20 % biomethane in natural gas, the carbon dioxide emission can be significantly reduced in comparison to petroleum.

However, Germany is still only starting with this form of use. Despite the technology being operationally ready, the potential is not being fully used. There are at present few filling stations at which pure biomethane is available, but around 1/3 of the 900 natural gas stations around Germany are already offering mixtures containing biomethane and natural gas, with this trend pointing upwards.

By now, almost all car manufacturers have models ready in their assortment that offer monovalent or bivalent drive (gas and petrol). Biomethane as a fuel can be applied to the fulfilment of the biofuel quota or alternatively it is tax exempt until 2015, outside of the quota obligation.

Filling station with biogas supply

4 PROCESS BIOLOGY

Biogas is a product of the microbial decomposition of organic matter in a moist environment that excludes air (an anaerobic medium). This decomposition is also termed anaerobic digestion. In nature, this biological process of decay takes place on the bottom of lakes, in swamps, or also in ruminants' stomachs.

In principle, the anaerobic digestion process involves four steps (hydrolysis, acidification, acetic acid formation, and methane formation), each respectively involving different groups of microorganism.

The gas mixture formed in this way predominantly consists of the following

- 50–75 % methane (CH_4),
- 25–45 % carbon dioxide (CH_2),
- 2–7 % water vapour (H_2O),
- ‹ 2 % oxygen (O_2),
- ‹ 2 % nitrogen (N_2),
- ‹ 1 % ammonia (O_3),
- ‹ 1 % hydrogen sulphide (H_2S) and
- ‹ 2 % trace gases.

In the liquefaction phase (hydrolysis), the complex organic compounds are broken down into simpler compounds. In the next phase, acidification, these are decomposed into low fatty acids. As part of this, alcohols, hydrogen and carbon dioxide also emerge as starting materials for methane production. In the following phase, acetic acid formation, the organic acids and alcohols are decomposed to become acetic acid, water and carbon dioxide. In the last phase – methane formation – the products of the preceding phases are then converted into methane, carbon dioxide and water.

In principle, the four phases take place simultaneously. Due to the different milieu conditions for the various microorganisms, there is thus a need to find the best possible compromise between the most important parameters, e.g. temperature, pH value or supply of nutrients. The anaerobic digestion process is sensitive to disturbances that can emerge due to operational measures or due to inhibitors. Even in small quantities, the latter can adversely affect the anaerobic digestion process.

SCHEMATIC DIAGRAM OF THE ANAEROBIC DIGESTION PROCESS

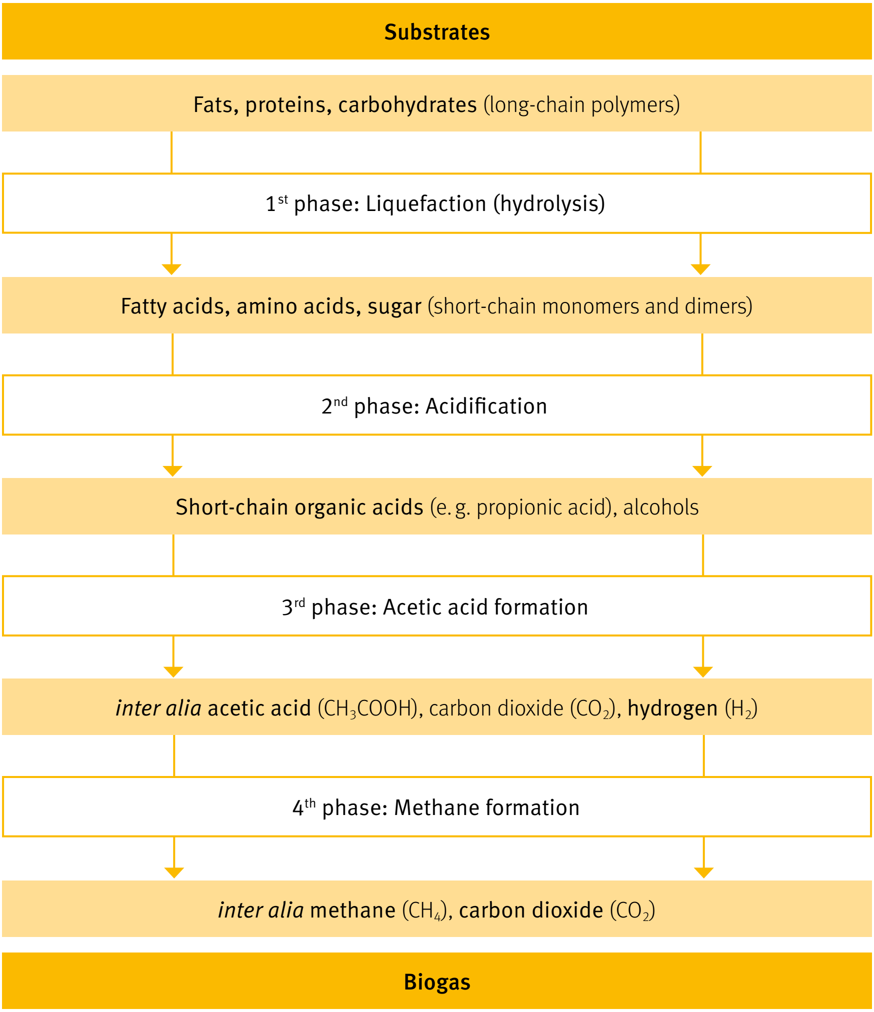


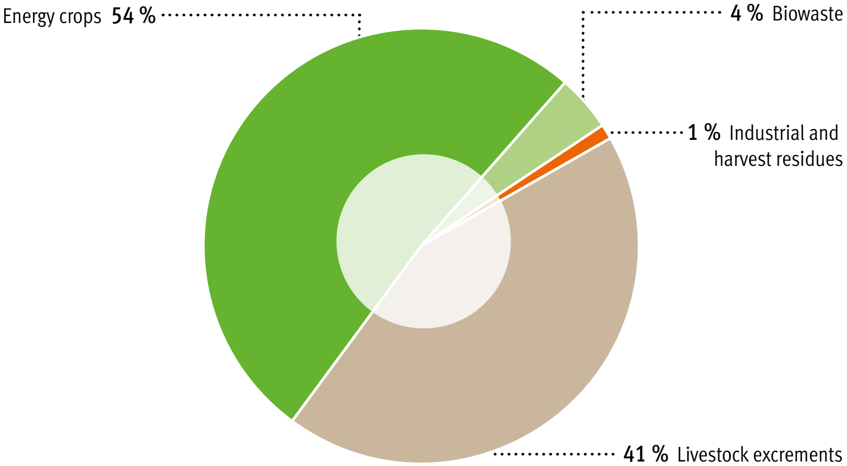
Fig. 8: Simplified diagram of the decomposition of organic matter during biogas production

5 INPUT SUBSTRATES

A large number of organic substrates can be used to obtain biogas. In agricultural installations the substrates used are mostly animal excrements (e. g. slurry from cattle and pigs) and energy crops grown especially for this purpose. With their help, new biomass is made available each year. But even organic waste from the processing industry and municipalities or residues from agriculture and industry, are suitable for biogas production.

