

Biogas to Biomethane

BIOGAS Know-how_3



UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

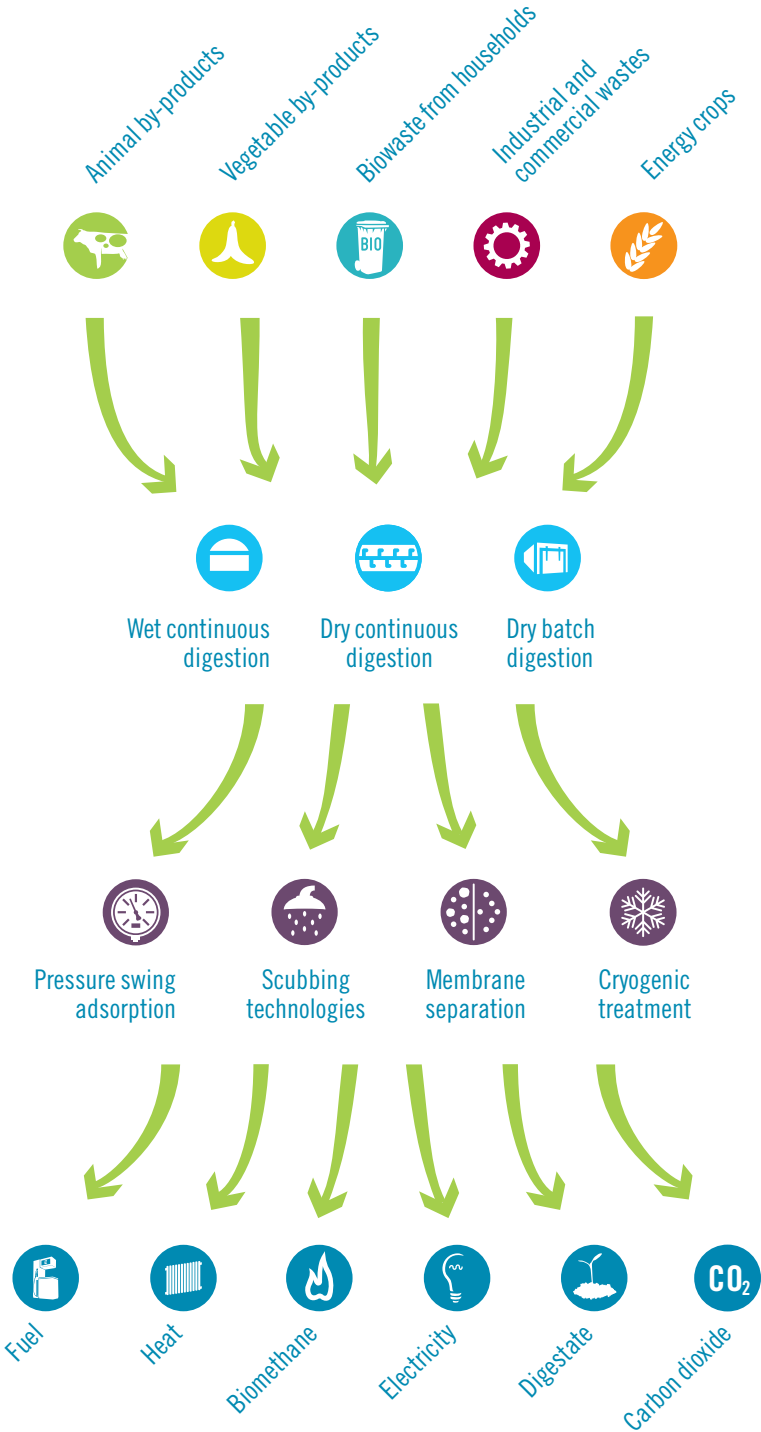


Fachverband
BIOGAS

German Biogas Association
www.biogas.org

BIOGAS TO BIOMETHANE

Flexible energy supply from biomass



The depicted symbols are consistently used throughout the booklet and as a classification system of the different companies in the directory.

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Statements



‘In order to successfully manage global energy demand, we need to move away from the use of fossil fuels for electricity, heat and transport. The flexibility of biomethane with regard to its potential applications makes it an ideal basis for advancing this development in the energy sector. In an international context in particular, biomethane technology, which is already well-developed, has the potential to provide a far more sustainable energy supply.’

– **Horst Seide, President of the German Biogas Association**



‘Biogas is an essential component of the global renewable energy mix allowing us to transit to a low carbon future. Biogas, produced from biomass, has the advantages of requiring low capital costs and being independent of weather patterns making it a very reliable source of energy. It also has a significant greenhouse gas mitigation potential especially when it is upgraded to biomethane, which can be distributed via already available natural gas pipelines or used directly in vehicles replacing fossil fuels.’

– **Philippe Scholtès, Managing Director, Programme Development and Technical Cooperation, United Nations Industrial Development Organization (UNIDO)**



‘Full deployment of biomethane in Europe will increase the security of our gas supplies, provide balanced power and seasonal storage for other renewables, substantially decarbonise the agriculture and transportation sectors, and can make gas supplies infinite and sustainable. It is a unique constellation of synergies. A true political commitment at the national and European levels is necessary to make this happen.’

– **Dr Jan Štambaský, President of the European Biogas Association**



‘DVGW actively supports the development of biomethane. The objectives of the energy turnaround can only be achieved in an economically justifiable way if biomethane is used as an immediately available option to lower the carbon-freight of the energy sector. In a future energy system that is increasingly fed by wind, solar and biomass, renewable gases like biogas and trendsetting technologies like power-to-gas are essential. They allow for the storage of energy and its distribution, via available gas infrastructures, to private and industrial customers as well as to distributed power units and fuel stations.’

– **Prof Dr Gerald Linke, CEO of the German Gas and Water Association (DVGW)**

Preamble

This brochure outlines important technical and legal aspects of the production and use of biomethane. Biomethane is produced by the enrichment of the methane content of biogas, sewage gas and landfill gas. Around 460 biomethane plants are currently in operation in Europe and the growth rate continues to be strong.

The information presented here was prepared by the German Biogas Association (Fachverband Biogas) in cooperation with the United Nations Industrial Development Organization (UNIDO), the European Biogas Association (EBA) and the German Technical and Scientific Association for Gas and Water (DVGW), in order to serve the growing international interest in biomethane plants and utilisation concepts. The profiles of these organisations are presented at the end of the brochure.

The brochure is basically divided into two main sections: the first section of the brochure presents the basics of biomethane production and application. It begins with a detailed description of the biogas process using various raw materials, and the possible energetic applications. Following this, the process of converting biogas to biomethane is examined. Firstly, the possible pre-treatment steps (e.g. drying, desulphurisation and the removal of other components) are explained. Secondly, the various techniques for methane enrichment (membrane separation, scrubbing technologies, pressure swing adsorption or cryogenic treatment) are discussed. In addition, there is a brief chapter covering safety issues relating to the operation of a biomethane plant.

This technical examination of biomethane production is followed by an examination of the possible applications of biomethane in the natural gas grid, in high-pressure cylinders and in the transport sector. Consideration is also given to the technical and legal conditions to be fulfilled within European and German contexts. The first section of the brochure then concludes with an overview of the various partnership and financing options for biomethane projects in developing and emerging economies.

The second section of the publication presents a number of international reference plants. This overview of the technologies on offer is supplemented by a directory of companies experienced in biomethane plant construction, project development, and component and process auxiliary production.

The publication of this brochure is intended to contribute to the safe and efficient production and use of biomethane. The contents of the brochure share experience gained in the production and use of biomethane, so that suitable partners with appropriate expertise can be identified for future biomethane projects.



1 Introduction

Biogas is acknowledged worldwide as one of the foremost technologies for producing valuable fertilizer and renewable energy from all kinds of digestible biomass. After undergoing a cleaning and upgrading process, biogas can be used in the form of biomethane as a renewable substitute for natural gas.

In Europe, the biomethane market is developing rapidly, with double-digit growth every year: the number of European biomethane plants has gone from 187 to 459 in just five years, with the market expected to continue growing in the years to come. Germany represents the largest share of this growth, with an increase from 87 to 185 plants within the same timeframe. Although there are still many European countries that do not have any upgrading units, 15 countries use upgrading techniques to produce biomethane (AT, CH, DE, DK, ES, FI, FR, HU, IC, IT, LU, NL, NO, SE, UK). Between 43% and 55% of all European biomethane plants are located in Germany – the exact percentage varies from year to year.

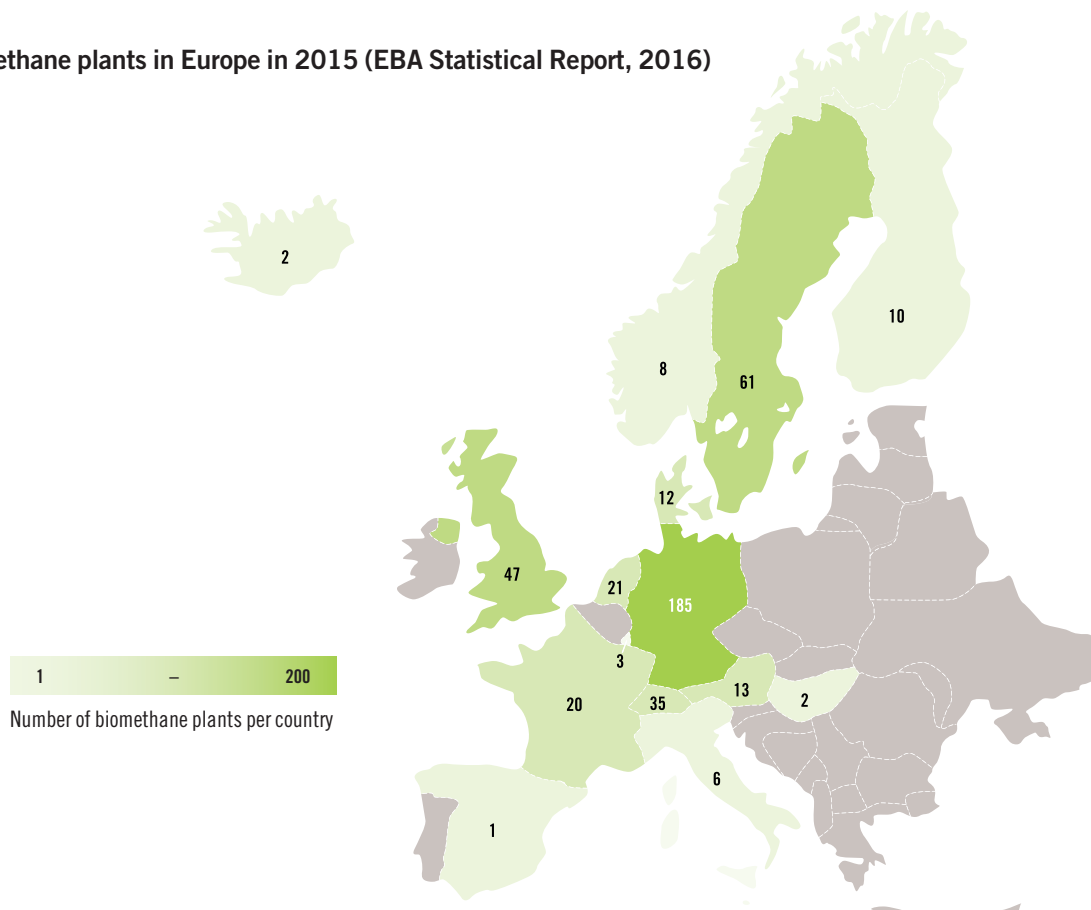
The possibilities for using biomethane are many and varied. The ability to inject processed biogas into the existing natural

gas infrastructure means that gas formed from biomass can be stored temporarily and drawn on as required. This practice allows the highest efficiency levels to be achieved, both in the production of electricity via simultaneous combined heat and power generation, and in direct heat utilisation. In this way, biomethane contributes significantly to the stabilisation of the energy supply and balances out fluctuations in renewable energy derived from wind and solar. Certificates that document the sustainable production of biomethane can be traded. In addition to stationary applications, biomethane can also be used as a vehicle fuel (for passenger transport, heavy duty transport such as trucks and ships, or in industry and agriculture), or as a raw material source for further material applications. Biomethane plants are of particular systemic importance as suppliers of climate neutral energy

production. Additionally, the by-product carbon dioxide (CO₂) can be used as the basis for power-to-gas synthesis or other industrial processes. This unique flexibility means that biomethane can be generated and put to use in centralised and decentralised applications around the world.

