



**SPIN background paper**

# Biogas production in Germany

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## Preface

The concept of biogas production by fermentation and its subsequent conversion into electricity in combined heat and power (CHP) plants or feeding as biomethane into the gas networks is an essential contribution to utilizing biowastes from households, communities and agriculture, on the one hand, and the purposeful production of CO<sub>2</sub>-neutral energy from regenerative raw materials, on the other hand. Owing to the great number of potential starting materials (substrates) and their simple regional availability the energy potential obtained from biogas solely in Germany totals 417 petajoule (PJ)<sup>1</sup> which corresponds to a share of 3 % of the primary energy consumption (13,878 PJ in 2007). The biggest share of biogas, approx. 85 %, is produced in agriculture, further gas quantities come from municipal and industrial biowastes, from dumps and sewage sludges. Biogas coming from dumps and sewage sludges is not considered here.

The Renewable Energy Act coming into effect in 2000 resulted mainly in a continuous increase in the production of biogas in Germany. After the Renewable Energy Act was first amended in 2004 the installation of biogas plants became especially dynamic which was basically due to the adoption of the regenerative raw material bonus. This development shows that a quick extension of the biogas production is mainly a question of the legal basic conditions or purposefully setting incentives, less of the availability of certain techniques. The last-mentioned develop automatically with the dynamics displayed by a specific field of application which was to be observed also in other fields such as e.g. photovoltaics and wind energy also supported by subsidization according to the Renewable Energy Act .

In addition to the national efforts made to promote biogas plants initiatives and targets relating to the development of renewable energies and thus also of the biogas branch were prepared or fixed. The EU Biomass Action Plan was presented to intensify the energetic use of biomass. The Directive 2009/28/EC fixes the joint target of obtaining at least 20 % of the gross final energy from regenerative sources until the year 2020.

The Renewable Energy Act may be considered as having launched and ensured the positive development of biogas production in the last 10 years in Germany. Apart from a short introduction into biogas production and consideration of the history mainly the legal regulations and their effects on the biogas sector are considered. As considering the equipment in detail would exceed the framework of a background paper, suppliers of turnkey plants with their main areas and producers of CHP plants and biogas treatment plants are mentioned in parts in Chapter 3. Reference is made to other papers<sup>2</sup> to get a comprehensive survey of the equipment applied for the

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<sup>1</sup> Hartmann, Hans; Kaltschmitt, Martin (Hrsg.): *Biomasse als erneuerbarer Energieträger*. (Biomass as renewable energy carrier), series of papers „Regenerative raw materials“, vol. 3;2., completely revised edition. Münster: Landwirtschaftsverlag GmbH, 2002 – ISBN 3-7843-3197-1.

individual components of biogas production. The „Biogas Guide“<sup>3</sup> of Fachagentur für Nachhaltige Rohstoffe (FNR) (Agency for Renewable Resources) provides a comprehensive survey of the biochemical fundamentals and agricultural, economic, legal and plant-operational aspects. Also the safety, environmental protection, gas treatment and feeding and microgas network fields are dealt with here in detail.

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<sup>3</sup> Fachagentur Nachhaltiger Rohstoffe e.V. (2010): Leitfaden Biogas – Von der Gewinnung zur Nutzung. 5. Vollständig überarbeitete Auflage (Biogas Guide – from production to use. 5th completely revised edition, Gülzow, 2010 ([www.biogasportal.info/](http://www.biogasportal.info/), 11.01.2011)).

# 1 General introduction

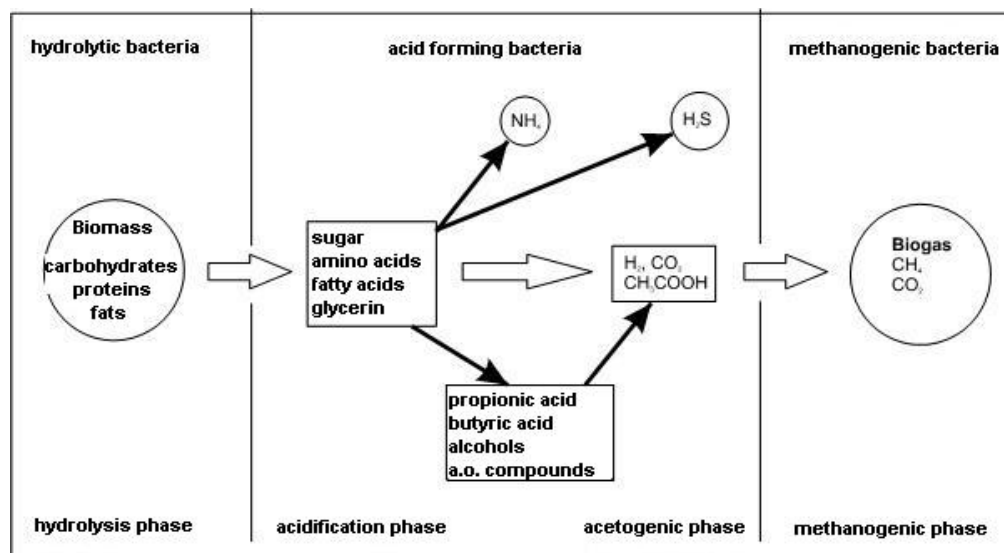
## 1.1 Production of biogas

In nature, biogas is produced where organic material is decomposed by microorganisms in an oxygen-free environment (anaerobic fermentation), e. g. in moors, in the sediments of surface waters or in rumen of ruminants. Given these conditions organic material is nearly completely converted into biogas.

The anaerobic decomposition of organic substances may be classified into four steps: hydrolysis, acid formation, acetate formation and methane formation. In the first two steps the organic substances are liquefied and decomposed. Their proper conversion into methane takes place in the last two steps of decomposition. The individual steps do not only differ from each other as regards the microorganisms participating and the products formed but also essentially by the environmental conditions required. The final product of fermentation is a flammable gas (biogas) of the following composition:

- 50 – 75% methane( $\text{CH}_4$ )
- 25 – 45% carbon dioxide ( $\text{CO}_2$ )
- 2 – 7% water ( $\text{H}_2\text{O}$ )
- < 2% oxygen ( $\text{O}_2$ )
- < 2% nitrogen ( $\text{N}_2$ )
- < 1% ammonia
- <1% hydrogen sulphide ( $\text{H}_2\text{S}$ )

Figure 1-1: Schematic representation of the anaerobic substance conversion

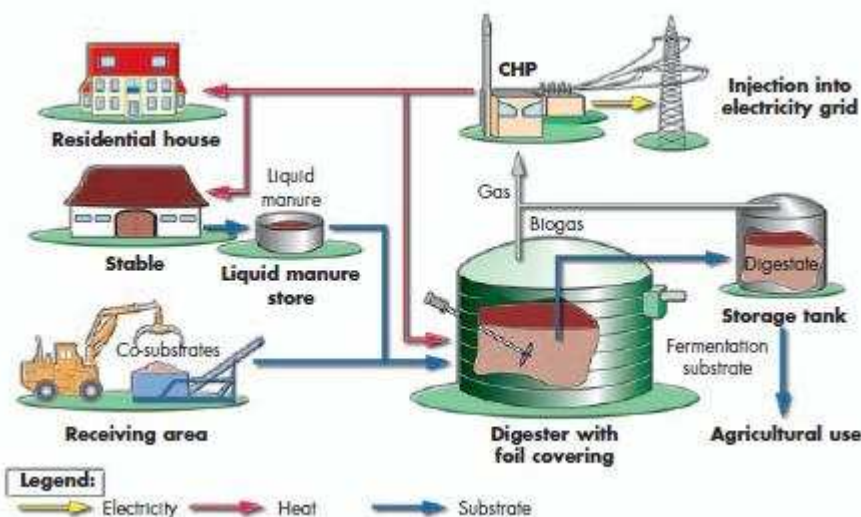


Source: Sahn, H.: Biologie der Methanbildung. Chem. Ing. Technol. 53 (1981), S.854-863

## 1.2 Biogas plants

The anaerobic decomposition of biomass in fermenters of biogas plants represented above is used for continuously producing methane. This may be subsequently either converted into energy and heat by combustion in combined heat and power (CHP) plants or processed to natural biogas for being fed into the gas network. A potential biogas plant concept is illustrated in Figure 1-2.