According to a current survey among operators (the monitoring report on the Renewable Energiy Sources Act – EEG), the following distribution applies to the use of substrates at biogas plants nationwide: 41 % livestock excrements, 54 % renewable resources (energy crops), 4 % biowaste, and 1 % residual substances from industry and agriculture.

MASS-RELATED USE OF SUBSTRATE INPUT IN BIOGAS PLANTS 2012



Source: DBFZ (2013)

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Fig. 9: Mass-related use of substrate input in biogas plants 2012

Renewable resources for instance include maize, grain, grasses, and sugar beet, with maize currently accounting for the largest share. Maize offers the best efficiency, technological suitability, and cost structure. Factors favouring maize include high dry matter yields and energy yields, and the fact that it requires less fertiliser and plant-protection products than grain does. Its risks are, in particular, the negative influence on soil fertility and biodiversity.

A consequence of the increasing criticism of the rapidly-growing cultivation of maize are intensified research efforts for alternatives. The objective is to structure the cultivation of energy crops in a way that is sustainable and spares environmental resources. Sugar beets are acquiring increasing significance, as they have similar potential to maize in terms of yield. There are currently numerous highly-promising research projects advancing this development.

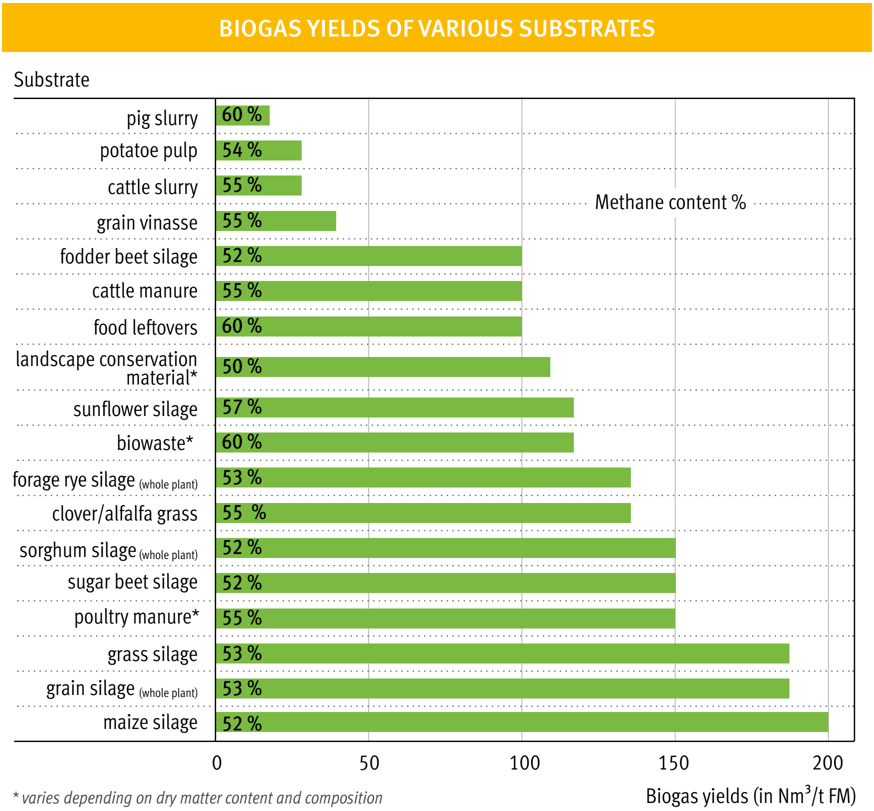
Meanwhile research projects are exploring potential of the cultivation of mixed crops, wild flowers and new energy crops such as cup plant (*silphium perfoliatum)* or species of sorghum. Overall, the aim is to integrate the cultivation of energy crops into crop rotations, and also to stagger the timing for the activities by various suitable measures, such as planting flower strips (more information at energiepflanzen.fnr.de). However, when grasses, sunflowers and most other energy crops are used as an alternative to maize, calculations must take into account a larger cultivated area.

The use of slurry and other farm fertilisers leads not only to a purposeful utilization of the available potential; these activities are also highly significant from the viewpoint of climate protection (avoidance of emissions). It is not a problem to combine slurry with most other input substrates; it is also attributed with having a stabilising effect on the fermentation process.

Aside from renewable resources, excrements, feed remains and other agricultural residues, non-agricultural substrates are suitable for biogas production as well. These include residues from the food industry (e. g. apple pomace, vinace, residues from the grease trap), vegetable waste from wholesale markets, food waste from restaurants, lawn cuttings, material from landscape conservation, or organic waste from municipal disposal sites.

As shown in Fig. 10, the various substrates generate different levels of biogas yield: the composition of the input substrates is the basis for fluctuations in the biogas yield and also the methane content. The gas output of the various substrates is determined not only by their potential for gas formation. The installation technology of the biogas plant and biological key figures of the fermentation process also have a major significance. Energy generated is the product of the daily gas quantity and the specific energy content (average: 6 kWh/m^3 of biogas).

While co-fermentation of non-agricultural residual material does close natural material cycles, harmful (in particular heavy



** varies depending on dry matter content and composition*

Source: KTBL (2010)

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Fig. 10: Biogas yields of selected substrates

metals) and disruptive substances can get into the biogas plants and following contaminate the fields through the digestate. That is why it is necessary to comply with the laws governing waste and fertilisers. Disinfecting agents and sanitising agents should not be put into the biogas plant, and neither should certain medications – such products disturb the anaerobic digestion process; likewise, they must not be applied onto arable soil. Similarly, excessively high ammonium concentrations obstruct methane production; that is why poultry manure should be diluted with water or mixed with co-substrates with low nitrogen content; occasionally the same applies to pig slurry.

6 INSTALLATION TECHNOLOGY AND OPERATION

6.1 Processes

Various concepts are applied to the installations used for biogas production. They differ according to the process characteristics, such as the dry-matter content, the way in which material is fed in, or the number of process phases.

With reference to the dry matter (DM) content, a distinction is made between wet and dry anaerobic digestion, yet there is no clear cut line of differentiation. At present almost all agricultural installations are wet anaerobic digestion facilities with the familiar round digesters, i.e. the dry matter content in the digester is ‹ 15 % (if the dry matter content is higher, the material can usually no longer be pumped or stirred). When using slurry, only wet anaerobic digestion is an option; solid biomass needs to be well broken down and mixed together with the fluid.