Moreover, use of biomethane counteracts the import dependency of natural gas and thus increases supply security. Regional added value is increased and jobs can be created in rural regions. Biomethane links decentralised agricultural structures with stakeholders from the transport, supply security and energy generation sectors. The use of renewable raw materials and especially of residues and waste in the production of biomethane leads to a unique positive carbon footprint.

Biomethane plants in Europe in 2015 (EBA Statistical Report, 2016)



2 Production and use of biogas

The biogas process is a natural process, which takes place, for example, in moors and swamps as well as in the digestive tracts of some animals, such as cows. During the process, organic material is decomposed by microbial organisms in the absence of oxygen and turned predominantly into methane (CH_4), which has a calorific value of 9.97 kWh/m^3 .

Biogas technology uses this natural process to convert organic material into energy. Possible feedstocks are vegetable and animal by-products such as manure, industrial and commercial wastes, biowaste from households, and energy crops. The main product of the decomposition process is CH_4 , which can be used as an energy carrier in a wide range of applications.

The methane content of the biogas generated varies from 50 vol% to 70 vol%, depending on the feedstock. The remaining part of the gas consists largely of CO_2 , of which 30 vol% to 45 vol% is contained in the biogas. In addition, raw biogas contains small amounts of water (H_2O), oxygen (O_2), hydrogen sulphide (H_2S), ammonia (NH_3) and other trace gases.

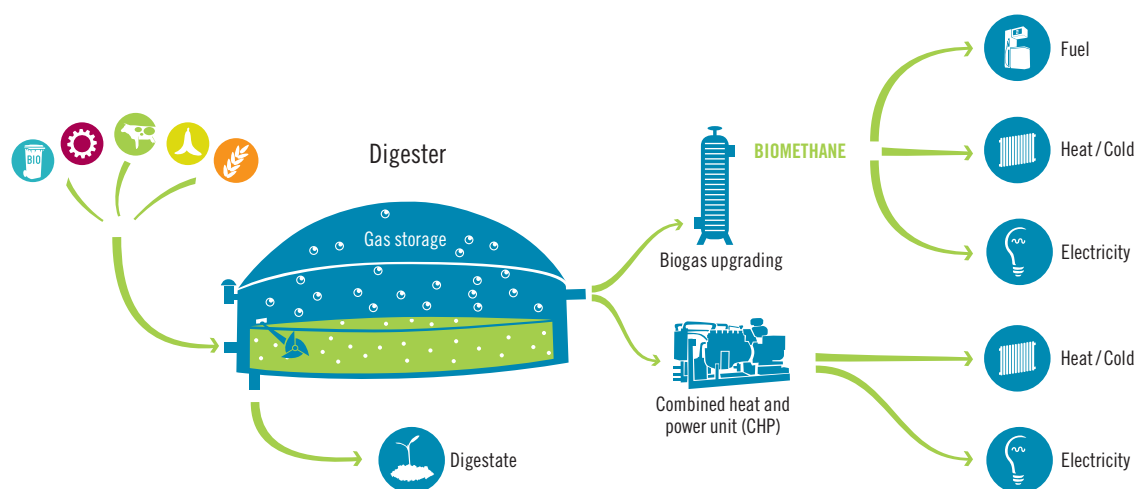
The decomposition of the organic material can be divided into four different phases. During **hydrolysis**, complex long-chain structures such as carbohydrates, proteins or fats are broken down into smaller molecules such as amino acids, sugars and fatty acids. During the

subsequent **acidogenesis**, the intermediate products formed in the first step are further degraded to form lower fatty acids and other carboxylic acids, such as butyric and propionic acid. In addition, hydrogen, carbon dioxide and acetic acid are produced, which are the basic elements for the subsequent production of methane. During the third phase of the decomposition process, referred to as **acetogenesis**, the lower fatty acids are broken down into acetic acid by acetogenic microorganisms. Thus, the starting products are available for **methanogenesis**, the fourth step of the biogas process. During this phase, archaea – the oldest forms of life on earth – convert acetic acid or hydrogen and carbon into methane.

These processes take place in a sealed, airtight system called a digester. This must be adapted precisely to the needs of the microorganisms with regard to pH value, temperature and feedstock composition in order to ensure an effective process.



Process description of production and use of biogas and biomethane



The biogas produced during this process can be used in a variety of ways. Most frequently, it is converted into electricity and heat by a **Combined Heat and Power unit (CHP)**. However, before the gas can be used in CHP engines, it must be conditioned. Raw biogas is water-saturated and contains varying levels of H_2S , which can lead to corrosion and damage the engine, catalysts or other metal, concrete or wooden surfaces. After treatment, the biogas can be combusted in the CHP, causing the engine to drive a generator. The heat generated can be made accessible to external users by heat exchangers. However, about 10–30% of the heat generated is required to heat the digesters and provide the bacteria with optimum living conditions. The remaining proportion of heat can be used in a variety of applications. In most cases the gas engine operates all year round. Therefore, heat is available throughout the year, which is particularly appealing to consumers who have a continuous demand for heat. These include, for example, industrial plants, public facilities, hospitals, swimming pools and greenhouses. Alternatively, the thermal energy can also be used for cooling, which is an attractive alternative for countries with a warmer climate.

In addition to the direct production of electricity and heat, biogas can also be processed into **biomethane** by separating the methane from the carbon dioxide. This increases the CH_4 content of the gas to approximately 98 vol%. Biomethane has similar chemical properties to natural gas and it is often fed directly into the natural gas grid, where it is stored and distributed. Subsequently, the gas can be retrieved from the natural gas grid at another location. It can then be converted into electricity and heat in a CHP or employed directly for heating or cooking. In addition, natural gas-powered vehicles can be refuelled using biomethane since the relevant fuel pumps are supplied via the natural gas grid at petrol stations. Alternatively, designated service stations may be supplied directly from the biomethane plant in order to fuel vehicle fleets. In addition, biomethane can be filled into high-pressure cylinders for transport and storage purposes. Biomethane is therefore one of the most flexible renewable energy sources available in the effort to reduce greenhouse gas emissions.

3 Pre-treatment

Pre-treatment and cleaning is necessary for the further processing and subsequent use of biomethane. If biomethane is to be injected into the gas grid, it must be compatible with the properties of natural gas. If it is to be used as vehicle fuel it must comply with the requirements for fuel quality.

The presence of potential impurities in raw biogas depends essentially on the feedstock used and on the technology applied in the production process. In compliance with the national legal quality requirements for biomethane (fuel, feed into the natural gas grid), pre-treatment procedures must be applied.

Gaseous impurities in biogas for pre-treatment can be:

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

Depending on the particular contents of the biogas, and the national grid and fuel requirements in question, other trace gases may also have to be removed.

Hydrogen sulphide is produced in greater quantities when using feedstocks containing high amounts of sulphur. As well as being toxic to humans, H_2S has corrosive properties. During combustion, H_2S oxidises to form sulphur dioxide (SO_2), which accumulates on sensitive components (e.g. catalysts) and acts as an environmental pollutant. Therefore, the release of sul-

phur dioxide into the atmosphere must be kept to a minimum. In Germany, a hydrogen sulphide content of max. 5 mg/m^3 is permitted in biomethane or natural gas. Consequently, biogas must be subjected to a desulphurisation process before further processing, feed-in and use. A variety of desulphurisation procedures can be followed:

- ▶ Biological desulphurisation: air injection to provide oxygen for bacteria converting H_2S to elementary sulphur provides an economic and simple procedure for the desulphurisation of biogas. This is not generally used at biomethane plants, however, because air contains about 80 vol% nitrogen, which is not wanted in biomethane;
- ▶ Adding doses of iron hydroxide and/or iron salts into the digester;
- ▶ Catalytic oxidation and adsorption with filtering materials (e.g. activated carbon);
- ▶ Caustic treatment with biological regeneration of the washing agent.

When selecting a desulphurisation process, the decisive parameters are the required hydrogen sulphide content in the gas and the subsequent processing methods for CO_2 separation.



Elementary sulphur accumulates e.g. at the roof of the digester



External insulated desulphurisation-unit (activated carbon) and cooling unit for dewatering

Water can also compromise the process considerably during the conversion of biogas to electricity or biomethane because the biogas is saturated with steam inside the digester. In order to avoid corrosion and other negative effects during subsequent gas treatment, it is necessary to dry the biogas. National regulations stipulate requirements either for the permissible water volume in mg/m^3 (DVGW G 260 in Germany: 200 or 50 mg/m^3 depending on grid pressure), or the dew point at a certain pressure (EN 16723-1 in the EU). Various methods are available for drying biogas:

- ▶ Condensation drying: the biogas is cooled in gas coolers (refrigeration units) or underground pipes so that the water vapour condenses;
- ▶ Adsorption dryer: silica gel, aluminium oxides or molecular sieves;
- ▶ Drying by increasing the pressure. Using this method, the water is not removed but the relative humidity reduced.

The origin of **silicon-organic compounds** (e.g. siloxanes) in biogas has not yet been fully clarified. Possible sources might be the feedstock, residues from cosmetics, detergents or anti-foam agents containing silicones, which are used in the digester. Silicon or siloxanes occur mainly in sewage treatment plants. Some grease sludge can also lead to the formation of siloxanes. During combustion, siloxanes are oxidised to form silicon dioxide (SiO_2). This sand can lead to deposits on burners and to serious engine damage. In the EU, the aim is a threshold of 0.5 ppm (parts per million) (EN 16723-1). However, there is as yet no acceptable method available for the online measurement of siloxanes.

Oxygen can also compromise the biogas process. Although the generation of biogas in the digester takes place in the absence of oxygen, there are a number of ways in which oxygen can enter the system. Some air is brought into the digester with the feedstock, for example. The admixture of air for biological coarse desulphurisation and for the regeneration of activated carbon during fine desulphurisation also introduces oxygen into the system. This generates approximately 0.5 vol% of O_2 content in the biogas. These proportions are too small to have an adverse effect on the natural gas distribution grid and can be tolerated. However, in the natural gas transmission grid, oxygen levels of this magnitude can lead to problems, especially when operating underground storage systems. Within Europe, a limit of 10 ppm has therefore been set for such cases (EN 16723-1).





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

Biomethane must additionally be free from impurities such as **dust, oil and aerosols**. Filters used in gas technology are installed for this purpose. In the past, the natural gas industry expressed concerns that biomethane could introduce microorganisms into the gas grid, which could lead to problems in the grid infrastructure or cause health hazards. However, several studies have shown that pathogenic germs are not present in treated biomethane. If **microorganisms** still exist in the flow of biogas after treatment, these organisms are the same as those found in natural gas pipelines anyway. It is worth mentioning that biomethane has been injected into the German grid since 2006. None of the afore-mentioned concerns of prejudicial effects on the gas grid have been borne out.