Figure 1-2: Agricultural biogas plant with co-fermentation



Source: Fachagentur Nachwachsende Rohstoffe e.V.

### 1.2.1 Fermentation

Depending on how the fermentation substrates will be fed into the fermenter, also called fermenting tank, we speak about

- continuous or
- discontinuous

processes.

In the case of discontinuous (batch) processes the fermenter is filled with fresh substrate and hermetically closed. Discontinuous processes are, as a rule, operated as dry fermentation (also called solid fermentation). Here, the garage-like fermenters are simply filled and emptied by means of wheeled loaders. The gas production starts slowly after filling and declines again slowly after reaching the maximum. Here, the substrate remains in the tank without adding or taking off substrate. After the biogas production will have been completed the fermented substrate will be replaced by fresh substrate, the process will start anew. Discontinuous dry fermentation processes are increasingly applied in fermenting biowastes.

**Continuous processes** are the classical form of biogas production. They are marked by a regular (quasi-continuous) feeding into the fermenter. The drawback of

this concept is the high demand for energy for operating stirring units as the content of the fermenter has to be regularly mixed. The investment costs of continuously operating plants are mostly slightly higher than those of discontinuously operating plants. Also the maintenance costs are slightly higher due to the movable stirring units. The essential advantage of continuously operating plants is the clearly higher gas output as compared with discontinuously operating dry fermentation plants. In Germany preferably continuous processes are applied in agricultural plants, with the substrate being fed into the fermenter a few times a day. Liquid (liquid manure, sludges) as well as solid substrates (maize silage, biowastes) may be used, with a sufficient water content having always to be reached in the mixture. When feeding into the fermenter an equal quantity of fermented substrate is transported from the fermenter into the next tank. Depending on the plant concept this may be a further fermenter, a secondary fermenter or a fermentation residue tank. Thus, it is possible to produce continuously biogas and thus electricity. The concept with one or a few fermenters and a fermentation residue tank is also referred to as storage-flow procedure.

The predominant part of methane bacteria has optimum temperatures in the mesophilic range of approx. 30°C to 40°C. The bulk (85 %) of biogas plants in Germany is operated at this temperature range which can cope with temperature variations of  $\pm 3$  K without having great negative effects. The operation of the plants is essentially more sensitive in the thermophilic range (50°C to 57°C). Here, the temperature variations have to be limited to  $\pm 1$  K as in the case of variations of a few degrees a drastic decline of the conversion rates and thus of the biogas production is to be expected. If high flow rates are striven for and the substrates used are a hygienically problematic material (biowastes) the thermophilic process will be of advantage. Thermophilic processes reach a higher decomposition speed, an insignificantly higher gas output and are more stable to shock loading. Mesophilic and thermophilic operations differ in the adaptation of bacteria cultures to their ambient temperature and may not be rapidly changed.

The energy content of biogas depends directly on the methane content. The higher the content of easily decomposable substances such as fats and starch will be in the fermentation substrate the higher will be the gas output. A cubic meter of methane has an energy content of nearly ten kilowatt hours (9.97 kWh). If the methane content will amount to 60 % the energy content of a cubic meter of biogas will total about six kWh, the calorific value will correspond roughly to 0.6 litres of fuel oil.

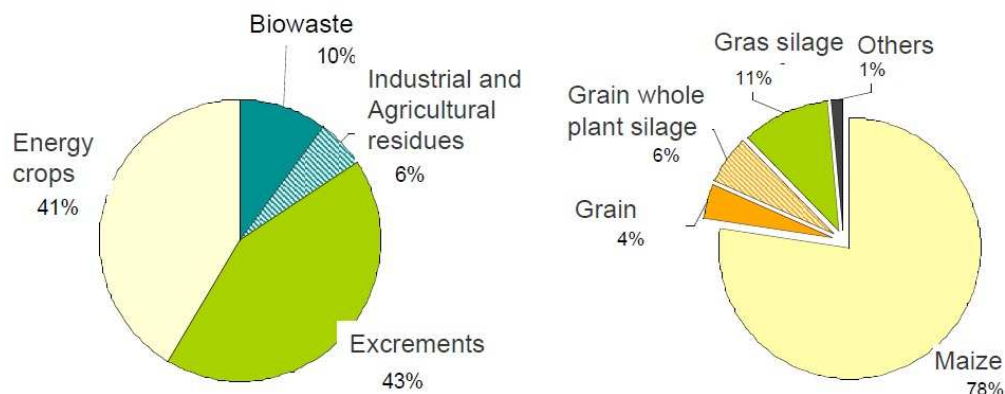
### **1.3 Substrates for biogas production**

By tradition notably liquid and liquified excrements of cattle, pigs and poultry are used as basic substrate for many biogas plants as they are easy to handle due to being pumpable. In addition, liquid manure is an ideal substrate due to its biochemical properties. It has a high buffering capacity, contains sufficient micronutrients in an available form and makes available the required bacteria population for the anaerobic fermentation. This refers notably to liquid cattle manure. In addition to liquid also solid substrates may be added to fermentation as e.g. solid manure, silages from green mass (maize silage), vinasse and pomace, rapeseed cake, plant residues and municipal biowastes. In Germany 10% of biowastes and 6% of plant residues from



industry and agriculture were used as fermentation substrates in 2008, with a big share having been animal excrements (43%) and energy crops (41%). In the latter-mentioned maize predominated with 78% (Figure 1-3).

**Figure 1-3: Use of substrates and energy plants in biogas plants in Germany (2008)**



Source: Deutsches Biomasseforschungszentrum (German Biomass Research Centre), Leipzig

### 1.3.1 Feeding

If the content of dry mass in a substrate exceeds 15% the substrate may no longer be pumped and has to be added to the fermenter separately. Solids and pourable goods may be directly fed into the fermenter via worms. This takes place via ascending worm screws or screw conveyors, plungers or punch presses. Apart from that solids may be mixed with liquid in a closed system either by means of a macerator<sup>4</sup> or added to the liquid by means of forced feeding. In both cases the solids in this suspension are pumped into the fermenter.

Substrates with a high content of dry mass are also suited for dry fermentation (solid fermentation). In the case of solid fermentation the material is fed into the fermenter by means of a wheeled loader or a comparable machine.

## 1.4 Biogas treatment and utilization

### 1.4.1 Desulphurization

During the anaerobic decomposition of organic substance groups in biogas plants, hydrogen sulphide (H<sub>2</sub>S) is formed. Hereby, the content of hydrogen sulphide in biogas depends on the sulphur content of the substrates used.

Apart from the highly toxic effect of hydrogen sulphide which should be considered when biogas is released, sulphur oxides are formed from hydrogen sulphide during the power-driven combustion process which in connection with humidity (formation of sulphuric acid) have strong corrosive effects on gas-bearing plant units. Especially the CHP plant and the heat exchangers in CHP plants are affected by them.

<sup>4</sup> Macerators are devices for crushing, homogenizing and dispersing flowable liquid/solid mixtures.