By contrast, dry digestion is particularly of interest for those operations with neither slurry nor any other liquid base substrates at their disposal, but which have enough stackable biomass available. This is because, in contrast to wet digestion, in dry digestion the input material is not pump- or flowable: Also there is not constant stirring during biogas production. However, as is the case with wet digestion, a moist medium is necessary for the biological anaerobic digestion process. This is produced by mixing the material with process fluid before the digestion or through constantly spraying the material with digestion fluid during

TABLE 1: CLASSIFICATION OF THE PROCESSES FOR GENERATING BIOGAS ACCORDING TO DIFFERENT CRITERIA

Criterion	**Distinguishing features**
Dry-matter content of the substrates	• wet digestion • dry digestion
Type of feeding	• discontinuous • quasi-continuous • continuous
Number of process phases	• single-phase • two-phase
Process temperature	• psychrophilic • mesophilic • thermophilic

Source: Leitfaden Biogas (Guide to Biogas) (FNR, 2010) the process. The processes for anaerobically digesting stackable organic biomass were originally developed for the digestion of municipal organic waste and are now being used in agriculturual biogas production. This makes it possible to digest biomass with dry matter contents of 20–40 %. The substrates that can be used include solid manure, renewable resources, harvest residues as well as green cuttings and other types of organic waste.

Dry digestion biogas plant

The differentiation according to the type of feeding is made between continuous systems (e. g. plug-flow process) and discontinuous systems (e. g. percolation process). Most installations work according to the continuous process (so-called through-flow installations), whereby the substrate is fed into the digester either constantly or at short intervals; biogas and also the digestate are removed on an ongoing basis. About 70 % of the biogas plants in Germany have this type of construction. This type of construction is further subdivided into through-flow and through-flow-storage processes.

In storage installations (discontinuous or batch process) the digester and the digestate storage are integrated. The digester is filled completely and locked airtight. After concluding the digestion process, the digester is then emptied. A small residue for inoculation purposes will be used for the next batch. In the case of high levels of dry matter content and fibrous substrates, this is the process used.

If all four phases of the anaerobic digestion (i. e. in the absence of air) are taking place in one container, this is referred to as a single-phase process. A two-phase operation is when there is a physical separation of the liquefaction/acidification, on the one hand, and the formation of acetic acid and of methane on the other. In this way, more favourable conditions can be created for the various microorganisms.

Through-flow installation with foil hood as integrated gas storage

6.2 Installation engineering

Agricultural biogas plants usually consist of preliminary tank, digester, and digestate storage. What follows for the gas generated and its utilisation are gas storage, gas cleaning, and usually CHP unit or respectively gas-upgrading installation.

The preliminary tank serves the purpose of interim storage of slurry and co-substrates and also the preparation of the substrates (removal of disruptive substances, breaking the material down in size, diluting, mixing, etc.). Its dimensions need to be such that any fluctuations caused by the substrate input can be balanced out. The subsequent anaerobic digestion can be positively influenced by suitable measures, such as homogenisation, hygienisation, aerobic preliminary decomposition, hydrolysis and disintegration. The digester, the core element of a biogas plant, is fed with substrate from the preliminary tank. Many different versions are possible (steel or concrete, rectangular or cylindrical, horizontal or vertical). What is decisive is that

SCHEME OF A FARM-BASED BIOGAS PLANT

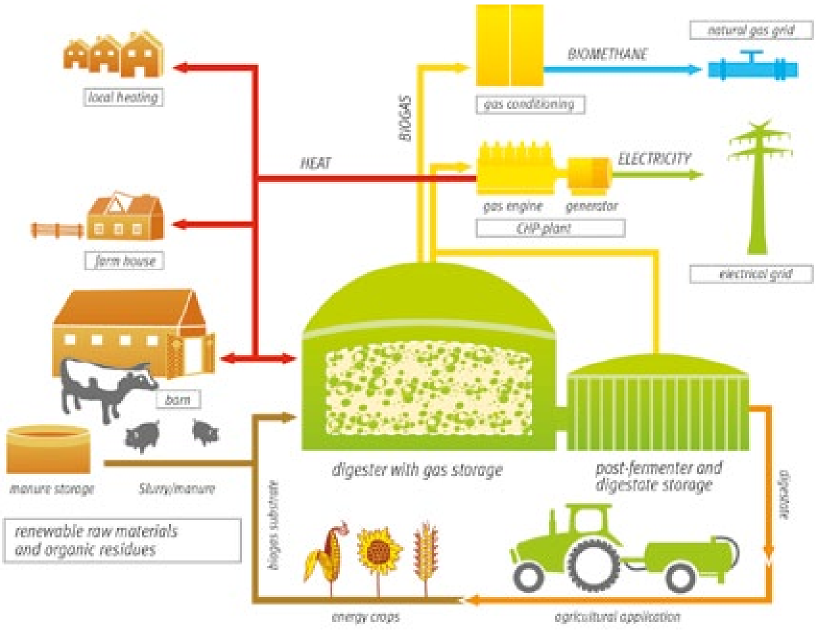


Fig. 11: Scheme of an agricultural biogas plant

the digester is water-tight and gas-tight and also impermeable to light. Usually a stirring device produces the desired homogeneity of the substrate. Depending on the input material, this is inclined to a varying extent to form layers of floating material or layers of sediment. The stirring movement also supports the escape of the gas from the substrate. If layers of sediment form, e.g. when digesting poultry manure or typical municipal organic waste, they must be regularly removed. A heating system ensures that the process temperature is maintained; for most installations this is in the mesophilic range (between 32 and 42 °C) and is only rarely in the thermophilic range (between 50 and 57 °C). The heating is usually sourced from the co-produced heat of the CHP unit. In case of installation concepts with a remotely located CHP unit or a biogas upgrading facility, it is also done by wood chip fired heating plants. From the digester, the digested substrate finds its way into the digestate storage. The latter is often extended to become a post-digestion container, or respectively there is a post-digester and a separate digestate storage. For installations approved since 2009 according to the Federal Immissions Control Act (BImSchG), and also for all installations going into service from 2012 onwards, the digestate storage is required to be gas-tight. This makes it possible to use the biogas from the post digestion process; at the same time, emissions and smells are reduced.

The orientation point determining the size of the digestate storage is the required storage time: this is determined by the rulings governing environmentally-suitable use of slurry in crop production (Fertiliser Application Ordinance – Düngeverordnung). If co-substrates are digested, depending on their characteristics it can be necessary to have additional assemblies for receiving and preparing the input substrates. Apart from breaking down and sanitising it, the separation of disruptive substances is of particular significance, both for the process to take its course without unwanted interruption and also for the quality of the digestate.

For the co-fermentation of substrates which justify concern in terms of disease-prevention – such as municipal organic waste, flotation sludge, stomach and ruminal contents, food waste etc. – the areas for substrate intake and conversion must be separated by maintaining one clean side and one unclean side. A sanitisation unit is necessary in which the substrates are heated to at least 70 °C for a minimum of 60 minutes. This is to prevent health-threatening pathogens from remaining in the substrate.