4 Biogas upgrading technologies

The main process involved in the upgrading of biogas to biomethane quality is the separation of CH_4 and CO_2 . There are several upgrading technologies available on the market that have been used and improved for many years.

Conventional biogas upgrading methods can be categorised as follows:

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

The aim of all upgrading technologies is to achieve high methane purity and low methane losses with low energy consumption.

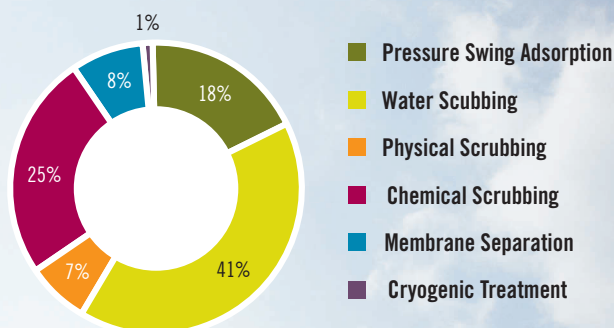
Water scrubbing accounts for the greatest proportion of upgrading systems, at 41%, and is used at 123 facilities in Europe. Chemical scrubbing is used at 77 facilities and constitutes a 25% share, followed by pressure swing adsorption with an 18% share (used at 53 facilities), membrane separation (8%) and physical scrubbing (7%). Cryogenic separation is only used in a

few plants in Europe. Total biomethane production in Europe was 1.23 billion m^3 in 2015. The total raw gas upgrading capacity in Germany rose to 201,265 m^3 per hour by the end of 2016, which corresponds to around 910 million m^3 of upgraded biomethane.

Each of the methods mentioned has its advantages and disadvantages. The best choice of treatment technology should always be based on local conditions.

The fact that CH_4 has a global warming potential about 25 times higher than CO_2 must always be taken into consideration, however. Since climate protection is the major motivation for biomethane production, and biomethane is generally dependent on state or social support, emissions of methane into the environment must be kept to the lowest possible levels. In Germany, for example, methane emissions, also known as “methane loss”, must be below 0.2 vol% of the biomethane upgrading process. If the methane content of exhaust gas from the upgrading process is above the limit, CH_4 must be converted to CO_2 , which has lower global warming potential. To ensure compliance with these regulations, the exhaust gas can be recirculated through the upgrading system or lean gas burners used, as in regenerative thermal oxidation (RTO).

Distribution of biogas upgrading technologies in Europe (EBA Statistical Report, 2016)



4.1 Membrane separation

Membrane separation methods are based on the principle that gases diffuse through the membranes at different speeds. A variety of polymers can be used as membranes.

A good membrane is highly permeable to smaller molecules such as CO_2 , and impermeable to larger molecules such as CH_4 . The aim is to achieve the highest possible permeability with high selectivity. For membranes typically used, the permeability of CO_2 is about twenty times higher than CH_4 .

Membranes are usually formed into hollow-fibre polymers, which are combined in a tube bundle to provide maximum surface area. When raw biogas is blown into the tube, gas components such as CO_2 , O_2 , H_2O and H_2S that diffuse well through the fibre wall are discharged outside the hollow fibre. CH_4 and N_2 remain inside. The membranes are very thin (about 0.1–0.2 micrometres) and are thus unstable. The tube shell protects the membranes, prevents bending and thus provides the optimum shape.

Membrane separation methods are available in very different designs. Typical operating pressures are 7 to 20 bar. In order to achieve high methane purities, the tube bundles are often connected in two-stage or three-stage cascades. A two-stage cascade means that the biogas is separated in an initial column. The exhaust gas is blown off. Subsequently, the methane-rich product gas – which still contains CO_2 – is passed into a second column in which CO_2 is further diffused. This results in higher CH_4 concentrations in the product gas. CH_4 also diffuses through the membrane, causing methane losses into the exhaust gas which should be converted to CO_2 .

The process of membrane separation has been substantially improved over the past 10 years. Initial problems, such as high pressure loss with an excessive power requirement, high methane loss or limited membrane service life, have largely been resolved. In order to protect the membranes, fine desulphurisation and drying are carried out before the gas enters the hollow fibre.

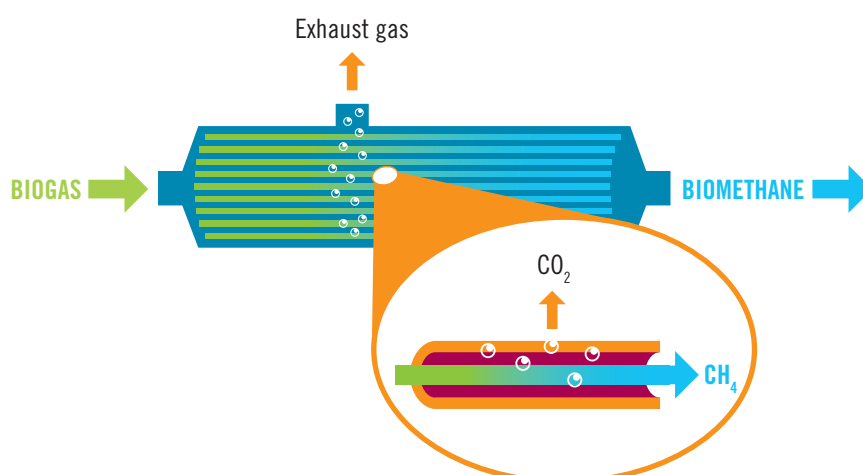
Advantages of membrane separation methods:

- ▶ Few moving parts, extremely robust design. System availability dependent (almost) solely on the compression blower;
- ▶ Modular design available;
- ▶ Can also be adapted for smaller volume flows.

Disadvantages of membrane separation methods:

- ▶ Power requirement between 0.18 and 0.33 kWh_{el} per m^3 of biogas;
- ▶ Methane loss between 0.5 and 2 vol%;
- ▶ A lean gas burner is advisable and in some countries required;
- ▶ Only limited practical experience available for new developments.

Physical and technical principle of membrane separation



4.2 Scrubbing technologies

Scrubbing, also referred to as absorption, is based on the effect whereby gas components are soluble in different fluids to varying degrees. For example, CO₂ dissolves much better in water than CH₄.

The most important influential variables in scrubbing processes result from the properties of the solvents used and the solubility of the gas components. In general, the solubility of the gas improves with increasing pressure or decreasing temperature.

In this section, the design principles involved in the scrubbing process are explained in general terms using pressurised water scrubbing as an example. The subsequent sections outline the properties of other solvents.

Physical scrubbing methods are based on the physical solubility of gas components in a wash solution without chemical reaction.

Water is used as a solvent in the pressurised **water scrubbing** method. Since much more CO₂ is dissolved in the water when the system is pressurised, water scrubbing usually takes place at a pressure of 4 to 10 bar.

A tall scrubbing column is used, in which water is sprayed from above, similar to a shower. The biogas is directed upwards from the bottom of the scrubbing column. As it rises, the gas is brought into contact with the falling liquid. In order to ensure a greater transitional surface area, filling bodies are added to the columns, in which the water runs down. In addition, multiple intermediate floors are installed, in which the water is collected and sprayed again into the lower gas space below. The purified biomethane, with small constituents of O₂ and N₂, is suctioned off at the top of the scrubbing column. Depending on the design of the column the methane purity is 90 to 99 vol%.

The water is collected at the bottom of the column, charged with CO₂ and small amounts of other gas components (e.g. H₂S or NH₃). In order to regenerate the liquid, it is first pumped into a vessel referred to as a flash column, where the pressure is partially released. In this process, some dissolved gas components are released. Since CH₄ is discharged along with CO₂ in this column, the flash gas is fed back to the beginning

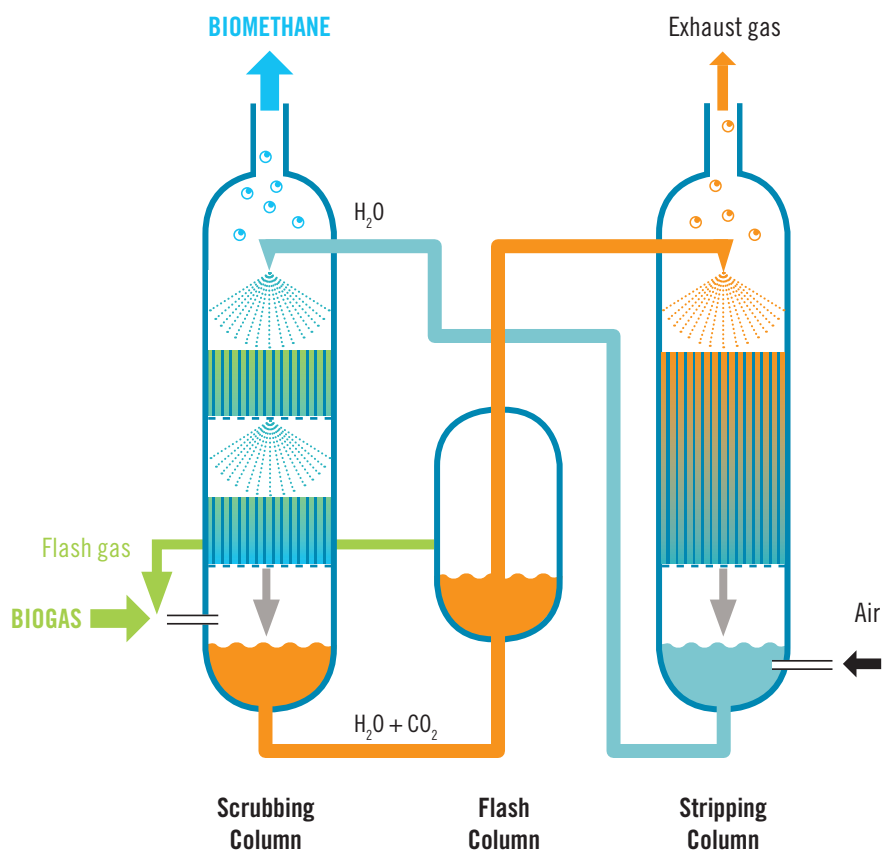
of the process, which decreases methane losses. Subsequently, the pressure in the stripping column is released to ambient pressure and air is blown in. The principal removal of the carbon dioxide takes place at this point – it is usually blown off into the environment as exhaust gas. The regenerated water is now pumped back to the first process step inside the scrubber.

During compression, the temperature of the biogas increases. According to thermodynamic principles, at higher temperatures less gas is dissolved in liquids. The compressed biogas is therefore cooled. The temperature inside the scrubber is about 15–20°C. This cooling makes it possible to recover surplus heat from the scrubbing process, which can then be made available for external use such as digester heating.

A proportion of less soluble gas components (e.g. CH₄) will, however, always dissolve in the washing liquid, just as some of the readily soluble gas components will not dissolve. The separation can never be absolute. In terms of emission regulation, it is therefore important to keep the methane loss as low as possible. Biomethane plants based on simple technology may have methane losses reaching several percent. Therefore, all pressurised water scrubbers must be equipped for post-combustion of the exhaust gas.

Since hydrogen sulphide also dissolves very well in water, the product gas contains very little H₂S. For this reason, the treatment also functions as a desulphurisation technique, which simplifies the pre-treatment of the sulphur. In practice, however, an ad-

Technical scheme of scrubbing technologies



ditional fine desulphurisation process is generally used for biogas pre-treatment. One reason is that the H_2S remains in the exhaust gas stream and the amount of emissions should or must be reduced. Moreover, H_2S is converted into SO_x in the RTO. The removal of the latter is technically more complex than the removal of H_2S .