That is why it is necessary to desulphurize and dehumidify crude gas to reach a low-maintenance and low-emission operation of the CHP plant and to avoid corrosion of the gas-bearing plant units.

When designing the desulphurization unit aerosols, a. o. also from elementary sulphur, have to be considered.

The following possibilities of desulphurization are given:

- Biological desulphurization procedures:
  - Biological desulphurization in the fermenter. As a rule, the ambient air is directly blown into the gas room of the fermenter.
  - Topped biological desulphurization procedures (After passing the fermenter and before entering the CHP the biogas is led through a separate tower where apportioned ambient air is blown in and bacteria settle down e.g. on the tower packing.)
- Chemical-physical desulphurization procedures :
  - Precipitation by adding iron salt directly to the fermenter
  - Alkali washing
  - Adsorption to iron-containing masses
  - Adsorption to charcoal filters

#### **1.4.2 Dehumidification**

As a rule, the biogas saturated by water vapour has to be dehumidified to observe the targets set by the engine producers. This often happens by condensation and separation of the water in earth-buried pipelines or cooling the gas in heat exchangers. By reheating the gas in front of the gas route of the CHP the relative air humidity is further reduced.

#### **1.4.3 Biogas treatment for feeding it into a gas network**

The treatment may be e.g. gas scrubbing (pressurized water scrubbing, pressureless amine scrubbing) or adsorption. When treating biogas undesired components of biogas, in particular CO<sub>2</sub>, are precipitated. After purifying and upgrading it to increase its calorific value the so-called biomethane may be used as fuel and fed into the public gas network. Thus, it replaces immediately fossil natural gas. This allows a high degree of using the total energy as well as maximum freedom in utilizing it.

When producing biomethane CO<sub>2</sub>-rich waste gas is produced which contains still relevant methane portions (depending on the procedure <0.1 % to 4%<sup>5</sup>).

That is why measures have to be taken to reduce the methane emissions. At present, the thermal use of the waste gases e.g. in a lean gas-fired boiler or waste gas purification procedures such as the (catalytic) post-combustion of lean gas are a possibility.

#### 1.4.4 Utilization of biogas

At present in most of the cases the biogas produced is used in combined heat and power plants for the production of electricity in a combined heat and power generation. Modern CHP plants work with an electrical efficiency of about 40 %. The electricity generated may be used for the process, own needs and for feeding into the mains of the local energy supplier. Alternatives to internal combustion engines are, at present, the conversion into electricity in microturbines or fuel cells.

The combined thermal energy is taken off by cooling water heat exchangers and waste gas heat exchangers. Here, the thermal efficiency is between 40 % and 50 % depending on the electric efficiency. The available heat serves, first of all, to supply process heat (substrate heating, fermenter heating).

The excessive heat which, as a rule, has a flow temperature up to 90°C is then available for external use. If such possibilities of use are lacking it has to be emitted into environment through cooling installations.

Depending on the individual profitability of the project or in the case of biogas being sold and used in other places process electricity or process heat will be provided also from outside.

A possibly extensive use of the excess heat will ever more become the focus of attention for reasons of efficiency and profitability. In practice this requirement will be taken into account, for the time being, mostly by using heat for heating purposes e.g. in residential houses and for livestock breeding as well as for drying agricultural or forestry goods (e.g. grain or wood chopping chips). Decoupling of district heat may be economical notably if an all-season demand may be covered in the immediate vicinity. First successful experiences have been already made in producing cold by means of adsorption refrigerating plants.

Using excess heat for producing additional electricity is comparatively new. This takes place in ORC (Organic Rankine Cycle) plants. They allow to increase the overall electrical efficiency of conversion into electricity by some per cent. Owing to the still high additional investment costs this option is notably suitable for larger biogas plants.

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<sup>5</sup> Urban, W.; Girod, K.; Lohmann, H.: *Technologien und Kosten der Biogasaufbereitung und Einspeisung in das Erdgasnetz. Ergebnisse der Markterhebung 2008 (Technologies and costs of biogas treatment and feeding into the natural gas network. Results and market survey 2008)*. Fraunhofer UMSICHT, Oberhausen.

Mobile heat and cold storage tanks do not yet play a part in using heat for biogas plants for reasons of costs.

Biogas has not necessarily to be used immediately at the place of its production. In an increasing number of projects it is transported to places with a better connection to the mains or with attractive heat consumers.

As the timelines of biogas production and biogas utilization may differ a sufficiently big gas accumulator will be required as buffer to avoid the emission of biogas. It will be used e.g. to bridge maintenance work. In most of the cases gas accumulators will be erected as foil storage tanks on fermenters, secondary reactors or fermentation residue tanks and as separate collapsible storage tanks. Their excessive operating pressure is always distinctly below 0.1 bar.

## 1.5 Relevance of biogas emissions to environment

Apart from carbon dioxide (CO<sub>2</sub>) methane is an essential component of biogas. As methane has a greenhouse gas potential which is 25 times higher than that of carbon dioxide<sup>6</sup>, already insignificant losses and emissions of methane result in worsening or even completely changing the basically positive climate balance of biogas production and use. Methane emissions from biogas plants occur if unburned biogas escapes into atmosphere (diffusion through foils, leaks, high-pressure cut-off valves, engines failures etc.) and if fermentation residue not completely decomposed leaves the closed system of the biogas plant (fermentation residue tank not gas-tight covered). In addition there is a methane leakage when burning biogas in engines. The treatment of biogas with the aim to feed it into the natural gas network or using it as fuel can be also connected with methane emissions. It is not yet clear as far as untight foils used for covering the fermentation tanks, defects in sealing them at the tanks and the frequent response of high-pressure cut-off valves contribute to emitting methane.

The uncovered fermentation residue tank has quantitatively the highest importance among these methane emission sources. Investigations carried out in the framework of the biogas measurement programme II<sup>7</sup> have shown that the residue gas potential determined in the fermentation residue at 20-22°C totalled between 0 and 8 % of the

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<sup>6</sup> IPCC (Intergovernmental Panel on Climate Change) (2007): Climate Change 2007 – the physical science basis. Contribution of the Working Group I to the fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

<sup>7</sup> Fachagentur für nachwachsende Rohstoffe e.V. (FNR) (2009): Biogas-Messprogramm II. (Biogas measurement programme II) Gülzow. Das Messprogramm wurde durchgeführt unter Leitung des Johann Heinrich von Thünen-Instituts (vTI) mit Mitteln des Bundesministeriums für Ernährung, Landwirtschaft und Verbraucherschutz. Untersuchungsgegenstand sind Biogasanlagen, deren Inbetriebnahme nach dem EEG 2004 (August 2004 bis Ende Dezember 2008) erfolgte. (The measurement programme was carried through under the direction of the Johann Heinrich von Thuenen Institute (vTi) with the aid of funds of the Ministry of Food, Agriculture and Consumer Protection. The object of investigation are biogas plants put into operation according to the Renewable Energy Act of 2004 (August 2004 until December 2008)).

biogas used in the plant. That means that solely the methane escaping from the fermentation residue in unfavourable cases may result in a negative climate balance.

Apart from methane further gas emissions endangering environment and health may occur. Examples are ammonia and hydrogen sulphide. These gases mixed with methane are contained in biogas; yet they can be formed already when the substrates are stored, treated and mixed. Open fermentation residue tanks are an important source for the emission of ammonia. When burning biogas in the engines of the CHP nitrogen oxides and formaldehydes are formed.

## 1.6 Plant safety

In spite of the positive name „bio“, biogas is a gas with dangerous properties which have to be absolutely taken into consideration to ensure safe operation of biogas plants.