Gas storage tanks serve the purpose of balancing out fluctuations between gas production and gas consumption; a storage capacity of one to two days' production volume is recommended. They must be gas-tight, secure against pressure, and impermeable to UV radiation as well as temperature and weather influences. The digester can be used as gas storage itself by using foil hoods on the reactor. The external storage tanks that are predominantly used are relatively low-cost foil tanks.

6.3 Gas upgrading and feed-in into the natural gas grid

Before the gas is utilised, particles and condensate must be removed. An important measure for protecting CHP units against corrosion is desulphurisation. A variety of processes is used: the primary favoured option in agricultural biogas plants is a cost-competitive desulphurisation process in which 3–5 % air is dosed into the gas area. In this way, subject to good control being exercised, sulphur separation levels reaching approx. 95 % can be achieved. However, this process is not suitable for a subsequent upgrade to natural-gas quality. After desulphurisation, the raw biogas is dried. For the purpose of upgrading to natural-gas quality carbon dixoide, oxygen and trace gases are separated.

For feeding biogas into the natural gas grid, the methane content of 50–55 % is raised to the methane content present in the respective natural gas grid, consisting of up to 98 %, in accordance with DVGW Worksheets G260 and G262. The arrangement of the process steps involved in reaching the necessary minimum quality is mainly dependent on the technology selected

BIOGAS UPGRADING PROCESS STEPS

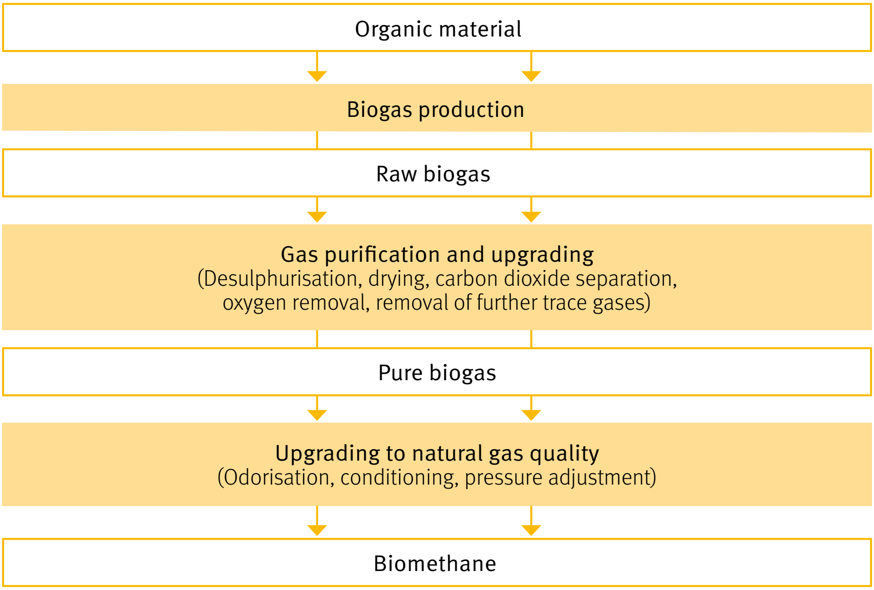


Fig. 12: Scheme of the biogas upgrading process

Biogas upgrading plant

and on the gas quality of the respective gas grid. Upgrading technologies currently used are pressurised water scrubbing, pressure swing adsorption, and physical and chemical absorption processes, as well as membrane technology. Figure 12 presents the general process steps involved in the upgrading process.

The biomethane is fed-in into the natural gas grid via a feed-in station, consisting of a unit for measurement and adjustment of gas pressure, a compressor unit, and a quantity measurement system. At this point, the composition of the gas is determined and adjusted so as to be compatible with the local natural gas network. The Gas Grid Access Ordinance (GasNZV) establishes the conditions according to which the gas grid operators must grant the biomethane producers access to the gas grids. This Ordinance states that, upon receiving a request, grid operators working at all pressure levels are obliged to connect biomethane plants to the gas grid on a priority basis and to ensure availability of the grid connection on an enduring basis (at least 96 % of the time). Together with the Gas Grid Charges Ordinance (GasNEV), this provision ensures that biomethane can be fed in and transported according to economically viable conditions.

It is, in particular, larger upgrading facilities that take on the task of upgrading biogas and then feed-in into the natural gas grid, due to the high investment and operating costs involved. Decentralised agricultural biogas plants can participate in this market through production of raw biogas, the following feeding of the raw gas into a collection pipeline, and transportation to an upgrading plant. The new and further development of upgrading technologies are also advancing at a brisk pace, possibly offering future prospects for smaller facilities.

6.4 Process measurement and control technology, safety

The biogas process can be monitored and controlled by recording several parameters. The most important of these include: temperature, pH value, gas quantity, methane content, CO_2 content and hydrogen sulphide content. What is important for reliably detecting the onset of acidification processes is to determine the ratio of volatile organic acids (VOA) to the total antioxidant capacity (TAC). Electronic measurement devices enable all values to be measured and evaluated continuously. The assessments then enable conclusions to be made about the gas production or the efficiency of the CHP unit.

Because of methane's major impact on the environment, it is a requirement that an additional appliance to burn waste gas and avoid any escape of biogas is available (e.g. a gas burner or a gas torch); the biogas can be burned in this, if for example the functioning of the CHP unit is disrupted. Also Biogas plants that went into service before 2012 are required to be retrofitted by 2014. To protect against any overload of the electricity grid, biogas plants of $> 100\,kW_{el}$ must be fitted with appropriate technical equipment, ensuring that in the event of a threat of overload of the grid, the grid operator can switch off the installation.

Biogas is flammable and in mixtures containing 6–12 % air it is explosive. For this reason, the safety rulings for biogas plants and the corresponding general regulations need to be taken into account. It is a matter of principle that the emergence and escape of dangerous gases must be avoided. According to the Ordinance on Industrial Safety and Health (Betriebssicherheitsverordnung), it is a requirement to have a formal process of inspection and approval for the plant. Beyond this, the operators have to provide evidence of a hazard assessment and numerous items of documentary proof. They have to conduct inspections guaranteeing safe operation. In doing so, they must take into account the European and national stipulations, as well as the technical norms and rulings established (e.g. by the VDI, DVGW, and DIN – see 8.3 – List of abbreviations). Subject to compliance with the statutory requirements and fulfilment of the safety standards, dealing with biogas entails no greater risk than natural gas does.

6.5 Digestate

The residues left after anaerobic digestion are generally called digestate, digestion product or biogas slurry. Returning this digestate to the agricultural lands that supply the substrates leads to a closed nutrient

Application of digestate

cycle. As a matter of principle, digestates from agricultural biogas plants are subject to the law governing fertilisers, the same as for farm fertilisers.

Uncontaminated digestate from agricultural biogas plants is used as organic fertiliser of high calibre. The overall quality of farm fertilisers is improved by the fermentation process because, in certain instances, pathogens and weed seeds are killed off. Nutrients also become better available for crops, making their more targeted use as a substitute for mineral-based fertilisers possible. The digestate also gives off a less intensive smell and has a less caustic effect on the crops. Depending on the original substrates used, the composition in terms of nutrients can fluctuate very significantly. Digestate from dry anaerobic digestion is similar to solid manure.