Advantages of pressurised water scrubbing:

- ▶ The process has proven itself in numerous plants over many years;
- ▶ Water is a harmless, low-cost solvent that is easy to handle;
- ▶ Technically, it is a relatively simple method;
- ▶ An external heat source is not needed and surplus heat can be used.

Disadvantages of pressurised water scrubbing:

- ▶ Power requirement between 0.2 and 0.3 kWh_{el} per m^3 of biogas;
- ▶ Pressure between 4 – 10 bar;
- ▶ Methane loss between 0.5 and 2 vol%;
- ▶ Water is less selective than other solvents;
- ▶ A lean gas burner is advisable and in some countries required.

In **physical scrubbing**, it is also possible to use **organic solvents** instead of water to upgrade the biogas. Polyethylene glycol dimethyl ether, which is marketed commercially under the names Genosorb or Seloxol, is one example. The process and the technical design are very similar to pressurised water scrubbing. The advantage of these solvents is the higher solubility of CO_2 and H_2S compared to water. The result is that less detergent is required and the height of the scrubber column can be reduced. Technically speaking, a pressure of 4 to 8 bar is sufficient inside the scrubber column. As a result, the energy required for compression is reduced compared to pressurised water scrubbing. Since CO_2 and H_2S are more strongly held in solution, the regeneration of the washing liquid is more complex. In addition to pressure release and air stripping, the solvent must be heated to between 40 and 80°C. In order to do this, heat must be provided. In most cases, heat from the lean gas burner is sufficient. The heat requirement is 0.1 to 0.15 kWh per m^3 of biogas. Simultaneous desulphurisation is possible with this method. In reality, however, fine desulphurisation is usually carried out before the scrubber.

Advantages of physical scrubbing with organic solvents:

- ▶ Higher solubility and higher loading of scrubbing liquid;
- ▶ Less surface required, therefore only a small installation size is necessary;

- ▶ Product gas is dried by the hydrophobic scrubbing solution.

Disadvantages of physical scrubbing with organic solvents:

- ▶ Power requirement between 0.23 and 0.33 kWh_{el} per m^3 of biogas;
- ▶ Heat is required to regenerate the scrubbing liquid;
- ▶ Solvent must not be released into the environment;
- ▶ Methane loss between 1 and 4 vol%;
- ▶ A lean gas burner is advisable and in some countries required.

In **chemical scrubbing**, some gases (e.g. CO_2 and H_2S) react reversibly with the washing liquid. The binding agent/solution is therefore substantially stronger than in the case of physical scrubbing. Mixtures of water with the additives monoethanolamine (MEA), diethanolamine (DEA), methyldiethanolamine (MDEA) and other amine compounds are usually used as detergent. The advantages are the higher loading of the solution, higher selectivity of the gas separations, and thus a higher purity of the product gas. A lean gas treatment is therefore not necessary, but fine desulphurisation must be carried out upstream. The scrubbing columns can be operated at almost ambient pressure. However, the higher binding strength adversely affects the regeneration process for amine solution. It requires to be heated to approximately 110–160°C for regeneration purposes, and must then be cooled to 40°C in order to be able to absorb gases again, before being returned to the scrubbing column. A portion of the heat can be recovered by heat exchangers and used externally, for example to heat the digester.

Advantages of chemical scrubbing:

- ▶ Low power requirement of 0.06–0.17 kWh_{el} per m^3 of biogas due to operation at ambient pressure;
- ▶ Strong binding forces, therefore high loading of the scrubbing liquid;
- ▶ High selectivity, therefore high methane purity (over 99 vol%);
- ▶ Low methane loss (about 0.1 vol%).

Disadvantages of chemical scrubbers:

- ▶ Energy intensive regeneration with a high heat requirement of 0.4 to 0.8 kWh_{th} per m^3 biogas;
- ▶ Solvent must not be released into the environment.

4.3 Pressure swing adsorption (PSA)

Adsorptive methods are based on the principle that different gas components are attracted differently to specific surfaces (adsorbed) or penetrate to varying degrees into the pores of the material.

In principle, adsorption is higher at higher pressures and lower temperatures. Adsorptive biogas upgrading processes mainly use pressure differences to carry out the separation. Pressure swing adsorption is a proven method of separation and has been used for decades. It was previously used in the gas industry, and has been adapted to meet the requirements of biogas processing.

The essential component for separating the gases is a column filled with activated carbon, zeolitic molecular sieves or carbon molecular sieves. These substances stand out for offering a large surface area and a certain pore size.

The gas separation is carried out in the following steps:

1. The pre-purified biogas is compressed to 2–7 bar. The compression increases the temperature of the gas. To improve the adsorption, it is cooled down to about 70°C and channelled into the adsorption column. CO₂ molecules, which are smaller than methane molecules, accumulate to a much greater degree on the surfaces or in the pores than CH₄, while the latter remains primarily in the gas phase.
2. A valve at the column head is opened, and the biomethane escapes from the column (methane-rich product gas).
3. After closing the valve, the pressure inside the column is released. The CO₂ desorbs from the surfaces, returns into the gas phase and can be blown off (CO₂-rich exhaust gas).
4. The column can be filled with biogas again.

Since the pressure swing adsorption is a batch process, several columns (typically 4 to 8) are operated and work in a slightly time-delayed manner to equalise the gas production.

Fine-cleaning must be carried out to remove H₂S before the biogas is pumped into the adsorption column. The methane losses are heavily dependent on the design of the system. The CH₄ in the exhaust gas must be burnt because of its greenhouse gas potential. Some system concepts are designed for low methane loss with an RTO connected. Other methods allow a higher methane loss of up to 10 vol% in order to burn the exhaust gas in a gas burner and utilise the heat, for example to heat the digester.

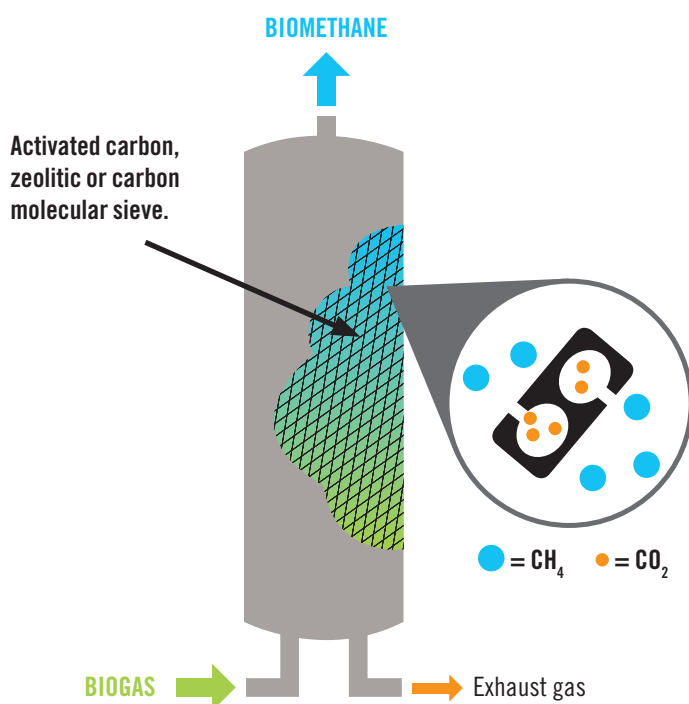
Advantages of pressure swing adsorption:

- ▶ Many reference plants and many years of operating experience;
- ▶ No solvents are used;
- ▶ Heat is not required for the regeneration.

Disadvantages of pressure swing adsorption:

- ▶ Power requirement between 0.15 and 0.35 kWh_{el} per m³ of biogas;
- ▶ Methane loss between 1.5 and 2.5 vol%;
- ▶ The high speed loading, pressure retention and release of the column require a very finely tuned valve clearance. Mechanical stress to the equipment is therefore relatively high;
- ▶ Lean gas burner required.

Physical and technical principle of pressure swing adsorption (PSA)



❄️ 4.4 Cryogenic treatment

In addition to the well-established and well-proven processing technologies described above, there are more recent developments, the market readiness of which has not yet been fully established. An interesting option is cryogenic treatment.

Its operating principle is briefly described below. Since there are different cryogenic methods and little verifiable actual data, a detailed description of the process and the naming of specific operating parameters (such as power consumption) are omitted here, but the following text explains the few basic principles involved.

Cryogenic treatment is based on the fact that, at low temperatures or high pressures, gases condense (become liquid) or re-sublimate (become solid). The temperatures or pressures at which this occurs can be found in a phase diagram. For example, CO_2 re-sublimates at -78.5°C at 1 bar while CH_4 remains gaseous. The gas components of biogas can be separated in different states of matter.

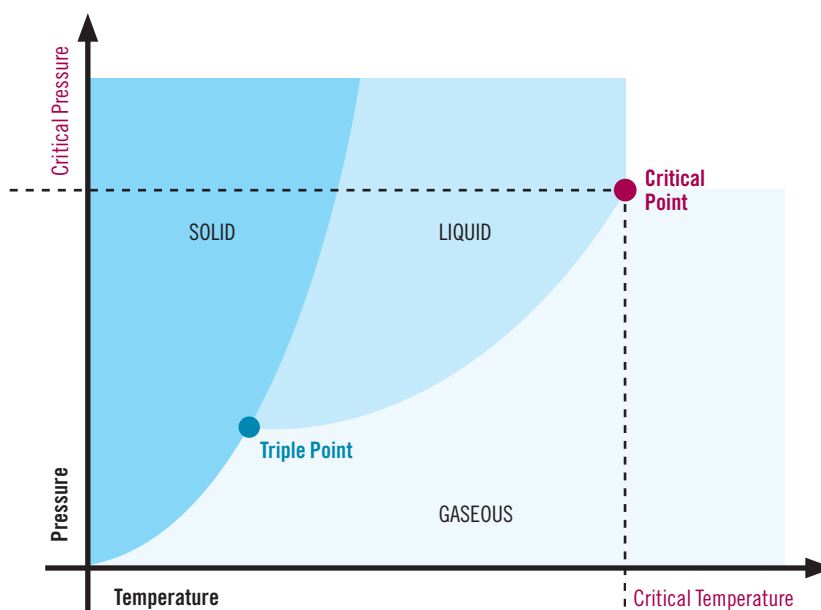
The phase diagram shows that there are many options for the adjustment of temperature and pressure in order to perform the separation. Consequently, there are various procedural approaches for cryogenic separation. Cryogenic separation can also be combined with other processing methods. The critical point marks the thermodynamic end point of the temperature-pressure curve beyond which there is no difference between the liquid and gas phases.

The actual separation takes place by means of rectification (counter-current distillation). Very pure CH_4 (up to 99.9 vol%) can be removed from the top of the column, while the CO_2 with a purity of approximately 98 vol% can be taken from the column sump.

The advantages of cryogenic treatment are the high separation accuracy of the gas components, high methane purity with low losses, and the fact that CO_2 – which can be gained in the form of dry ice – can be recycled and marketed (see Chapter 8). Cryogenic treatment is also advantageous if the biomethane is to be liquefied, since the biomethane must be very cold for this purpose.

A disadvantage of cryogenic treatment is the energy required for refrigeration. The temperature of the gas is reduced to -78.5°C or -150°C using a combination of external cooling (e.g. in electrically driven Stirling engines) and natural cooling (by depressurisation). The power consumption for this process is extremely high. A further challenge is to ensure that frozen CO_2 does not clog the equipment in the gas refrigeration process. The biogas must be fine-cleaned very accurately if it is to be upgraded via cryogenic treatment.