The methane component makes it, as a rule, a highly flammable gas which mixed with air may form an explosive atmosphere. The explosion range of methane in air is between 4.4 and 17.0 per cent by volume. As biogas is mainly a mixture of methane and carbon dioxide the explosion range of biogas varies depending on its composition. That is why requirements relating to the explosion protection legislation (such as e.g. indication of explosion protection zones in the plant, use of equipment approved for the respective zone, drawing up of an explosion protection document) have to be observed.

This dependence is essential for the consideration

- in which units of a plant an explosive atmosphere is to be expected,
- which effects have potential failures and
- which protection measures are suited.

If biowastes or animal by-products (e.g. protein wastes from slaughter houses, liquid manure, solid manure, rapeseed cake, residues from yeast production or substrates stabilized by sodium hydrogen sulphite) will be used – contrary to regenerative raw materials being used exclusively - it is to be expected that hydrogen sulphide (H<sub>2</sub>S) will be formed. This is of importance notably when feeding substrate (cesspit, mixing tank etc.) and when storing raw material or fermentation residues. By respective chemical reactions (e.g. acid-base reactions) hydrogen sulphide will be formed in dangerous quantities if acid components are added. That is why knowing the type and composition of the raw materials and their pH is important for the operator of biogas plants to assess potential hazards and to fix respective protection measures.

Hydrogen sulphide is a highly flammable, extremely poisonous gas. The lower explosion limit is around 4.3 % by vol., the upper limit is 45.5 % by vol. of H<sub>2</sub>S in air. Yet, the poisonousness of this gas shall be paid special attention. At extremely low concentrations (0.02 ppm and more, accordingly in ml/m<sup>3</sup>) H<sub>2</sub>S produces a typical smell of foul eggs. From approx. 100 ppm upwards the sense of smell is anesthetized, thus higher, dangerous concentrations will be no longer smelled. Concentrations smaller than 100 ppm may result in extremely dangerous symptoms of poisoning when inhaled for several hours. At approx. 500 ppm they occur already

after 30 min., at approx. 5000 ppm a lethal effect will occur already after a few seconds (caused by disturbances of breathing, cramps, unconsciousness). For the sake comparison there should be mentioned here that the maximum concentration at the workplace shall not exceed 5 ppm.

Biogas shall be classified in accordance with the Dangerous Preparations Directive 1999/45/EC depending on its composition (e.g. as highly flammable preparation” or “poisonous preparation (T; R23)” if its content of hydrogen sulphide is between 0.2 % by vol. and 1 % by vol. of H<sub>2</sub>S).

For the sake of completeness there should be noted that as to the further components of biogas carbon dioxide and nitrogen these are gases with a suffocating effect.

Thus, mainly the following hazards & effects result:

- Mortal danger and health hazard by suffocating or poisoning, e.g. by inhaling carbon dioxide or hydrogen sulphide in shafts and tanks. Both gases are heavier than air.
- Depending on its composition biogas can show a behaviour of light gas, heavy gas or of a gas with a neutral density.
- Explosion by explosive (flammable) biogas/air-mixtures
- Development of fire
- Corrosion by aggressive gas components such as ammonia or hydrogen sulphide
- Endangerment of water by liquid components
- Air pollution by gaseous emissions

Detecting and assessing these dangers in the framework of an assessment of dangers (according to the Industrial Labour Act, Ordinance relating to dangerous and biological substances and to industrial safety) and fixing of respective safety measures are an essential cornerstone for a safe operation of such plants. This does not only refer to the normal operation (including starting and shutting down) but also to maintenance and repair measures and the selection of materials with regard to their mechanical, chemical and thermal stability.

Basically attention should be paid to the fact that the quality and operation of the plants will correspond to the state of the art and an emission of dangerous gases will be prevented<sup>8</sup>.

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<sup>8</sup> The commission for plant safety published a leaflet ([http://www.kas-bmu.de/publikationen/kas/KAS\\_12.pdf](http://www.kas-bmu.de/publikationen/kas/KAS_12.pdf)) giving instruction for a safe operation of biogas plants. In addition, accidents are documented and essential laws, ordinances and regulations for biogas plants are listed.

## 2 Biogas production in Germany

The biogas production in Germany was given a first modest impetus already in the 1950-ies with 50 to 70 plants (FRG and GDR) as estimated. As the supply with coal and oil improved increasingly beginning in 1950 and natural oil was dirt cheap, agricultural biogas plants were again shut down.

### 2.1 Development between 1970 and 1999

Only the oil price crisis in the 1970-ies made revive the application of the biogas technology. This period designated as pioneer's phase (1970 – 1990) was marked by searching for alternatives of power industry. Small-structured enterprises in Bavaria and Baden-Württemberg were considered to be the basic unit of farm plant construction, first biogas plants were built predominantly in cattle keeping enterprises with a high share of self-construction. "Expert knowledge" was passed on among the co-operating farmers who were members of the environmental movement, people supported each other. Biogas was produced at a low efficiency on a low technological level. In spite of many setbacks farmers were the protagonists of the development in the case of success lowering the inhibition threshold for people willing to imitate this. Only in the early 1980-ies also research institutions of agriculture and some agricultural faculties devoted themselves to the biogas topic.

Measures which were to counteract the problems of placing excessive liquid manure – water pollution and nitrate pollution of groundwater – proved to be a further mainspring of anaerobic fermentation. Considerations on a suitable use of residues and, at the same time, the limitation of the problem have found expression in the liquid manure ordinances of the *Laender* (states) issued from the mid-1980 onwards. Fermentation was to contribute to improving the fertilization properties of liquid manure with the energetic aspects, first of all, not playing a part.

The Electricity Feed Act of 1991, first of all, providing for a remuneration of 14 pfennings/kWh formed the start of a remuneration system for electricity production from biogas. However, an increase in plant construction worth mentioning was to be stated only after the amendment of the Electricity Feed Act in 1994 (insignificant increase to 15 pfennigs/kWh) entered into effect in combination with the „100 million programme“ of the Federal Ministry of Economics providing for investment grants for plants using regenerative energies. In the period between 1995 and 1999 biogas plants have been supported by about DM 14 million which further improved the economic basic conditions. To reach a repayment within foreseeable periods the investment costs, however, had to be kept low which limited the equipment of the fermenters. In 1998 approx. 400 biogas plants had been installed, furthermore preferably as farm biogas plants in animal production enterprises. The size of the plants based on liquid manure was oriented to the availability of substrate depending on the farm and totalled, on average, 50 to 60 kW<sub>el</sub>.

## 2.2 Development from 2000 till the present

### 2.2.1 Intensified progress between 2000 and 2004

Several political initiatives accelerated the extension of plants at the beginning of the new century, also the average output power doubled from 60 kW<sub>el</sub> at the end of 1999 to roughly 120 kW<sub>el</sub> in 2004. This was, first of all, passing of the Renewable Energy Act (EEG) in 2000 which replaced the Electricity Feed Act and bringing about a clear increase of the remuneration rate to 20 pfennigs (cents 10.23)/kWh (plants up to 500 kW) by decoupling remuneration from the average profit (consumer price). Parallel to the Renewable Energy Act the Market Incentive Programme of the Federal Government provided a promotion up to 30 % of the investment costs. The Biomass Ordinance passed in June 2001 ensured that the Renewable Energy Act did not serve waste management targets but served primarily power industry and climate policy targets. Biowastes should be only permitted for energetic purposes as far as they contribute to implementing the conversion of biomass into electricity at lower costs. In the framework of the European legislation the Renewable Energy Act was secured by the EU Directive 2001/77/EC for the promotion of regenerative energies passed in September 2001. There finally a Europe-wide uniform promotion system was renounced which the Commission advocated under the pressure of energy supply companies. This would have defeated the Renewable Energy Act which was prevented by the EU Parliament by a majority advocating a remuneration system and the European Court of Justice. The Advocate-General of the European Court of Justice announced late in 2000 that the Electricity Feed Act, the forerunner of the Renewable Energy Act, was no inadmissible support which forced the Commission to give up its position.