Suitable water-tight tanks must be used for storing the digestate. Because of the emission of ammonia, methane and other environmentally relevant substances, it is by now a statutory requirement to have the storage tanks sealed gas-tight.

If municipal organic waste is digested, regulations governing waste and disease-prevention also apply. In such a case, the digestate is usually sanitised before being applied onto soil (e.g. by heating it). The digestate must be distributed onto the soil in accordance with the Fertiliser Application Ordinance (Düngeverordnung – DüV) and, where applicable, further applicable regulations. The available technology for slurry or manure can be used for applying the digestate onto the soil. After its application onto untilled land, digestate must be worked into the ground without delay, as is also the case for other fertilisers containing ammonia. The objective is to make optimum use of the nutrients and to reduce nutrient loss.

Especially in regions with a high density of biogas plants and livestock, the basis for responsible use of slurry and digestate as fertiliser is often no longer present. In such cases, it is purposeful to treat the digestate and to market the product (in dried or pellet form) in other regions. Thus, by means of various processes, dry matter content and the concentration of nutrients are increased and the digestate is rendered transportable.

7 LEGAL FRAMEWORK, FUNDING, AND ECONOMIC EFFICIENCY

7.1 Legislative framework

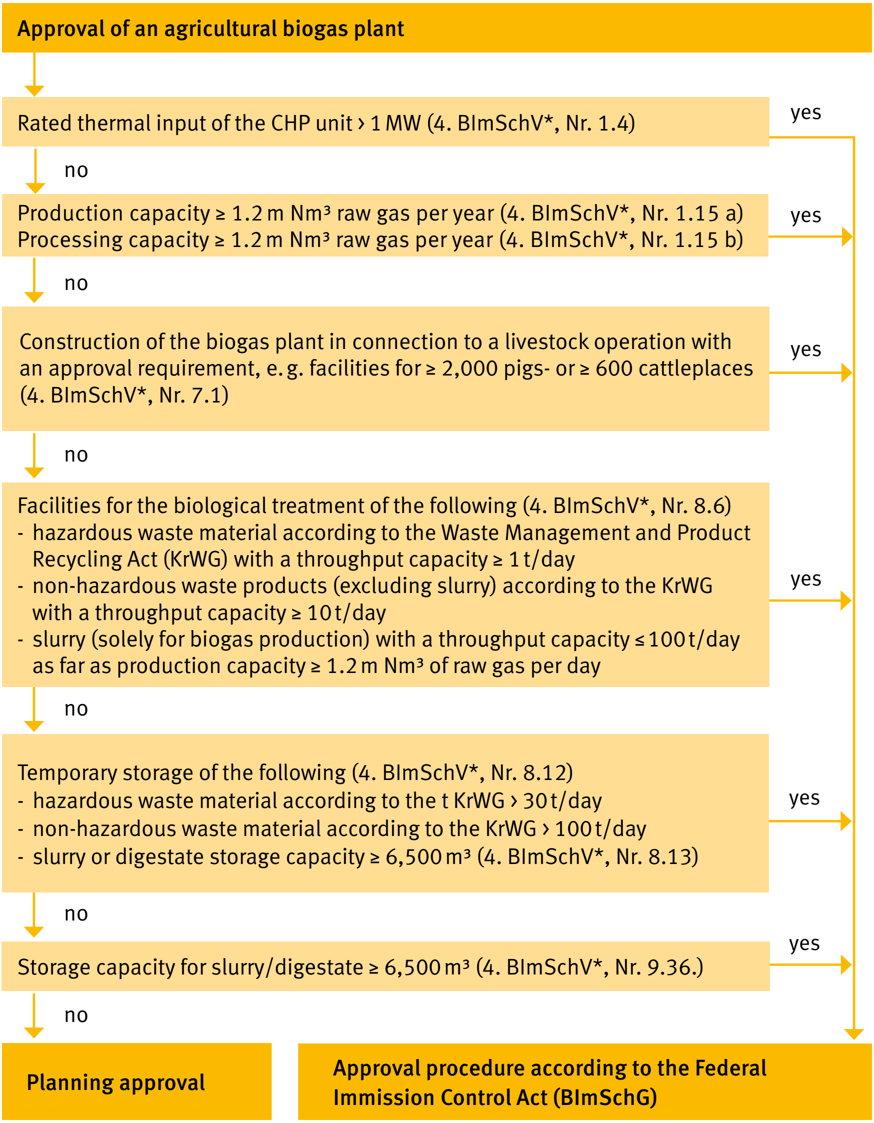
For establishing and operating biogas plants, as well as for applying the digestate onto soil, a large number of laws and ordinances needs to be taken into account. These requirements encompass planning law, construction law, water law, fertiliser law, and waste material law. The provisions in the laws on immission control, nature conservation and hygiene are relevant as well.

Depending on the size of the plant, or the type of substrate to be processed, a procedure is necessary according to construction law or immission-control law (Fig. 13).

The construction approval procedure takes the rules on construction projects at state level (not national level) as its orientation point. This is usually simpler and demands less time and fewer costs than a procedure conducted according to the Federal Immission Control Act (BImSchG). A distinction is made between construction planning law (planned or unplanned interior area, outlying area) and building regulations law. The latter clarifies questions regarding (e. g. minimum/maximum) distances, access roads, fire protection etc. In the unplanned outlying area, it is permissible to construct a biogas plant according to Article 35 of the Building Code (Baugesetzbuch), if it is operated in connection with an agricultural enterprise and the corresponding prerequisites are fulfilled.

The legal requirements governing immission-control are aimed at minimising immissions (air pollution, noise, smell) emerging as a result of constructing and operating biogas plants. The operator who requires approval in terms of immission-control law is required to undertake corresponding precautionary measures. Limits are stated in the following documents: Technical Instructions on Air Quality Control (TA Luft), Technical Instructions on Noise Control (TA Lärm), and also the Ordinance on the Immission of Odours (Geruchsimmissions-Richtlinie). Within the procedure governed by the Federal Immission Control Act (BImSchG) an environmental impact assessment is made, where applicable, to determine environmental compatibility.

If it is planned that the installation is to digest biowaste, there is a requirement to comply with the rulings in Regulation (EC) No 1069/2009 governing animal by-products not designated for human consumption, and also the Waste Management and Product Recycling Act (KrWG). While it is Regulation (EC) No 1069/2009 that applies in the case of animal by-products (including digestate), in the case of waste of plant origin (also food waste and domestic organic waste) the document that applies is the Biowaste Ordinance (BioAbfV).