Phase diagram relevant for cryogenic treatment



5 Safety first!

By producing clean energy and valuable fertilizer, biogas and biomethane plants contribute to the mitigation of climate change and the protection of the environment in general. However, if these plants are not operated safely, they can present hazards that negatively affect the environment and human health.

Given that biomethane is a **highly flammable gas**, it carries a number of risks that must be taken into consideration when operating a biomethane plant. In general, the occurrence of a dangerous explosive atmosphere is unusual, but it may arise in situations where biomethane reaches a concentration of between 4.4 vol% and 16.5 vol% of the volume of the ambient atmosphere as a consequence of leakages or unintentional releases. To avoid explosions resulting from these conditions, plant operators must define **explosion protection zones** and implement measures that should be documented in an explosion protection document. Besides the risk of explosions, there are also **health hazards** associated with biomethane plants. These could be categorised as: gas hazards (e.g. intoxication, suffocation), fire hazards, mechanical hazards and electrical hazards, as well as noise pollution and the emission of hazardous substances.

To address these kinds of hazards it is essential to perform a **risk assessment** and take all necessary precautions. For the risk assessment, the plant operator must determine, evaluate and minimise any possible hazards by implementing appropriate technical, organisational and personal protective measures. For example, this involves the choice of plant components, which should be made according to the practical requirements of the plant (gas quality, corrosive constituents of the gas, internal pressure, climate and geographical location). Potential deformation, deflection and linear expansion must be taken into consideration when installing pipework, in accordance with site-specific regulations. Pipes carrying gas must always have corrosion protection, ignition protection, equipotential bonding and specific labelling. If gas pipes are exposed to the risk of mechanical damage (e.g. from vehicles), they must be protected accordingly.

Regarding construction and maintenance work, only approved specialised companies/skilled workers should be permitted to perform welding work on pipes and gas-carrying systems. Detailed parameters concerning welding work and testing of the weld are set out in national regulations (in Germany: DVGW GW 350 and G 472). Welding work on gas-carrying plant parts is not permitted in installation rooms (exceptions may be possible if justified).

In order to ensure that leaks in pipes or parts of indoor gas installations are noticed promptly, specific prescribed **warning odours** are added to natural gas and biomethane. These are usually highly volatile, typical-smelling organic sulphur compounds such as tetrahydrothiophene (THT), which smells like rotten eggs, and mercaptan mixtures.

If condensate is expected to occur, **regular maintenance** of the pipes and condensate discharge systems must be carried out. Pipes above ground level must be checked for leaks on an annual basis. Shorter intervals should be planned for compensators and other specialist components where necessary. Components must be maintained and serviced in accordance with the manufacturer's instructions (method, intervals, etc.). Before any maintenance work is carried out, an individual hazard assessment is required, with appropriate protective measures.

Qualifications held by responsible operators and personnel must meet national requirements. The same applies to the companies involved. Regular training should be obligatory in order to keep technical knowledge up-to-date with the latest findings and technical requirements.

If the appropriate protective measures are taken, hazards in and around biogas plants and biomethane plants can be limited and reduced to a manageable level, so that the plants can operate as intended.

For further information regarding the safety of biogas plants, consult the booklet *BIOGAS know-how_2 "Safety first! Guidelines for the safe use of biogas technology"*, published by the German Biogas Association and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, available at www.biogas-safety.com.



Gas leak detection during the maintenance

6 Biomethane utilisation

Biomethane can be utilised for all applications where natural gas is used. In order to store and/or transport the gas, it can either be fed into the natural gas grid or filled into pressure tanks.

In Germany, as one of the leading markets for biomethane, over 90% of the biomethane produced is used for cogeneration in CHP, 3.5% solely for heat supply, and about 4% in the transport sector. Until now, the use of

biomethane in the chemical industry and for export to other European countries has played a subordinate role with high potential for development.

6.1 Biomethane utilisation – Gas grid injection

Gas grids rank as the second energy grid after the power grid. Whether these grids are developed densely or thinly depends on the specific country in question. Essentially, however, there are three types of gas grids: gas transmission grids, regional grids and distribution grids.

Gas transmission grids are used to transport gas from the source site or the transfer point (terminal) to the regions and/or metropolitan areas, or to transport the gas across borders. They are operated at the highest pressure stages, in the range of 50 to 100 bar, and in some cases even higher. Only a few industrial large-scale consumers, underground storage facilities and gas filling stations are connected directly to gas transmission grids.

- ▶ Natural gas storage tanks can store gas, and thus energy, seasonally. However, the grid itself can also store energy within certain limits, since regional grids can be operated with fluctuating pressure;
- ▶ Gas quality can also be subject to fluctuations because gas from different production and storage facilities can be fed into the grids.

Gas transmission grids represent the upstream stage for **regional grids**, which transport the gas within a region or city. These pipelines are mostly operated in the pressure range of 4 to 40 bar. Industrial users, commercial consumers, and most natural gas refuelling stations are connected to regional grids.

Historically, the gas grid has emerged as a grid that distributes gas from one or very few sources, such as storage facilities or terminals throughout the country. In future, the grid will have to be rebuilt step by step into a 'recovery system', because biomethane is now supplied by many sites and is also consumed throughout the country. The importance of the gas transmission grid will decrease, and the regional grid will need to be expanded. That means that pressure from the distribution grid must be increased at specific locations, in order to inject biomethane into the regional grid at points where local gas consumption is lower than injection capacity, or during periods of reduced demand.

Regional grids are located upstream of **distribution grids**, which constitute the third type of gas grid. These are used to transport the gas to residential properties. These pipelines are predominantly operated in the pressure range of 20 mbar to 1.0 bar. In addition, biomethane grids can optionally be operated completely independently of the natural gas grid, to provide regional transport from the generating biomethane plant to the consumer.

The gas grid is the largest existing energy storage facility in many countries. It can be used in the future for the seasonal storage of volatile electricity production (in particular production from wind and solar) via application of the power-to-gas process. This will make the gas grid a key element in the transition from the existing energy system to one based on renewables.

When compared to the electric power grid, some special features are noteworthy:

- ▶ The gas grid not only transports energy but substances too. Therefore, the fed-in gas must be qualitatively matched to the main gas stream;
- ▶ The gas grid is a "directed" grid in which the gas flows from higher pressure to lower pressure;
- ▶ Since the gas is consumed mainly in the heat market and in colder regions, there are seasonal load fluctuations, which may be between 1:6 and 1:10 in summer and during colder winters;

In many countries, gas grids are still in the hands of the state or a few private grid operators. As there is generally no pipeline competition, the local grid operator acts as a "monopolist" towards the company that feeds in the biomethane. Therefore, it is the task of the legislator to regulate the **essential conditions for access to the grid for biomethane** by determining:

- ▶ Non-discriminatory access to the gas grid for each pressure level;
- ▶ Binding regulations concerning the procedure for grid compatibility assessment (content, costs, time periods and sanctions, if applicable) and the grid connection;
- ▶ Obligation of the grid operator to transfer the produced gas quantities to its grid at any time (priority of biomethane over fossil natural gas);
- ▶ If the grid capacity is insufficient or temporarily insufficient, it would be advisable for the grid operator to be obliged – within a reasonable time period (6–12 months) – to adapt the grid capacity by means of appropriate grid technology (e.g. back-compression into upstream grids, interconnection between different grids of the same pressure stage, etc.);
- ▶ Specifications for the gas trade;
- ▶ Optionally, regulation concerning financial compensation for biomethane would help promote the biomethane sector: the production of renewable gas is usually more expensive than the production of natural gas – which is a result of geological processes – if other costs, for example environmental damage caused by CO₂ emissions from fossil fuels, are not included in the calculation;
- ▶ State authorities should give support by settling conflicts between the supplier and the grid operators as early as possible, ideally during the planning phase.



Construction of biomethane pipelines

biomethane to the calorific value of the main gas flow. However, this increases the costs, and liquefied petroleum gas is of fossil origin. Furthermore, adding LPG is limited to maximum 5 vol% in order to avoid condensation in the grid. The second means of ensuring gas quality is to implement gas quality tracking systems. A mathematical model of the grid or a sub-grid is generated, including all its load flows. Based on this modelling process, it is possible to determine which consumer has received which gas quality and at what time. By including standard load profiles, it is possible to create a calculation with sufficient accuracy. The advantage of this method is that it can be adapted relatively easily to changing conditions; the disadvantage is the high set-up cost.

Since natural gas and biomethane are odourless by nature, this can present a considerable safety risk if leakages occur. The gas must therefore be **odourised** by adding odour substances, which are usually tetrahydrothiophene mercaptans or sulphur-free odourising agents. This typical warning smell is intended to indicate to people when gas installations are leaking or gas escapes unburnt. Leaked gas is always an explosion or poisoning hazard. However, not all grids are odourised. In Germany, the following principle applies: if gas is fed into the main gas flow, it must be odourised if the main gas flow is odourised. If the main gas flow is not odourised, the gas that is fed into the main flow does not have to be odourised either.

The actual requirements of the grid are decisive in determining the required degree of biogas upgrading quality. The essential parameters of gases are explained

When gases are removed from the grid, these are usually measured volumetrically at the end customer (m³ per time unit), while the billing is performed as energy (kWh per time unit). The gas is measured under operating conditions and converted into standard conditions for correct billing. In order to make this conversion possible, knowledge of the gas composition is required. In some countries, a gas chromatograph, which is calibrated based on specifications listed in an indelible document, is required as proof and for the statement of biomethane quality. Other measurement methods that meet the same requirements should also be accepted.

A grid operator must be aware of the **quality of the gas** at any time to ensure that the energy delivered and the costs are calculated correctly. There are two different approaches to ensuring gas quality in Germany. One is by using liquefied petroleum gas (LPG) to condition the biomethane in order to adjust the calorific value of the

below. Technical restrictions are outlined, which are necessary to ensure the safe operation of the gas grid.

When biomethane is fed into the grid, **the gas quality and energy quantity** introduced must be determined exactly and the accuracy of these values must be demonstrated. If the measured data is made available to the grid operator online, they will have the authority over the last tap upstream from the grid, which they can close if there is a limit value violation. In the gas sector in Germany, the actual amount of energy supplied must not deviate by more than 2% from the calculated energy quantity. The energy quantity is calculated in kWh or MJ per unit of time unit.

Temporary fluctuations in the **calorific value and the Wobbe index** are common in the gas grid. National (or regional) technical regulations or laws stipulate to which threshold limits the calorific value and the Wobbe index may fluctuate. Compliance with the limits of the Wobbe index is mandatory, since gas equipment (particularly burners) operating in the gas grid is adapted to the gas quality. Failure to comply could result in safety-relevant malfunctions, especially on the burners – e.g. raising or extinguishing the flame. If, on the other hand, the gas quality in the gas grid (or a grid section) is to be generally and permanently changed, all gas equipment that receives gas from the relevant grid must be adapted to the new conditions.

For this reason, CO₂ must be separated from biogas until compliance with the minimum requirements with regard to calorific value and the Wobbe index is ensured. Note that in the case of biomethane no other hydrocarbons except methane are present, whereas natural gas also contains small amounts of ethane and propane that have a higher calorific value.

The most frequent **physical adaptation to the grid conditions** is pressure adjustment. In order to feed biomethane into the gas grid, the pressure must be higher than the grid pressure. Of course, safety precautions must be taken to ensure that the feed system is not capable of producing a higher pressure than is permissible in the relevant grid. In addition, effective precautions must be taken to ensure that gas cannot flow back into the supply line when the supply is interrupted.