The Directive 2001/77/EC resulted Europe-wide only in an intensified extension of wind power whereas water power stagnated and biomass increased only insignificantly. For this reason the European Commission presented a Biomass Action Plan in 2005 requesting the member states to make intensified efforts for increasing the energetic use of biomass. Respective concepts were made up in national action plans, the German Action Plan<sup>9</sup> was published in April 2009.

In 2009 Directive 2001/77/EC was replaced by Directive 2009/28/EC prescribing that in 2020 altogether at least 20 % of the gross final energy consumption shall be provided by regenerative energies. Individual targets were adopted for the member states, for Germany a share of 18 % was fixed.

Owing to the extended promotion by the Renewable Energy Act an economically stable foundation had been created for the operation of biogas plants. The prime costs of electricity were between 8 and 13 cent/kWh. A wide variation was to be detected as regards the operating costs notably where regenerative raw materials had been used. The payout time for biogas plants was about four to twelve years. In 2004, 2010 biogas plants were in operation.

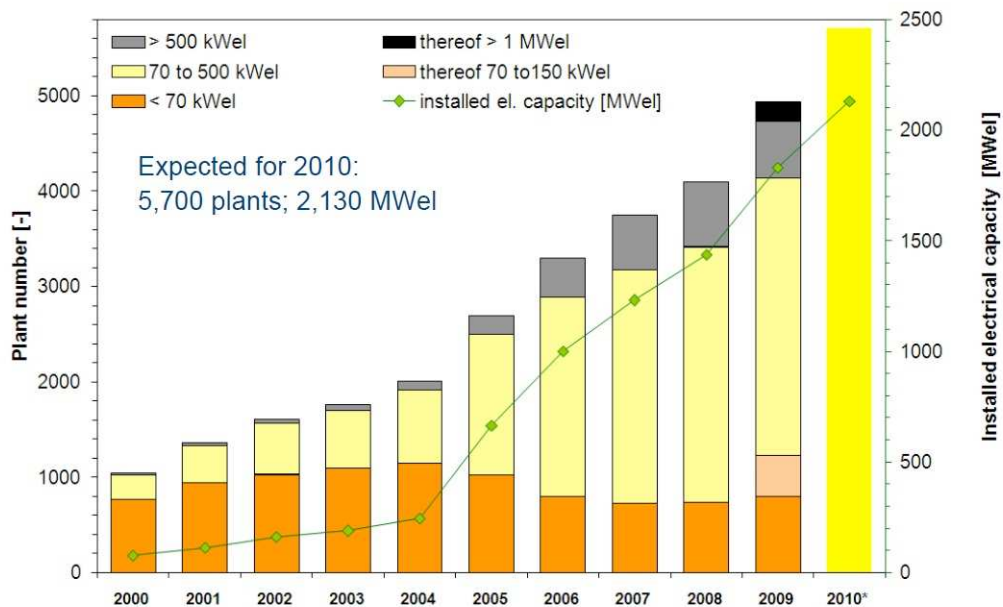
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<sup>9</sup> Biomasseaktionsplan für Deutschland (2009): Beitrag der Biomasse für eine nachhaltige Energieversorgung ([http://www.bmu.de/erneuerbare\\_energien/downloads/doc/45556.php](http://www.bmu.de/erneuerbare_energien/downloads/doc/45556.php); 5. Januar 2011). (Biomass Action Plan for Germany (2009): Contribution of biomass to reach a sustainable energy supply).



In the phase of beginning market relevance companies (e.g. Schmack Biogas GmbH, PlanET Biogastechnik und MT-Energie GmbH) established in the 1990-ies extended distinctly. Further companies, among them ÖKOBit GmbH and Hese Biogas GmbH, entered the biogas market.

**Figure 2-1: Biogas plants in Germany – number and electrical capacity**



### 2.2.2 Boom phase, development downturn und present state

In the framework of amending the Renewable Energy Act in 2004 the remuneration rates were diversified on the basis of the plant size with the aim to promote, in particular, more small plants up to a capacity of 150 kW<sub>el</sub>. In addition remuneration was supplemented by a bonus system with the regenerative raw material bonus having notably sustainable effects. New plants were designed exclusively for using regenerative raw materials, existing biogas plants changed over to using them. Due to this the use of industrial and agricultural residues (notably liquid manure) in agricultural biogas plants was reduced. Approx. 60 % of all biogas plants benefitted from the regenerative raw material bonus in 2006, already more than 83%<sup>10</sup> in 2007.

Also the CHP bonus had the intended guiding effect, the use of heat increased further. 43 % of the operators said that they used a heat and power combination since the Renewable Energy Act had been amended in 2004.

<sup>10</sup> Scholwin, F.; Thrän, D. (2008): Monitoring zur Wirkung des novellierten Erneuerbare-Energien-Gesetzes (EEG) auf die Entwicklung der Stromerzeugung aus Biomasse. Endbericht. Institut für Energetik und Umwelt Leipzig [Hrsg.]. Leipzig. (Monitoring of the effects which the amended Renewable Energy Act had on the development of electricity generation from biomass. Final Report. Institute of Energetics and Environment Leipzig (ed.)).

**Table 1: Remuneration for electricity obtained from biogas according to the Renewable Energy Act of 2004 [Cent/kWh]**

Share of capacity	Basic remuneration	Regenerative raw material bonus	CHP bonus	Technology bonus
up to and including 150 kW	11.5	6	2	2
up to and including 500 kW	9.9	6	2	2
up to and including 5 MW	8.9	4	2	2
up to and including 20 MW	8.4	0	2	0

The European Law Adaptation Act for the construction sector<sup>11</sup> amended in 2004 simplified the building permit for biogas plants up to 500 kW, supporting in addition the construction of further plants. Privileges for small external biogas plants were increasingly granted according to § 35 of the Federal Building Code, thus the material used should no longer come predominantly but only by still 50% from the own production or from neighbouring enterprises of the same type. The amendment was aimed at supporting the structural change in agriculture as well as improving landscape protection.

After the Renewable Energy Act had been amended a real explosion of the market occurred. It was possible to nearly quadruple the installed capacity between 2004 and 2006 (Figure 2-1), the additional construction of plants a year increased from 30 to 60 MW<sub>el</sub> to 420 MW<sub>el</sub>. In particular, the adoption of the regenerative raw material bonus was responsible for that.

Owing to the fast growth and the demand for substrate connected with it the environmental strain aggravated. In 2008 the area under cultivation for maize in Germany reached a new maximum with more than 2 million hectares resulting essentially from the additional construction of biogas plants on a regenerative raw material basis. Nature conservation associations such as NABU summarized the undesired side-effects as „loss of biodiversity caused by monostructural oversteering and additional loading of the environmental media soil and water as a result of the intensive cultivation of the land, fertilization and, if required, use of pesticides”. To reduce these negative effects the cultivation systems for energy plants should be rather included in concepts of ecological agriculture and forestry<sup>12</sup>,

<sup>11</sup> Gesetz zur Anpassung des Baugesetzbuchs an EU-Richtlinien (Europarechtsanpassungsgesetz Bau-EAG-Bau (European Law Adaptation Act for the construction sector) of 24/06/2004, Federal Law Gazette, part I, no. 31. p. 1359

<sup>12</sup> NABU (o. J.): *Naturverträgliche energetische Nutzung von Biomasse. (Ecologically compatible energetic use of biomass)*

however, at least in concepts of integrated cultivation. From the viewpoint of nature conservation the new identification of biotope composite areas and protected areas worsened owing to the intensified pressure to use them as a result of the extension of biomass cultivation. Also the Expert Council on Environmental Issues reminded of the fact that promoting regenerative energies, i.e. also producing and using biomass, has to correspond to the principles of sustainability and ecological compatibility<sup>13</sup>.