Approval of an agricultural biogas plant

Rated thermal input of the CHP unit › 1 MW (4. BImSchV*, Nr. 1.4)

Production capacity ≥ 1.2 m Nm³ raw gas per year (4. BImSchV*, Nr. 1.15 a)
Processing capacity ≥ 1.2 m Nm³ raw gas per year (4. BImSchV*, Nr. 1.15 b)

Construction of the biogas plant in connection to a livestock operation with an approval requirement, e. g. facilities for ≥ 2,000 pigs- or ≥ 600 cattleplaces (4. BImSchV*, Nr. 7.1)

Facilities for the biological treatment of the following (4. BImSchV*, Nr. 8.6)
- hazardous waste material according to the Waste Management and Product Recycling Act (KrWG) with a throughput capacity ≥ 1 t/day
- non-hazardous waste products (excluding slurry) according to the KrWG with a throughput capacity ≥ 10 t/day
- slurry (solely for biogas production) with a throughput capacity ≤ 100 t/day as far as production capacity ≥ 1.2 m Nm³ of raw gas per day

Temporary storage of the following (4. BImSchV*, Nr. 8.12)
- hazardous waste material according to the t KrWG › 30 t/day
- non-hazardous waste material according to the KrWG › 100 t/day
- slurry or digestate storage capacity ≥ 6,500 m³ (4. BImSchV*, Nr. 8.13)

Storage capacity for slurry/digestate ≥ 6,500 m³ (4. BImSchV*, Nr. 9.36.)

Planning approval

Approval procedure according to the Federal Immission Control Act (BImSchG)

(without any claim to completeness)

Fig. 13: Criteria for approval of biogas plants

** 4th Amendment to the Federal Immission Control Act*

In general, all substances listed in Annex 1 of the Biowaste Ordinance (BioAbfV) may be used. Regulation (EC) no 1069/2009 subdivides the materials into three categories according to the degree of hazard that they represent, establishing the various approval conditions, such as distance, sanitisation, safety, and monitoring, in addition to cleaning and disinfection. With regard to animal by-products, there is also a requirement to comply with Disposal of Animal By-Products-Act (Tierische Nebenprodukte-Beseitigungsgesetz; TierNebG) and also the associated ordinance implementing the act (TierNebV).

According to the new version of the Waste Management and Product Recycling Act (KrWG), under certain circumstances the slurry used in biogas plants is also subject to the regulations of the law on waste.

For using digestate, and depending on the substrates used in the biogas plant and the use and upgrading process envisaged, various legal requirements must be complied with, arising from the laws governing fertilisers, hygiene and waste respectively. According to the Biowaste Ordinance (BioAbfV) there is a requirement that digestate applied onto the soil and containing vegeta-

TABLE 2: REQUIREMENTS FOR THE HANDLING OF DIGESTATE (ACCORDING TO AID INFODIENST E. V.)

Digestate from	**Distribution on the farm's own land**	**Distribution on other farm's lands**
Farm fertiliser	Fertiliser Application Ordinance (DüV), Waste Management and Product Recycling Act (KrWG), where applicable Biowaste Ordinance (BioAbfV)	DüV, KrWG, where applicable BioAbfV, Farm Fertiliser Ordinance (WDüngV)
Renewable resources	DüV	DüV, Fertiliser Ordinance (DüMV)
Plant-based waste from the operators enterprise	DüV	DüV, DüMV
Organic waste as defined by BioAbfV and DüMV	Biowaste Ordinance (BioAbfV), DüV	BioAbfV, DüV, DüMV
Food waste and other substances as defined by Regulation (EC) No 1069/2009	BioAbfV, Disposal of Animal By-Products-Act (TierNebG), DüV, Regulation (EU) 142/2011	DüV, DüMV, TierNebG, Regulation (EU) 142/2011
Sewage sludge and farm fertiliser or municipal organic waste according to the Ordinance on Biowastes (BioAbfV), Annex 1	Sewage Sludge Ordinance (AbfKlärV), DüV	AbfKlärV, DüV, DüMV

(without any claim to completeness)

ble waste, is harmless in phyto-hygienic and disease-prevention terms. The Fertiliser Ordinance (Düngemittelverordnung – DüMV) requires that substances brought into circulation must be harmless in terms of hygiene. Moreover, when digestate is submitted, transported or received, there is a requirement to comply with the Farm Fertiliser Ordinance (WDüngV).

Information on statutory requirements to be complied with and approval procedures to be implemented for construction and operation of biogas plants, as well as the necessary documents, can be requested from the authorities with relevant responsibility at state, administrative district, and municipal level.

7.2 The Renewable Energy Sources Act and funding

The Renewable Energy Sources Act (EEG) sets the regulations for feeding in and remunerating the supply of electricity from renewable energies. It entered into force in the year 2000 and was amended in 2004, 2009 and 2012, according to the political goals aimed at expanding renewable energies, and taking account the respective market developments. The EEG has immensely improved the framework conditions for the generation of electricity from renewable energies. The first two amendments particular, led to a very positive development in the biogas sector. The Act obliges the grid operators to connect installations generating electricity from renewable sources to their grid on a priority basis, as well as to purchase the electricity thus produced at fixed rates of remuneration. The remuneration for feeding-in the electricity differs according to the size of the installation, the substances used, and other criteria. The basic remuneration results from the respective remuneration applicable for the year in which the facility entered into service; this amount is fixed for a duration of 20 years plus the year of the installation's starting year. The basic remuneration and bonuses are subject to an annual degression of 2 % (EEG 2012).

For biogas plants going into operation in 2012 or later, there is an additional input substrate remuneration aside from the particular basic remuneration. The possible input substrates are divided into two remuneration classes, according to the Biomass Ordinance (BiomasseV): it is predominantly energy crops that are in input substrate class 1, while class 2 has substrates of greater environmental value, such as slurry or material from landscape conservation areas. There is also class 0, used for the recognised forms of biomass for which there is no additional remuneration because providing them gives rise to no cost or very little cost (e. g. green cuttings or pomace). Bonuses are also made available for gas upgrading and for biowaste digestion. There is furthermore a special remuneration for small slurry plants of up to 75 kW_{el}. In addition, the last amendment introduced both a requirement that a minimum of the produced heat has to be used and also an upper limit on the amount of input substrates from maize and grain kernels.