The gas **temperature** at the transfer point to the grid is also often limited. Temperatures in the range of 5 to 35°C are common. If necessary, the gas must be cooled or heated.

Other technical rules governing gas characteristics in Germany are controlled by the DVGW G 260 and G 262 regulations. At the EU level, EN 16726, EN 16723-1 and EN 16723-2 are applicable.

Requirements for gas grid injection in Germany according to DVGW G 260

Characteristics	Unit	Gas value
Wobbe Index	kWh/m ³	13.6 - 15.7
Calorific value	kWh/m ³	8.4 - 13.1
Relative density		0.55 - 0.75
Total sulphur content	mg/m ³	< 8 (short-term up to < 30)
Total hydrogen sulphide content	mg/m ³	< 5
Water content	mg/m ³	< 50 in grids > 10 bar < 200 in grids ≤ 10 bar
Hydrogen content	vol%	< 2 in exceptional case up to < 10
Carbon dioxide content	vol%	in L-gas grids < 10 in H-gas grids < 5
Oxygen content	vol%	< 3 at injection in dry grids < 0.5 at injection in wet grids

DVGW G 265 is used in Germany and is relevant for the technical execution of installations, planning, construction and operation. This technical standard differentiates between:

- ▶ Biogas production plants: production of biogas from organic feedstocks by digestion;
- ▶ Biomethane upgrading plants: removal of H₂S, CO₂, and other trace gases, and drying;
- ▶ Biomethane feed-in plants: calibrated measurement of quality and quantity for billing purposes, pressure increase to grid pressure, if necessary conditioning with liquefied gas and odourising;
- ▶ Recovery systems: pressure increase in order to transport gas from one grid level to the upstream grid levels.

In Germany, it is stipulated that biomethane feed-in plants and recovery systems must be planned, set up and operated by the grid operator so as to ensure compliance with biomethane quality requirements. The grid operator must meet the cost of feed-in and operation, within reason. This ensures that the grid operator does not make excessive demands on biomethane injection to exclude biomethane participants from the market. Furthermore, the grid operator can decide which way they will adapt their grid to comply with the legal requirements, such as gas conditioning or gas quality tracking. Different rules may apply in other countries. In any case, it is beneficial when biogas and biomethane production, and biomethane grid injection stay in the same hands.

6.2 Biomethane utilisation – Biomethane in gas pressure cylinders

Another method of storing and transporting biomethane is compression in pressurised gas cylinders, typically at about 200 – 250 bar. This opens up various application options.

Biomethane is usually produced in large volume flows, often in rural areas. The utilisation of large quantities of energy produced in many locations is not immediately feasible, or a usable gas grid infrastructure is not available. In this case, biomethane can be compressed and filled into **pressurised gas cylinders**, making it easy to transport. In order to achieve the highest possible energy density, the biomethane is typically compressed to 200 – 250 bar. The fuel quality is equivalent to that of natural gas. Compression to a lower pressure is possible but less energy would then be stored or transported. Steel pressure tanks are used to store the biomethane. Increasingly, however, full-composite containers – plastic liners coated with carbon fibres – are used as storage vessels. These are tested to ensure they are burst-proof and are offered in a wide range of sizes. Small pressurised cylinders have a capacity of 2 kg. If trucks are used for transportation, larger cylinders containing several hundred kg of biomethane are used, sometimes fastened together in bundles. One kg of biomethane has an equivalent energy content of approximately 13.3 kWh. The energy required to compress biomethane to 200 bar is about 0.2–0.3 kWh_{el} per m³ when using a highly efficient compressor.

Biomethane in pressurised gas tanks is typically used in the transport sector (see Section 6.3). An example project from Malaysia consists of a lagoon biogas plant in which process waters from palm oil production are utilised for biogas production. The biogas is upgraded to biomethane quality and is transported to the nearby consumer in pressurised containers.



Cooking with biogas prevents deforestation and pollution in developing countries

In many countries, the provision of household fuels, in particular for food preparation, is a major challenge. Billions of people around the world use wood for cooking. This leads to various problems such as deforestation and labour-intensive fuel procurement, as well as lung and eye diseases caused by particle pollution or soot. Biogas has already proved its worth as an alternative to wood in several million household systems. A new development is to supply households with biomethane in compressed gas cylinders. In many regions of the world this is less expensive than fossil fuels (such as LPG or kerosene) and helps to avoid problems that are prevalent when using wood. The challenge is to ensure that gas pressure tanks can be safely operated in their daily use for many years to come.



Transport of biomethane in gas pressure cylinders in India

6.3 Biogas utilisation in the transport sector

Vehicles running on compressed natural gas (CNG) or liquefied natural gas (LNG) play an important role in the development of an environmentally-friendly transport sector. The contribution to GHG emission savings when vehicles use biomethane reaches up to 90 % compared to a conventional petrol-fuelled vehicle.

Biomethane has immense potential in the transport sector due to its burning characteristics, which are similar to natural gas. It is usually compressed to about 200-250 bar to increase the energy density of the gas to make it more efficient for use in transport. Biomethane can be used in all engines running on natural gas. There are many state-of-the-art gas engines on the market for cars, heavy duty vehicles, ships and trains, which can be operated with biomethane. Most vehicle manufacturers offer models that run on CNG. There is also the option of converting a gasoline-powered vehicle to run on gas, which is commonly done in developing countries.

The total **carbon footprint** is very low, when compared to its fossil equivalents. A major advantage for using biomethane as fuel, apart from protecting the environment, is the economic savings – it is cheaper for consumers to use biomethane or CNG than petrol or diesel, depending on the tax regime. However, this aspect still needs to be highlighted at filling stations, where natural gas is currently sold per kilogram while other fuels are sold per litre, making it difficult for the consumer to compare prices.

Transport is a big issue in numerous countries that are struggling to reduce emissions from this sector. Furthermore, many countries depend on the importation of fossil fuels. In this case, locally produced biomethane can offer a solution for the decarbonisation of the

transport sector. To make this sustainable, the use of biomethane must be supported through incentives that take into account external factors like the environmental impact of the fuels. For example, in Sweden, the use of biomethane in transportation is heavily subsidised by taxation advantages, as well as by additional bonuses like free parking or other benefits for vehicles powered by renewables.

In Germany, there are currently about 900 CNG filling stations, with a fleet of around 100,000 gas-powered vehicles including cars, buses and trucks. Most CNG filling stations sell a mixture of natural gas and biomethane, and about 125 of them already sell 100% biomethane from biogas plants. In 2015, there were around 22.7 million natural gas-powered vehicles worldwide. The countries leading this trend are China, Iran, Pakistan, Argentina, India and Brazil.

There are already many **success stories** regarding the use of biomethane in the transport sector. In Berlin, the biogas plant run by the environmental and operational services company (BSR) processes 60,000 tonnes of separately collected biowaste from households per year. The biogas produced is upgraded to biomethane and provides 150 waste collection trucks with biomethane at three gas filling stations, reducing diesel consumption by 2.5 million litres of diesel and CO₂ emissions by 12,000 tonnes of each year. In agriculture, prototypes of tractors operated with CNG are being



Waste truck is collecting feedstock for the production of its biomethane fuel



Public transportation in buses running on CNG

tested and adjusted to respond to the specific demands of this sector. And in 2018, a milestone project is to be commissioned at Lake Constance in southern Germany, where a ferry will run on either CNG or LNG. The fuel for the ferry will be produced via biogas upgrading and liquefaction plants nearby. Industrial and farm residues will be used as feedstock.

In 2015, the **biofuel quota in Germany** was replaced by a flat-rate savings target in order to implement what is referred to as the “decarbonisation strategy” of the EU. From 2015 onwards, there must be an annual cut of 3.5% in the greenhouse gases emitted by fuel consumption, with the required annual saving increasing to 6% by 2020.

The use of biofuels offers a means to achieve this cut. The actual greenhouse gas reduction potential of the biomass fuel in question must be taken into account. Greenhouse gas reduction potential relative to conventional fuels is defined by the **Renewable Energy Directive (RED)**. Since 1 January 2017, the minimum reduction in CO₂ emissions of a biofuel compared to the fossil equivalent is 50%, and as of 1 January 2018, the reduction will be 60%. The admixture of biomethane opens up a new source of revenue to energy suppliers operating natural gas fuelling stations. The biofuel quota obtained can be sold to mineral oil companies that are thereby able to fulfil their obligation to mix biofuels. The biofuel sector advocates an increase in the admixture rates of renewable energies, as this would contribute significantly to the reduction of GHG emissions and the promotion of biomethane in the fuel sector.



CNG operated ferry at Lake Constance

Biomethane used is also subject to other sustainability criteria, which are regulated by the Renewable Energy Directive in Europe, and have been translated into national law via the **Biofuel Sustainability Ordinance** in Germany. According to this directive, the feedstocks must not originate from areas of high biodiversity, protected areas, or high carbon content areas, for example rainforests, moors or permanent grassland. The cultivation of arable land and grassland must also follow what is referred to as “good professional practice”. In Europe, this is based on the requirements specified in cross-compliance. Rules are determined here for fertilizer use, fertilization period, soil processing, etc. First and foremost, the sustainability criteria exist to ensure the preservation of soils and nutrients, to avoid the erosion and pollution of groundwater, and to ensure that biofuels actually help to reduce greenhouse gases.



CNG is available for various applications e.g. for tractors

7 Biomethane applications

7.1 Application requirements – European Framework

Many products on the EU market are subject to harmonised rules that protect consumers, public health and the environment. These rules not only ensure the free circulation of products, removing unwarranted barriers to trade, but also provide a predictable legal framework for business.

The clarity leads in the long run to economies of scale for operators, resulting in lower prices for end-consumers. Creating common standards in the energy sector contributes to the enhancement of energy security and solidarity across the EU countries. The adoption of production standards such as for biomethane ensures the high quality of gaseous fuels transported and exported across the whole of Europe, and makes it possible to source biomethane in any European country.

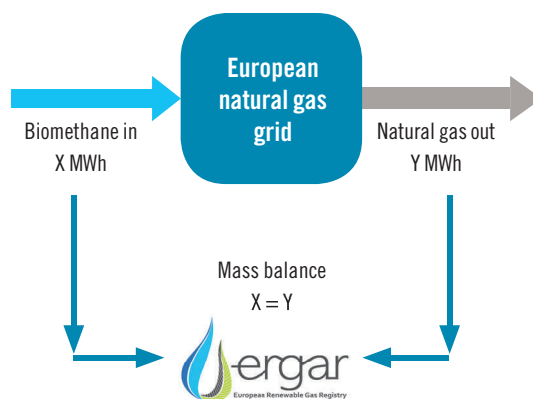
Under European Commission mandate M/475, granted in 2010 to the European Committee for Standardisation, **standardisation in the field of biomethane specifications** is expected to be finalised by 2017. This aims to facilitate the market penetration of biomethane either as a transport fuel or as a blending component with natural gas. The work of Technical Committee (TC) 408 appointed to this effect, is specifically progressing towards quality requirements for allowing biomethane injection in high- and low-pressure gas pipelines. Stakeholders are assessing different parameters, such as the concentration of hydrogen or sulphur along with the minimum calorific value at the injection point and at the fuelling station. Sustainably produced biofuels such as biomethane are essential for a green transition in the transport sector, and support long-term, sustainable strategy for climate change mitigation. Biomethane in particular is a true alternative to fossil fuels for several modes of transport. The work of TC 408 on specifications for biomethane as a vehicle fuel is expected to help overcome current barriers, accelerating the penetration of a green product in the market as a transport fuel.