The biogas sector regarded itself exposed to a first crisis in the years 2007/2008 which was due to the prices for agricultural products having distinctly gone up. Since late in 2006 the price of maize and wheat increased by more than twice. Notably operators of plants dependent on buying additional substrates who had no long-term fixed price supply contracts with farmers due to the increase in prices were near inefficiency. This fact slowed down considerably the further construction of plants. If in 2007 only about 450 plants with approx. 300 MW went on stream with about 300 plants the number had still gone clearly down in 2008. For the reasons already mentioned notably biogas plants based on regenerative raw materials were concerned. Mid-2008 the prices of maize declined again distinctly, reaching again the level of 2006 late in 2008. Apart from that, with the amendment of the Renewable Energy Act, an amended Directive relating to the Access to the Gas Distribution System and a Renewable Energies Heat Act, the legislator gave important impulses. In the second half of 2008 an increase in the demand for plant constructors and planners has been already emerging.

The remuneration for feeding in electricity from biogas fixed in the Renewable Energy Act of 2009 was increased by 1 Cent for small plants (<150 kW) as well as for plants up to 500 kW, equally the regenerative raw material bonus the exclusiveness principle of which has been effective so far was a bit loosened up. Since that time the bonus can be made use of also when using, at the same time, residues from industry such as e.g. brewer's grains or rapeseed cake and glycerine from the biodiesel production. To counteract the reduced use of liquid manure as fermentation substrate a liquid manure bonus was additionally adopted. A landscape conservation material bonus of 2 Cent/kWh was added which was to bring about an economic betterment of using plants/plant material obtained in the framework of landscape conservation. The bonus means an acknowledgement for environment and nature conservation associations.

In the framework of the integrated Energy and Climate Protection Programme of the Federal Government the Gas Network Access Ordinance included already in the Energy Economy Act amended in 2005 was supplemented by ambitious targets for biogas to be fed into the gas network. In addition, a preferable access of biogas to the network was laid down. The Gas Network Fees Ordinance amended at the same time envisaged that the network operator shall pay the transport clients, in this case the biogas supplier, a fee as a lump sum to the amount of 0.7 Cent/kWh for avoided network costs. As producing, treating and feeding of the biogas obtained will be

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<sup>13</sup> SRU (2007): Sondergutachten „Klimaschutz durch Biomasse“ (Expert Council on Environmental Issues (2007): Special expert opinion „Climate protection by biomass“) [http://www.umweltrat.de/cln\\_135/SharedDocs/Downloads/DE/02\\_Sondergutachten/2007\\_SG\\_Biomas\\_Bi\\_Buch.html](http://www.umweltrat.de/cln_135/SharedDocs/Downloads/DE/02_Sondergutachten/2007_SG_Biomas_Bi_Buch.html); 9.12.2010)

economical only from a certain minimum size of the plant (> 1.000 m<sup>3</sup>/h raw gas) onwards these regulations are of benefit primarily for operators of large biogas plants. This gives, in a way, opposite impulses to the Energy Economy Act of 2009 which is directed rather to the demand of the agricultural clientele with its small and medium-sized plants. Owing to the increased demand for investments notably bigger enterprises (energy supply companies, plant producers, municipal departments of works) are very active as operators of biogas feeding-plants. At present (December 2010) already 44 plants are in operation, 29 plants are under construction and 32 further plants are planned. The reason for this strong growth is the ambitious feeding target included in § 41a of the Gas Network Access Ordinance aiming at reaching 6 billion m<sup>3</sup> of biogas up to 2020 and 10 billion m<sup>3</sup> of biogas up to 2030. In addition, the technology bonus of the Renewable Energy Act makes the construction of plants feeding in bio-methane interesting.

**Table 2: Fees for electricity from biogas acc. to § 27 and Annex 2 of the Renewable Energy Act of 2009 [Cent/kWh]**

Share of capacity	Basic fee	Regenerative raw material bonus	Landscape conservation material bonus	Liquid manure bonus	CHP bonus	Technology bonus
Up to and including 150 kW	11.67 (12.67)	6	2	2	3	3
Up to and including 500 kW	9.18 (10.18)	6	2	2	3	3
Up to and including 5 MW	8.9	4	-	-	3	3
Up to and including 20 MW	8.4	-	-	-	3	-

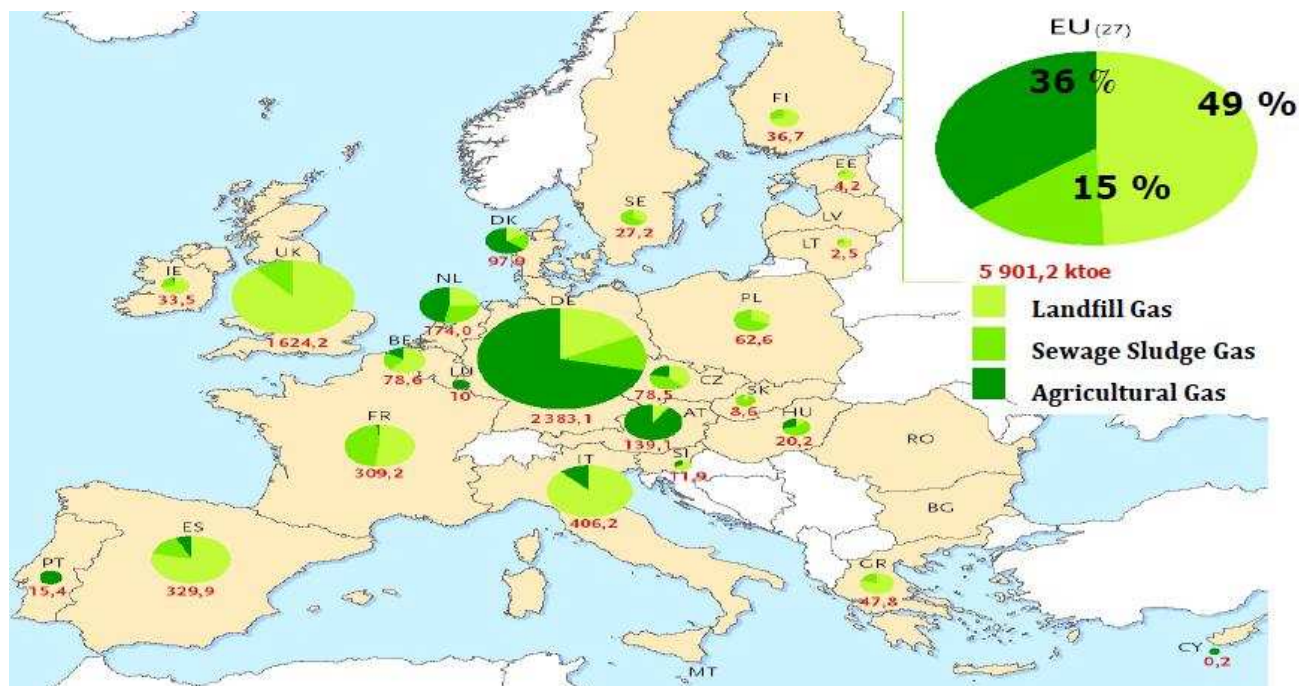
Values in brackets: If the formaldehyde limits of the Technical Instructions on Air Quality Control have been observed (as a rule, plants with a capacity of more the 350 MW<sub>el</sub>)

In spite of the intensified construction of plants declining in 2007/2008 it may be realized that the biogas sector in Germany has been given an impressive impetus, in particular, since the Renewable Energy Act was first amended in 2004 (Figure 2-1). For the time being, approx. 5.700 biogas plants with an installed capacity of 2.130 MW<sub>el</sub> are in operation. A prediction from 2008<sup>14</sup> proceeded from 5.900 plants with a

<sup>14</sup> ecoprog & fraunhofer UMSICHT (2008): Der Markt für Biogasanlagen in Deutschland. (The market for biogas plants in Germany) [http://ecoprog.com/studie\\_biogas.php](http://ecoprog.com/studie_biogas.php); Abruf 21.08.2009)

capacity of 2.140 MW<sub>el</sub> up to 2012. This shows that the predictions lag behind the actual development – a phenomenon which is to be observed also in other fields of renewable energies.