TABLE 3: REMUNERATION RATES FOR BIOGAS PLANTS ACCORDING TO EEG 2012 (IN EURO CENTS/KWH)

		Remuneration ct/kWh	
		2013[8]	**2014**[8]
Basic tariff[1, 3]			
	up to 150 kW$_{el}$	14.01	13.73
	› 150 kW$_{el}$ to 500 kW$_{el}$	12.05	11.81
	› 500 kW$_{el}$ to 750 kW$_{el}$	10.78	10.56
	› 750 kW$_{el}$ to 5 MW$_{el}$	10.78	10.56[7]
	› 5 MW$_{el}$ to 20 MW$_{el}$	5.88	5.76[7]
Special tariff[2]	up to 75 kW$_{el}$	24.50	24.01
Input substrates tariff[3]			
Input subsrate tariff class I	up to 500 kW$_{el}$	6	6
	› 500 kW$_{el}$ to 750 kW$_{el}$	5	5
	› 750 kW$_{el}$ to 5 MW$_{el}$	4	4
Input subsrate tariff class II	up to 500 kW$_{el}$	8	8
	› 500 kW$_{el}$ to 5 MW$_{el}$	8/6[4]	8/6[4]
Gas upgrading bonus[5]			
	up to 700 Nm^3	2.94	2.88
	up to 1,000 Nm^3	1.96	1.92
	up to 1,400 Nm^3	0.98	0.96
Biowaste fermentation bonus[6]			
	up to 500 kW$_{el}$	15.68	15.37
	› 500 kW$_{el}$ to 20 MW$_{el}$	13.72	13.45

Source: EEG 2012

Information given is not of a legally-binding nature

[1] *including the obligation to make use of the generated heat, i. e. at least 60 % of the electricity generated in the installation must be generated through combined-heat-and-power process and the heat must be used according to the requirements of Annex 2 of the Renewable Energy Sources Act (EEG). Exceptions: Installations using ≥ 60 % (by mass) slurry or participation in direct marketing*

[2] *Small slurry plants, using ≥ 80 % slurry/Manure (by mass) (without poultry manure/dried poultry manure)*

[3] *Basic tariff and input substrate tariff only if ≤ 60 % (by mass) maize and cereal grain is used*

[4] *for slurry/manure 6 euro cents/kWh for installations › 500 kW to 5 MW*

[5] *700 Nm^3/ha (circa 2.8 MW), 1,000 Nm^3/h (circa 4.0 MW), 1,400 Nm^3/h (circa 5.5 MW)*

[6] *≥ 90 % biowaste (by mass) as defined in the Biowaste Ordinance (Bioabfallverordnung)*

[7] *from 2014 for new installations › 750 kW remuneration only through direct marketing (market premium model)*

[8] *annual degression of 2 % on the basic tariff and bonuses, but not on the input substrate tariff*

For installations that have started operation before 2012, the relevant provisions are of the EEG 2009 (see biogas.fnr.de/rahmenbedingungen).

To receive the remuneration the operator is required to show certain documentary proof. This encompasses the provision of documentation on the input substrates used through to checks by environmental verifiers and certifications from public authorities.

In 2007, an act of law established the EEG Clearing House (Clearingstelle EEG) as the neutral mediator in the event of any disputes in relation to the EEG. If so requested, the Clearing House examines any disputes, on a non-legally-binding basis, or it issues recommendations.

Measures were taken to launch renewable energies onto the market and to initiate electricity production that is in accordance with demand: the direct marketing segment was strengthened and an optional market premium model was introduced. In combination with a flexibility premium model, this was done in order to enhance the attractiveness of marketing electricity in accordance with demand, and as an alternative to the Renewable Energy Sources Act (EEG) feed-in arrangement.

In addition to the EEG, there are various direct and indirect investment promotions for the biogas sector at EU, national and state level. These are among others the market incentive programme (MAP) by the Federal Office of Economics and Export Control (BAFA) and the funding opportunities via the Kreditanstalt für Wiederaufbau (KfW promotional bank for the Federal Republic and the Federal States). The FNR website biogas.fnr.de provides an overview of the respective funding programmes of the European Union, the German Government and the federal states.

7.3 Economic efficiency

A decision for a biogas plant entails large investments. In the planning stage, there is a need to painstakingly check the issues involved in integrating the plant into the operational sequences: this relates to the organisational and technical aspects as well as to managing labour-input aspects. The size and the concept for the installation, as well as the choice of location have a substantial influence on the economic success. These must be very carefully coordinated in terms of the available resources of land, labour and capital. Right from the construction phase, the challenge is to keep costs low. To construct a small biogas plant (< 150 kW_{el}) for renewable resources and slurry it is appropriate to expect specific investment costs of 6,000–7,000 € per kW of installed electrical capacity. As the capacity level of the unit goes up, these costs per unit of capacity go down. Accordingly, larger installations for wet anaerobic digestion can be set up with specific acquisition costs of approx. 3,000–4,000 €/kW_{el}.

For the commercial success of a biogas plant, monitoring and reduction of costs are just as important as technical optimisation,

Agricultural biogas plants

the enhancement of efficiency, and the maximisation of revenue. One aspect of the last issue is the comprehensive use of the heat generated in the process of operating a CHP unit. Yet taking part in the direct marketing model or using the digestate profitably can also lead to additional revenue. Among the expenses in operating the installation, the substrate costs account for the largest share. Price fluctuations and, in particular, substantial increases in substrate prices can strongly influence the economic viability of a biogas plant. Above all, plants needing to buy large quantities of substrate are faced with the challenge of securing substrate costs for as long a period as possible. An important approach in pursuing cost reductions is the enhancement of the plant's efficiency. It is essential to optimise both the technical operation and also the biological process; This is in order to structure the acquisition and use of biogas successfully over the long term as well. Efficiency-boosting measures begin at the stage of harvesting the energy crop and ensilaging it. Especially for smaller facilities, tapping into the potential of the available farm fertiliser can lead to success. Likewise, raising gas output and raising the methane content, or sealing the post-digester, lead to a distinct improvement in economic viability. Other measures that increase the return on the investment are stable operation of the installation and a high number of hours in which the CHP unit is working at full capacity. The use of organic residues from the processing industry can lead to an increase in gas production and to reduced substrate costs or additional income from taking over of these residues. Because most measures aimed at raising efficiency entail investments, it is appropriate to make a proper analysis in advance.

Attentive and conscientious operation of the facility is important for recognising any problems as early as possible. The daily requirement in terms of working hours for a biogas plant can be between 1 and 5 hours, depending on the size of the facility and the substrates used.

The research and development work currently in progress in science and industry is forcing the pace on exploiting all opportunities for raising efficiency in the use of renewable resources and of other biomass. These relate to the whole chain of activities in the process. Intensive scientific research into biogas generation only began a few years ago. It offers the prospect of substantial development progress. The objective is to use less biomass to generate more energy sourced from biogas and to be competitive with fossil-based energy sources.