The transition to a European market can only happen, however, by having in place a mass balancing system for biomethane, based on recognising the natural gas system operating within the EU as a closed logistical facility. In this way, registration of biomethane volumes is only performed at the injection and withdrawal points, resulting in the option of freeing up the trading of biomethane across national borders within Europe. The proposal for revision of the **Renewable Energy Directive (RED)**, the lead policy document for the promotion of renewables, introduces a legal framework to support such a system in the EU, while ensuring common rules on sustainability criteria for bioenergy production. This revision also aims to extend Guarantees of Origins to

renewable gases, to track the production and sustainability characteristics of gas that is transferred across national borders.

The **European Renewable Gas Registry (ERGaR)** will fulfil this task in the form of a recognised voluntary scheme, serving as a bridge between the producer country and the consumer country, thanks to the mutual recognition of the national registries involved.

Application requirements – European Framework



This link will secure the robust tracking of biomethane and potentially other renewable gases injected into the gas grids, along with the cross-border transfer of sustainability claims for all applications – transport, electricity, heating and cooling.

The combination of European standards with incentives and tools framed within the European legislation will prove effective in helping to unlock the potential of biomethane generation and accelerating the deployment of renewable gaseous fuels in the EU market.

7.2 Application requirements – The German Framework as an example

In general, the legal thematic areas regarding the development of biomethane utilisation can be grouped under the following categories: “grid connection questions” and “grid access questions”. Grid connection questions concern the physical feeding of biogas into the natural gas grid. Grid access questions refer to transport in the natural gas grid.

The decisive factor for the success of biogas feed into the German natural gas grid is that a regulated grid connection method has been included in the **Gas Grid Access Ordinance**. It stipulates the review period in which the grid operator has to examine the connection request, and what costs are incurred by the request. It is only if a grid connection is economically unreasonable or technically unfeasible that the grid operator can refuse permission. Furthermore, the quality of the gas to be fed into the grid is clearly regulated, and the grid operator in Germany is responsible for gas conditioning: they must adapt the biomethane to the natural gas quality in the grid with regard to calorific value.

- ▶ the costs involved in the planning, production, maintenance and operation of the grid connection;
- ▶ the costs generated by the increase in the capacity of the grid in order to feed-in biomethane all year round;
- ▶ the cost to the grid operator of conditioning of the biomethane upstream of the feed-in;
- ▶ the cost of odourising and measuring;
- ▶ the cost of the flat rate power usage fee avoided;
- ▶ the costs to the balancing group grid operators for the separate accounting of biomethane.

Furthermore, the Gas Grid Access Ordinance regulates **grid access**. The grid access of biogas transport customers represents the possibility to use the grid and its capacities to transport the gas.

In order to promote the transport and feed-in of biomethane in Germany, the Gas Grid Access Ordinance stipulated that the biomethane transport customer, the company transporting the biomethane within the natural gas grid, is entitled to avoid a power grid fee of 0.7 Eurocents per kWh of biomethane. In principle, power grid fees are avoided, due to the decentralised feed-in services in upstream grids. However, the financial concession granted goes far beyond the power grid fees actually avoided, which means that this strategy is subject to a considerable subsidy. The amount of power grid fees avoided was set for a period of 10 years. After 10 years have elapsed, grid operators have to present plausible calculation procedures for an adaptation of the avoided grid charges.

The costs incurred by grid connection shall be borne by the grid operator and the power grid charges avoided are transferred to the grid charges nationwide. The apportionable costs include:



The gas grid access has to be regulated precisely

The current versions of the Gas Grid Access Ordinance and the Gas Grid Feed Regulation, the conditions for the grid connection of biogas upgrading plants and grid access for biomethane transport customers have improved considerably. The regulations are appropriate and promote the feed-in of biomethane into the natural gas grid.

8 Technological innovations and perspectives

The treatment of raw biogas to produce biomethane offers the potential to develop various innovative techniques that go beyond the production of a primary energy carrier.

Methane and carbon dioxide are products that have a wide range of applications and a high value, especially if the gas is pure. Cryogenic gas treatment in particular is an optimum basis for alternative utilisation of the products generated. This technology employs high pressure and temperature differences along with an excellent rectification method to produce methane as well as carbon dioxide with a high level of purity. This pure CO₂ alone can lead to additional revenue potential for the plant operator. For example, the CO₂ separated in the process can be marketed as **dry ice**. Dry ice is produced from gaseous carbon dioxide at a temperature of -78.5°C. The difference to conventional ice, however, is that dry ice does not melt during heating, but evaporates without residue. This makes it an appealing alternative for a wide range of industrial applications. For example, dry ice is used for cleaning large-scale industrial plants. When the dry ice is injected, residues from fats and oils become brittle and burst. Since the dry ice immediately passes into its gaseous phase, there is no danger of subsequent corrosion of metal parts.

Other upgrading technologies can also lead to additional revenue potentials when carbon dioxide can be

sold or used. The CO₂ content in the air in rural areas is 400 ppm. However, it has been shown in various studies that the range for optimum plant growth is well above this value. In **greenhouses** in particular, the microclimate can be optimally adapted to the plants' requirements increasing the CO₂ content in the air artificially maximises potential yield, and makes economically viable use of the separated CO₂. The additional income that can be achieved through improved growth of the plants is an extra gain for the operator of the system. CO₂ can also be further processed to produce calcium carbonate (CaCO₃), which is required in many areas of application.

As mentioned before, another advantage of biogas upgrading and gas grid injection offers tremendous potential for the flexibility and **optimisation of the system integration** of renewable energies. On the one hand, biomethane fed into the grid can be removed and converted into energy according to demand, wherever the CHP can be employed to greatest effect. This ensures efficient energy use of existing systems, not to mention considerable cost savings in the restructuring of electricity grids. These grids no longer have to be the subject of costly upgrades to high voltage operating levels in order to distribute large amounts of electricity. The existing gas grid can be used as an alternative means of energy distribution and thus offers a corresponding savings potential for infrastructure expansion.

On the other hand, the CO₂ generated during gas treatment can be used as a starting product for the methanation of hydrogen from the electrolysis of wind and photovoltaic electricity (power-to-gas). Subsequently, this can either be fed into the natural gas grid or be utilised as a vehicle fuel.

As an alternative to the path of methanation, biogas/biomethane can also serve as a raw material for the production of **hydrogen**. Afterwards, the hydrogen can be used in fuel cells, for example, so that the stored energy can be converted into electrical power or used as a fuel.



The production of dry ice leads to additional revenue potentials beside the biomethane production

In addition to energy use, hydrogen production also opens up possibilities for system operators in various industries. For example, in the production of ammonia, hydrogen and nitrogen are required in order to provide the agricultural sector with important fertilizers. Likewise, hydrogen can also be blown directly into biogas production to obtain biogas with significantly increased methane content. This is done by blowing hydrogen into the digester, where the hydrogen transforms with carbon to form methane molecules. Promising laboratory tests show that methane levels of > 85 vol% can be obtained.



Hydrogen could be produced by Power-to-Gas technologies

Overall, biomethane technology provides biogas operators with a wide range of opportunities to tap into additional potential revenue. The utilisation of CO₂ in the production of dry ice, the optimisation of living conditions for cultivated plants in greenhouses, and the methanation of hydrogen, are just a few of many applications where operators can benefit from use of this by-product. The production of hydrogen or the use of the power-to-gas synthesis offer entrepreneurs

further opportunities to operate plants as contributors to a power supply system, which is optimally adapted to the integration of renewable energies. This can be an important factor in promoting the sustainable and environmentally-friendly use of energy and resources in sectors other than electricity or heat production.



Carbon dioxide could be used in greenhouses to improve the plant growth



The promotion of biomethane in developing and emerging countries

The use of biogas technology is growing worldwide and biomethane in particular is becoming increasingly attractive for developing and emerging countries. Many of these economies generate large volumes of organic waste that can be utilised energetically, creating opportunities for investment and technology partnerships between local and international companies specialising in biogas and/or biomethane.

At the same time, such undertakings often lack the appropriate political framework, besides facing cultural and geographic challenges, and the need to adapt technology and identify suitable financing. International technical cooperation agencies, such as the United Nations Industrial Development Organization (UNIDO), are working with these countries to help overcome existing barriers so as to catalyse market-based development of industrial-scale biomethane and enhance the multiple environmental, economic and social benefits of this industry.

In countries where electricity prices are low or biomass is located in remote areas without a productive use for the generated heating and cooling, the upgrading

of biogas to biomethane may represent a more viable option than local production of electricity and heating/cooling with a CHP. The biomethane produced could then either be injected into the natural gas grid, as it is most frequently the case in Europe, or it could be directly used in filling stations, or compressed into gas cylinders for easy storage and transportation. The latter two options are particularly attractive for developing and emerging countries with high agricultural and agro-industrial activity, where there is great potential for meeting transportation needs in rural areas.

Vehicles could run on compressed or liquefied biomethane, which, if produced locally, can constitute a more attractive fuel supply than fossil fuels. In some emerg-

ing economies, the size of biogas plants, and thus the potential for biomethane upgrading, is far greater than the average plant size in Europe, meaning that the cost savings are even higher, as it is far more cost-effective to produce biomethane in larger plants. The use of CNG as a transport fuel is quite common already. However, most vehicles so far run on natural gas rather than biomethane. In New Delhi, Bangkok and Islamabad, for example, most taxis, public buses or rickshaws run on CNG. Furthermore, several countries such as Brazil, China, Colombia and India have made recent changes to their policy and regulatory frameworks, enabling the injection of biomethane into the natural gas grid. In view of the prevailing low oil prices, the development of a biomethane sector very much depends on public incentive schemes such as feed-in tariffs, biogas-upgrading bonuses, quota systems, tax reduction, renewable fuel quotas, free parking for renewable vehicles, or CO₂ taxes.

The role of technical cooperation

The use of biogas and especially biomethane entails several advantages from a development perspective, including creating employment, promoting rural development, reducing GHG emissions and producing decentralised, storable, flexible and clean renewable energy. International organisations such as the United Nations Industrial Development Organization (UNIDO), as well as service providers for international cooperation and sustainable development, such as the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, therefore provide technical assistance to support these processes. They help set up policy and regulatory frameworks for biogas and biomethane, develop the necessary technical capacities of local stakeholders, and partner with the private sector to set up demonstration projects. At present, UNIDO is actively engaged in the promotion of biogas and/or biomethane in several countries, including Argentina, Brazil, Chile, Ghana, India, South Africa and Uruguay. Working closely with national counterparts and donors such as the Global Environment Facility (GEF) and/or bilateral ones, as well as local and international finance institutions such as the AFDB, Banco do Brasil, the IADB, the World Bank and the like, UNIDO provides policy and technical advice, carries out related studies, engages in raising awareness and capacity building activities, and cooperates closely with the private sector (technology providers, project developers, operators, investors, beneficiaries, etc.) to remove barriers and encourage the widespread uptake of biogas and biomethane solutions. Similarly, the GIZ is currently executing biogas projects

in Brazil, Chile, Mexico and other Central American countries, Serbia, Uganda, South Africa, Kenya, India and Indonesia.