**Figure 2-2: Primary energy production of biogas in Europe in ktoe (2007)**



Source: EurObserv'ER

A comparison with other European states illustrates that the development in the biogas sector is far advanced in Germany (Fig. 2-2). 40 % of the total biogas produced in the EU is to be registered in Germany. The share of biogas from the agricultural domain is even essentially higher as most of the EU member states obtain biogas nearly exclusively from landfills and sewage sludge. Biogas quantities from agriculture worth mentioning are only produced in Austria, the Netherlands and Denmark. In the Czech Republic the number of plants has developed very positively in the last few years thanks to a feeding remuneration of 16/Cent/kWh and the investment grant of 30 %. It totals, at present, approx. 230 plants with an installed electrical capacity of 112 MW.

In the whole Baltic Sea Region, except for Germany and Denmark, biogas has so far virtually not been playing a part. Owing to the high importance the agricultural sector has now as before, e.g. in Poland, and to the biomass potential so far not used the Baltic Sea Region is an essential market for biogas equipment suppliers which, however, has first still to be opened up. Owing to the targets set by the European Commission to increase the share of renewable energies in energy generation (Directive 2009/28/EC), the extension of the biogas sector will be speeded up. In Latvia the attractiveness to erect biogas plants was essentially improved by introducing a legal feeding remuneration. Granting 13 to 23 Cent/kWh, remuneration nearly reaches the German level.

Poland the electricity generation of which is based on hard and brown coal plans to install 2000 biogas plants up to 2020. To this end, comprehensive programmes are

drafted by the Ministry of Agriculture and Economics. The direct grants for regenerative energy projects which may reach up to 70 % of the investment sum provided in the framework of the EU structural fund are a great stimulus to invest in biogas plants.

## Survey of suppliers of biogas equipment in Germany

The present survey is to illustrate the market of biogas equipment in Germany giving for potential clients a short description of the companies in note form and their contact data. It does not claim to be complete<sup>15</sup>. Producers of individual components are only mentioned as examples.

### 2.3 Suppliers of turnkey plants

The producers mentioned hereinafter plan and install turnkey plants.

#### **BEKON Energy Technologies GmbH & Co. KG**

FeringastraÙe 9  
D-85774 Unterföhring  
Tel: (+49) 089/ 90 77 959-0  
Fax:(+49) 089/ 90 77 959-29  
kontakt@bekon.eu  
<http://bekon.eu>

- Dry fermentation plants for biowastes and regenerative raw materials with a capacity between 330 and 1000 kW<sub>el</sub>
- The capacity of existing plants may be extended by a due to modular concept (garage method)
- Reference plants in Germany, Italy and Switzerland partly with self-financing

#### **BioConstruct GmbH**

Büro Niedersachsen  
Wellingstr. 66  
D-49328 Melle  
Tel: 05226 / 5932 - 0  
Fax: 05226 / 5932 – 11  
Büro Sachsen-Anhalt  
IndustriestraÙe 8a  
D-39291 Schoppsdorf

<http://www.bioconstruct.de>

- Plants (wet fermentation) predominantly up to 500 kW<sub>el</sub>
- Reference plants in Italy and the Czech Republic
- Experiences made with plants for grass silage fermentation
- Web presence available also in English and Polish
- Approx. 80 staff members

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<sup>15</sup> Weitere Herstellerfirmen sind z.B. unter <http://www.multitalent-biogas.de/> zu finden. (Further producers are to be found in <http://www.multitalent-biogas.de>)

## **BiogasNord GmbH**

Werningshof 2-4  
 D-33719 Bielefeld  
 Tel: +49 (0)521 9633 0  
 Fax: +49 (0)521 9633 500  
 info@biogas-nord.de  
<http://www.biogas-nord.com/>

- Plants of 60 kW<sub>el</sub> up to the megawatt range according to the storage-flow procedure
- Projects predominantly in Germany and the Netherlands, two plants installed in Belarus
- Homepage available a. o. in English and Polish
- 180 staff members, market capitalization for € 67 million

## **FARMATIC Anlagenbau GmbH**

Kolberger Straße 13  
 24589 Nortorf (Schleswig-Holstein)  
 Tel: +49 (0) 4392/9177-0  
 Fax: +49 (0) 4392/5864  
 info@farmatic.com  
<http://www.farmatic.com/>

- Regenerative raw material, co-fermentation and sewage sludge plants in Germany, Denmark and worldwide
- Installation of sewage plants; tank construction (drinking water, silos, tower silos for silage)
- Offers additionally individual components, in particular fermenter roofs, stirring units and heat exchangers

## **Eggersmann Anlagenbau**

Carl-Zeiss-Str. 8  
 D-32549 Bad Oeynhausen  
 Tel: +49 (0)5734 6690-0  
 Fax: +49 (0)5734 6690-140  
 anlagenbau@f-e.de  
[www.f-e.de](http://www.f-e.de)

- Product KOMPOFERM<sup>®</sup> plus: thermophilic dry fermentation procedure with percolate store with automatic filling (optional)
- Product KOMPOFERM<sup>®</sup> Hybrid: parallel dry and wet fermentation with aftertreatment of fermentation residues (retting tunnel)
- Both procedures were developed for biowastes



### **EnviTec Biogas GmbH**

Boschstraße 2  
 D-48369 Saerbeck  
 Tel: +49 (0) 25 74 / 88 88 - 0  
 Fax: +49 (0) 25 74 / 88 88 - 800  
 info@envitec-biogas.de  
 http://www.biogas.de

- Plants of a capacity from 70 kW<sub>el</sub> up to 4 MW<sub>el</sub>
- Market leader in Germany (according to own data), representations worldwide, among them in Poland and Latvia
- Altogether 411 staff members
- Offers additionally reduction of formaldehyde and treatment of biomethane in cooperation with Greenlane
- Polish subsidiary company EnviTec Polska
- Certified according to DIN EN ISO 9001

### **MT-Energie GmbH**

Ludwig-Elsbett-Straße 1  
 D-27404 Zeven (Niedersachsen)  
 Tel.: +49 (0) 42 81 / 98 45 0  
 Fax.: +49 (0) 42 81 / 98 45 100  
 info@mt-energie.com  
 http://www.mt-energie.com

- Plants with 110 kW<sub>el</sub> up to 1MW<sub>el</sub> with two-stage, continuous wet fermentation (3 tanks)
- Own input component development
- 350 staff members, annual sales: € 80 million
- Europawide engagement, websites available in Polish and Latvian

### **ÖKOBiT GmbH**

Jean-Monnet-Straße 12  
 D-54343 Föhren  
 Tel: +49 (0) 65 02 /93859-0  
 Fax: +49 (0) 65 02 /93859-29  
 info@oekobit.com  
 http://www.oekobit-biogas.de