8 ANNEX

8.1 Further information

Fachagentur Nachwachsende Rohstoffe e. V. (FNR)
(Agency for Renewable Resources)
OT Gülzow, Hofplatz 1
18276 Gülzow-Prüzen
Tel.: +49 3843/6930-0
Fax: +49 3843/6930-102
info@biogasportal.info
http://biogas.fnr.de
www.nachwachsenderohstoffe.de

Deutsches Biomasseforschungszentrum gGmbH (DBFZ)
(German biomass research centre)
Torgauer Straße 116
04347 Leipzig
Tel.: +49 341/2434-112
info@dbfz.de
www.dbfz.de

Kuratorium für Technik und Bauwesen in der Landwirtschaft e. V. (KTBL)
(Association for Technology and Structures in Agriculture)
Bartningstraße 49
64289 Darmstadt
Tel.: +49 6151/7001-0
ktbl@ktbl.de
www.ktbl.de

Leibniz-Institut für Agrartechnik Potsdam-Bornim e. V. (ATB)
(Leibniz Institute for Agricultural Engineering Potsdam-Bornim)
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info@biogas.org
www.biogas.org

Biogasrat+ e. V.
(The association for decentralised energy supply)
Dorotheenstraße 35
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Tel.: +49 30/201431-33
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www.biogasrat.de

Clearingstelle EEG (EEG Clearing House)
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info@clearingstelle.de
www.clearingstelle-eeg.de

8.2 Useful figures

1 m^3 Biogas	5.0–7.5 kWh$_{total}$
1 m^3 Biogas	50–75 % methane content
1 m^3 Biogas	1.9–3.2 kWh$_{el}$
1 m^3 Biogas	circa 0.6 l heating oil equivalent
1 m^3 Methane	9.97 kWh$_{total}$
1 m^3 Methane	3.3–4.3 kWh$_{el}$
1 m^3 Methane	1 l heating oil equivalent
CHP unit: efficiency$_{el}$	33–45 %
CHP unit: efficiency$_{th}$	35–56 %
CHP unit: efficiency$_{total}$	circa 85 %
CHP unit: operating time	7,900–8,200 operating hours/year
Micro gas turbine – efficiency$_{el}$	26–33 %
Fuel cell – efficiency$_{el}$	40–55 %
Electricity requirement biogas plant	5–20 %
Heat requirement biogas plant	5–25 %
Work requirement biogas plant	4–10 Akh/kW$_{el}$ • a
Optimum VOA/TAC area	< 0.8
Foil permeability	1–1.5 parts per thousand of biogas/day
Interruptions to operations per year (BGP)	1.2 for each 10 kW$_{el}$
Specific investment costs	
BGP 75 kW$_{el}$	approx. 9,000 €/kW$_{el}$
BGP 150 kW$_{el}$	approx. 6,500 €/kW$_{el}$
BGP 250 kW$_{el}$	approx. 6,000 €/kW$_{el}$
BGP up to 500 kW$_{el}$	approx. 4,500 €/kW$_{el}$
BGP 1 MW$_{el}$	approx. 3,500 €/kW$_{el}$
Biogas upgrading plant 500 Nm^3/h	approx. 7,500 €/Nm^3 • h
ORC installation 75 kW$_{el}$	approx. 4,000 €/kWh$_{el}$
Micro gas turbine 65 kW$_{el}$	approx. 2,000 €/kWh$_{el}$
Costs biomethane production 500 Nm^3/h	7.8–8.4 ct/kWh
Costs biomethane production 2,000 Nm^3/h	6.4–7.0 ct/kWh

Biogas yields in agriculture	
Dairy cow: 20 m^3 slurry/a	500 Nm^3 biogas
Pig: 1.5–6 m^3 slurry/a	42–168 Nm^3 biogas
Cattle: 3–11 t solid manure/a	240–880 Nm^3 biogas
Horse: 8 t solid manure/a	504 Nm^3 biogas
100 chicken: 1.8 m^3 dry excrement/a	252 Nm^3 biogas
Silo maize: 40–60 t FM/ha*	7,040–10,560 Nm^3 biogas
Sugar beet: 40–70 t FM/ha	5,200–9,100 Nm^3 biogas
Grain whole plant silage: 30–50 t FM/ha*	5,016–8,360 Nm^3 biogas
Grass: 26–43 t FM/ha*	4,118–6,811 Nm^3 biogas
Example – annual substrate requirement biogas plant 350 kW_{el}	5,500 t maize silage (125 ha)
	3,000 t cattle slurry (150 dairy cows)
	1,000 t grain whole plant silage (28.5 ha)

Source: FNR based on KTBL, Leitfaden Biogas (Guide to Biogas), Fraunhofer-IWES, DBFZ

* *12 % silo losses taken into account*

8.3 List of abbreviations

a	year
AbfKlärV	Klärschlammverordnung (Sewage Sludge Directive)
AGEE	Arbeitsgruppe Erneuerbare Energien-Statistik (Working group on renewable energy-statistics)
BGP	Biogas plant
BHKW	Blockheizkraftwerk (engine-based combined-heat-and-power (CHP) unit)
BioAbfV	Bioabfallverordnung (Ordinance on Biowastes)
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Federal Ministry of the Environment, Nature Conservation and Nuclear Safety)
DBFZ	Deutsches Biomasseforschungszentrum gGmbH (German Biomass Research Centre)
dena	Deutsche Energie-Agentur GmbH (German Energy Agency)
DIN	Deutsche Institut für Normung (German Institute for Standardization)
DüMV	Düngemittelverordnung (Fertiliser Application Ordinance)

DüV	Düngeverordnung (Fertiliser Ordinance)
DVGW	Deutscher Verein des Gas- und Wasserfaches e. V. (German Technical and Scientific Association for Gas and Water)
EE	Renewable energies
el.	electrical
EU	European Union
FM	fresh mass
Fraunhofer IWES	Fraunhofer Institut für Windenergie und Energiesystemtechnik (Fraunhofer Institute for Wind Energy and Energy System Technology)
FvB	Fachverband Biogas e. V. (German Biogas Association)
Getreide-GPS	Cereal whole plant silage
h	hour
ha	hectare
IE	Institut für Energetik und Umwelt gGmbH (Institute for Energy and Environment)
KrWG	Kreislaufwirtschaftsgesetz (Waste Management and Product Recycling Act)
KTBL	Kuratorium für Technik und Bauwesen in der Landwirtschaft e. V. (The Association for Technology and Structures in Agriculture)
KWK	Kraft-Wärme-Kopplung (combined heat and power)
kW	kilowatt
kWh	kilowatt hour
m^3	cubic metre
NawaRo	Nachwachsende Rohstoffe (renewable resources)
Nm^3	norm cubic metre
MW	megawatt
PJ	petajoule
t	tonne
TA	Technische Anleitung (Technical Instructions)
th	thermisch (thermal)
TierNebG	Tierische Nebenprodukte-Beseitigungsgesetz (Disposal of Animal By-Products Act)
TM	Trockenmasse (dry matter)
TWh	terrawatt hours
VDI	Verband Deutscher Ingenieure e. V. (The Association of German Engineers)
WDüngV	Wirtschaftsdüngerverordnung (Farm Fertilisers Ordinance)

8.4 List of publications

Fachagentur Nachwachsende Rohstoffe e.V. (Hrsg.):
These and other FNR publications can be ordered or downloaded free of charge at http://mediathek.fnr.de:

Biomethane (2013)

Guide to Biogas (2012)

Bioenergy (2013)

Bioenergy in Germany: Facts and Figures (2013)

The Renewable Energy Sources Act
Publisher: Federal Ministry of Food, Agriculture and Consumer Protection (2012)

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