- Planning and construction of plants with a two-stage, continuous wet fermentation
- Plant monitoring, maintenance, process-biological service
- Substance flow management
- equity contribution to plant installation
- Biogas treatment by means of pressurized water scrubbing

- 70 staff members
- Website in English and Polish

### **PlanET Biogastechnik GmbH**

Niederlassung Essen  
 Girardet Straße 2-38  
 D-45131 Essen  
 Tel.: + 49 (0) 2 01 / 24 49 83 - 0  
 Fax: + 49 (0) 2 01 / 24 49 83 – 10  
 info@planet-biogas.com  
 www.planet-biogas.com

- Farm biogas, regenerative raw material and co-fermentation plants (storage-flow plants) with a capacity between few kW and several MW
- Biogas treatment will be implemented with cooperation partners
- Worldwide active company, approx. 200 staff members

### **SBBiogas GmbH**

Mainleite 35  
 D-97340 Marktbreit  
 Tel.: +49 (0) 9332 - 50 55 0  
 Fax: +49 (0) 9332 - 50 55 55  
 info@sbbiogas.de  
 http://www.sbbiogas.de

- Combination of thermophilic fermentation and mesophilic maturing with a gas output increased by 20 – 30 %
- Tank-in-tank construction
- Use of the bioheat potential for neighbouring buildings
- Removal of sediments during operation (patented procedure)
- Maintenance of all components (including stirring units) during operation
- Young subsidiary company of SBB Beutler & Lang GmbH & Co.KG (tank construction)

### **Schmack Biogas GmbH**

Bayernwerk 8  
 D-92421 Schwandorf  
 Tel.: +49 (0) 94 31/ 751 – 0  
 Fax: +49 (0) 94 31/ 751 - 204  
 info@schmack-biogas.com  
 http://www.schmack-biogas.com/

- Company of the Viessmann group
- Construction of a 5 MW<sub>el</sub> plant in Kallmünz for E.on Bayern AG und REWAG

- Treatment of biogas by pressure-change adsorption (Schmack CARBOTECH GmbH)

### **WELtec-BioPower GmbH**

Zum Langenberg 2  
 D-49377 Vechta  
 Tel.: +49 (0)4441 / 99 97 8-0  
 Fax: +49 (0)4441 / 99 97 8-8  
 info@weltec-biopower.de  
 http://www.weltec-biopower.de

- Liquid fermentation plants with a capacity of <150 kW up to large-scale plants in the MW range
- Includes suitable CHP solution when designing the plant
- Biogas treatment by means of amine scrubbing, pressure-change adsorption or pressurized water scrubbing (in cooperation)
- Erection of the biogas park Koennern (Saxony-Anhalt) with 1.800 Nm<sup>3</sup>/h of biomethane
- Certified according to DIN EN ISO 9001 and 14001

## **2.4 Suppliers of components**

### **Block heat and power plants (CHP) and engines**

#### **HAASE Energietechnik AG**

Hans Josam (Biogas plants/regenerative raw material/cofermentation plants)  
 Gadelander Straße 172  
 D-24539 Neumünster (Schleswig-Holstein)  
 Tel.: +49 (0) 4321 878-218  
 Fax: +49 (0) 4321 878-29  
 hans.josam@haase.de  
 http://www.haase-energietechnik.de

- CHP (500 kW<sub>el</sub> up to several MW<sub>el</sub>) for biogas, landfill and sewage gas plants
- Suppliers of biomethane plants including treatment of biogas („Biogas promoters“: physical-organic biogas scrubbing)
- Works management reports on the biological service and technical and commercial management of biogas plants
- Certified according to DIN EN ISO 9001 and 14001
- Website available in English

#### **Dreyer & Bosse Kraftwerke**

Streßelfeld 1  
 D-29475 Gorleben  
 Tel.: +49 (0) 5882 - 9872-0  
 Fax: +49 (0) 5882 - 9872-20  
 info@dreyer-bosse.de

<http://www.dreyer-bosse.de>

- Block heat and power plants with pilot injection (70 up to 265 kW<sub>el</sub>) or gas spark ignition engines (80 to 1030 kW<sub>el</sub>)
- Production of biomethane by means of amine scrubbing
- Website also available in English

### **enertec Kraftwerke GmbH**

Trefffurter Weg 11  
 D-99974 Mühlhausen  
 Tel.: +49 (0) 36 01 / 40 68 5 -0  
 Fax: +49 (0) 36 01 / 40 68 5 -21  
[info@enertec-kraftwerke.de](mailto:info@enertec-kraftwerke.de)  
<http://www.enertec-kraftwerke.de>

- CHP with a capacity of 15 to 500 kW<sub>el</sub>
- Apart from biogas also plants for liquid, light carburetted hydrogen, sewage and landfill gas
- 20 staff members

### **Schnell Zündstrahlmotoren AG & Co. KG**

Hugo-Schrott-Straße 6  
 D-88279 Amtzell  
 Tel.: 07520 - 966 10  
 Fax: 07520 - 53 88  
[info@schnellmotor.de](mailto:info@schnellmotor.de)  
[www.schnellmotor.de](http://www.schnellmotor.de)

- Pilot injection engine CHP with a capacity of 40 to 350 kW<sub>el</sub>, efficiency up to 47%
- In addition to biogas also suited for waste vegetable oil
- 180 staff members

### **Biogas treatment and feeding**

#### **MT-Biomethan GmbH**

Ludwig-Elsbett-Straße 1  
 D-27404 Zeven  
 Tel.: +49 (0) 4281 / 98 45 0  
 Fax.: +49 (0) 4281 / 98 45 100  
[info@mt-biomethan.com](mailto:info@mt-biomethan.com)  
<http://www.mt-biomethan.com>

- Biogas treatment by means of non-pressurized amine scrubbing

- Feeding and transport equipment (conditioning, compression, drying, volumetric measurement, quality measurement and odouring)

### 3 Literature used

Bruns, E.; Ohlhorst, D; Wenzel, B.; Köppel, J. (2009): Erneuerbare Energien in Deutschland – eine Biographie des Innovationsgeschehens. (Renewable energies in Germany – a biography of innovation.) Universitätsverlag der TU Berlin.

Fachagentur Nachwachsende Rohstoffe e.V. (2009): Biogas – eine Einführung. 6. überarbeitete Auflage (Biogas – an introduction. 6th revised edition), Gülzow, Juli 2009 ([www.bio-energie.de](http://www.bio-energie.de), 15.12.2010).

Kaltschmitt, M.; Hartmann, H.; Hofbauer, H. (2009): Energie aus Biomasse: Grundlagen, Techniken und Verfahren. 2. Auflage. (Energy from biomass: fundamentals, methods and procedures. 2nd edition) Berlin: Springer, 2009 – ISBN 978-3-540-85094-6

Postel, J.; Jung, U.; Fischer, E.; Scholwin, F. (2009): *Stand der Technik beim Bau und Betrieb von Biogasanlagen. Bestandsaufnahme 2008.* (State of the art in building and operating biogas plants. Inventory 2008) Dessau-Roßlau, Umweltbundesamt.

VDI-Richtlinie 3475 Blatt 4 (2010): Biogasanlagen in der Landwirtschaft – Vergärung von Energiepflanzen und Wirtschaftsdünger. Kommission Reinhaltung der Luft im VDI und DIN – Normenausschuss KRdL, Fachbereich Umweltschutztechnik. (VDI guideline 3475 page 4 (2010): Biogas plants in agriculture – fermentation and energy plants and farm fertilizer. Commission on Air Pollution Prevention in VDI and DIN standards committee KRdL, Environment protection equipment department)