With regard to financial cooperation, the KfW banking group, and the German Investment and Development Corporation (DEG), offer loans and equity participation to companies in developing and emerging countries. Long-term investment funding for biogas projects usually comes in the form of loans, participations or mezzanine financing models, with volumes of around USD 10 million and more. There are therefore two different types of biogas projects which are most likely to be eligible for this type of funding:

- i. projects that bundle together plants of the same type and with the same feedstock at different sites, and
- ii. large biogas plants with a minimum investment volume of around USD 10 million – often together with larger agricultural or processing firms such as dairy plants or citrus fruit processors.

As plants with biomethane upgrading are usually larger, these projects are more likely to fulfil the investment volume criterion. Funds for feasibility studies or consultations and other accompanying measures can be provided by the DEG as well as funding under the German develoPPP.de programme (GIZ, DEG and sequa), which supports the involvement of the private sector in areas where entrepreneurial opportunities and development policy requirements intersect; more than 40 projects in the biogas sector have already been supported in this way. It should be noted that neither UNIDO nor the GIZ directly finances biogas/biomethane projects.

Inclusive and sustainable development

Biogas and particularly biomethane hold great potential for actively contributing to inclusive and sustainable development. With successful partnerships between sectors, including offers of technical and financial cooperation and the involvement of the local and international private sector, the use of biogas and biomethane can play an important role not only in mitigating climate change but also in enhancing the competitiveness of the sectors involved at the same time as providing energy security and helping to move closer to the idea of a circular economy.

Further information:

www.unido.org
www.giz.de

Reference plants



Fraser Valley Biogas



Water scrubbing unit of the Fraser Valley Biogas Plant



PlanET Biogas Solutions, a subsidiary of the PlanET Biogas Group, constructed the anaerobic digester at Fraser Valley Biogas Ltd., which was the first of its kind in Canada. Heppell's Potato Corporation is the operator for Fraser Valley Biogas, and they have been growing potatoes in the Fraser Valley for almost 100 years. Heppell's was looking for an experienced and reliable biogas plant designer-builder with high standards for quality and security to help them utilize the waste from their operations, as well as off-farm organic waste. Naturally, they chose the leading AD plant builder worldwide with state-of-the-art technology to build the anaerobic digester: PlanET Biogas. PlanET constructed four concrete tanks: three anaerobic digester tanks and one digestate storage vessel.

Manure from 1,000 cows and 1.5 million chickens, crop spoilage and residues, and industrial food waste feed the digester to produce biogas. The biogas is upgraded to Renewable Natural Gas quality using water scrubbing technology to remove hydrogen sulphide and carbon dioxide for injection into Fortis BC's natural gas distribution

Manufacturer:
PlanET Biogas Solutions Inc.

Commissioning: 2012

Types of fermentation:
wet digestion,
separate hydrolysis

Upgrading technology:
water scrubbing

Gas treatment capacity: ~500 m³/h



grid for use in thousands of homes throughout British Columbia. The plant produces on average the equivalent of 50,000 gigajoules of RNG gas per year, reducing GHG emissions by approximately 2,500 tonnes of CO₂ per year. Supporting the production of local, carbon-neutral energy is a key contribution to more climate protection.

Additionally, high-quality fertilizer is produced as a byproduct. The fertilizer is used by neighbouring farms to enhance the crop quality and yield, supporting farmers in their nutrient management plans.



Feedstock

Animal by-products:
others: 60%
manure: 40%

Operator

Fraser Valley Biogas

2016 Interprovincial Highway
V3G 2H7 Abbotsford · Canada
Contact: Brendan Van Biert
Phone: +1 604-702-8905
E-Mail: brendan@fvbg.ca
URL: www.heppells.ca

Required amount of feedstock: 70.000 t/a

Energetic usage: biomethane

Generated products: liquid digestate, solid digestate

Application of the digestate: spreading as fertilizer

EnviThan Minhe I & II



The Minhe biogas upgrading plant in China



In Minhe, Shandong province, commissioning is now just around the corner for EnviTec's first gas upgrading plant in the People's Republic of China. The plant will generate 1,000 Nm³/h of biomethane, with the feed gas being supplied by an existing biogas plant. The customer is Shandong Minhe Biological SCI-Tech Co., Asia's largest poultry farmer.

The proven EnviThan membrane technology is an especially cost-effective and environmentally friendly innovation, as it operates without chemicals, water or the use of other external resources.

EnviThan gas upgrading is simple and robust while also being compact and space-saving. Components for desulphurisation, compression, condensation, filtration and gas purification can be installed in standalone modules. This container-based design means each

Manufacturer:
EnviTec Anlagenbau GmbH & Co KG

Commissioning: 2016

Types of fermentation:
digestion

Upgrading technology:
membrane separation

Gas treatment capacity:
two times 1,500 Nm³/h rawbiogas



facility can be customised to suit the performance requirements of individual owners – anywhere in the world.

The biomethane will be compressed to 20 MPa at a nearby CNG-Bottle station. This mobile stored energy can be transported decentrally to any gas consumer or CNG filling station.

Feedstock

 **Animal by-products:**
Poultry Chicken Manure 100%



Operator

EnviThan Minhe I & II

City Penglai, Province Shandong - China

Contact: Dong Taili

Phone: +86 535 56-66750

Fax: +86 535 56-46041

E-Mail: dongtaili@126.com

URL: www.sd-minhe.com

Energetic usage: biomethane

Generated products: digestate

Application of the digestate: spreading as fertilizer

Agrifyl's



agriPure – Biogas Upgrading System



In September 2016 in the French department of Haute-Marne, agriKomp France has successfully commissioned a biomethane-to-grid plant. The plant, which feeds agricultural substrates such as cattle slurry, manure, catch crops, mixed grain and maize, produces 125 Nm³/h of biomethane and is a joint venture of four farms. It covers the gas requirements of the city of Chaumont up to 5 percent in winter, while in the summer the production for the municipality will increase to 35 percent of the gas requirement.

This plant was built within the framework of the biogas upgrading system “agriPure”. The plant is therefore a successful project within the framework of the new biogas treatment system. The innovative and environmentally friendly biogas upgrading plant agriPure was developed by agriKomp in cooperation with VORWERK-ASA GmbH. The biogas upgrading process converts biogas produced by anaerobic digestion into biomethane by using special membranes. The membrane system has excellent separating properties and is based on the different flow-through speed and solution behavior of

Manufacturer:
agriKomp GmbH

Commissioning: 2016

Types of fermentation:
mesophilic
wet digestion

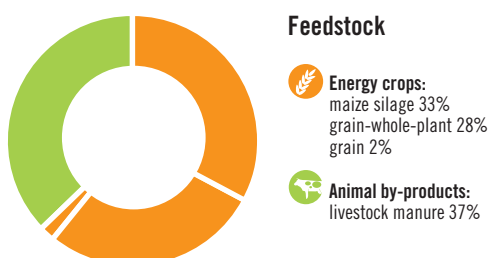
Upgrading technology:
membrane separation

Gas treatment capacity: 250 Nm³/h



the gases. Thus, the raw biogas runs through several sophisticated technical steps before it enters the national gas grid in natural gas quality.

With agriPure, we offer a complete solution for anaerobic digestion and biogas upgrading. The result is a first-class, coordinated installation of different components. With a wide-range service network, experienced service engineers and high spare parts availability, your agriPure receives a perfectly coordinated service and thus the best conditions for a long and trouble-free plant lifespan.



Required amount of feedstock: 10,750 t/a

Energetic usage: biomethane

Generated products: liquid digestate, solid digestate

Application of the digestate: spreading as fertilizer

Operator

Agrifyl's

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52000 Chaumont · France

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Phone: +49 9826 65959 - 0

E-Mail: info@agrikomp.de

URL: www.agrikomp.com

Biomethane plant Woellenheim



Biomethane plant Woellenheim – France

Manufacturer:
ÖKOBIT GmbH

Commissioning: 2016

Types of fermentation:
mesophilic
wet digestion

Upgrading technology:
membrane separation

Gas treatment capacity: 300 Nm³/h

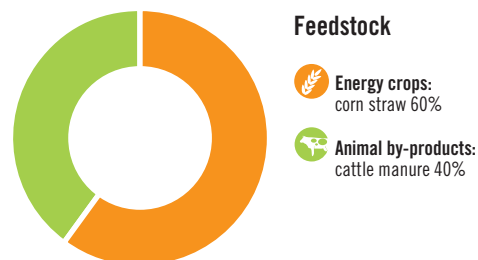


Biomethane from straw

At the Woellenheim site in France, agrogaz france, a subsidiary of ÖKOBIT GmbH, on behalf of SAS Méthachrist, has built a biomethane plant where a high-quality, but unusual, ecological substrate concept is being implemented.

The substrate, which feeds the plant, is comprised of maize straw and solid manure together with cattle slurry in a 60:40 ratio. The concept is being promoted regionally due to its eco-friendliness. Although maize straw is a cheap waste product, it has rarely been used for biogas production. In Woellenheim, 25 km from Strasbourg, the straw achieves its full energy potential by means of special pretreatment, a thorough shredding. This ensures an optimal homogenization, which allows a comparatively higher gas output and faster outgassing. The pretreated maize straw delivers a significantly high yield as for instance grain straw.

The biomethane plant, which was constructed in just six weeks in 2015/16, produces 150 Nm³ of gas per hour, which corresponds to 2.1 million Nm³ of gas each year. It also provides CO₂ savings of 3,570 tonnes per year. Florian Christ, Managing Director of the company, ascribes the extremely profitable operation of his biomethane plant to the combination of the particular substrate mix, ÖKOBIT's unique technical plant system concept and also the favorable local conditions. He is enthusiastic about the concept and its implementation and gives lectures on this subject in France and Germany.



Operator

Biomethane plant Woellenheim

4, rue de l'église
67370 Woellenheim / Willgottheim - France
Contact: Florian Christ
E-Mail: flochr@hotmail.fr

Required amount of feedstock: 13,000 t/a

Energetic usage: biomethane

Generated products: liquid digestate, solid digestate, litter

Application of the digestate: spreading as fertilizer

Investment volume: 4.3 Mio. €

Heinfelder Bioenergie GmbH & Co. KG



The amine scrubbing system has been proving as a reliable upgrading system

Manufacturer:

BWE Energiesysteme GmbH & Co. KG

Commissioning: 2006

Types of fermentation:

mesophilic
wet digestion

Upgrading technology:

amine scrubbing

Gas treatment capacity: 600 Nm³/h raw gas,
400 Nm³/h Biomethane



The biogas plant Heinfelder Bioenergie GmbH & Co. KG processes about 52,000 tons of food waste per year and is one of a few biogas plants in Germany which uses food wastes as feedstock and produces biomethane as product. The required substrates are delivered by an collection logistics enterprise associated to the plant, which purchases wastes from different segments like grocery retail, catering and the food processing industry.

During the first nine years the biogas was used for power production, but in 2015 the biomethane upgrading system and the injection station to natural gas grid is added. The pretreatment contains a depacking station for plastics, cans and glasses. In order to neutralize potential biological pathogens, the whole substrate gets pasteurized after the fermentation process. Because of the high methane content (65%), it is possible to achieve around 400 cubicmeters biomethane out of 600 cubicmeters biogas.

The energy concept is innovative, due to: the simultaneous way of using the biomethane upgrading system, the flexible operation of a CHP, and the maximum heat usage through a digestate evaporation system. In this innovative operation mode, it's possible to maximize the use of heat produced by CHP.



Feedstock

-  **Animal by-products:**
flotation tailings 40%
digestive tract contents 10%
processing waste water 10%
-  **Industrial & commercial waste 35%**
-  **Vegetable by-products: 5%**

Operator

Heinfelder Bioenergie GmbH & Co. KG

Heinfelder Straße 20

26169 Friesoythe · Germany

Contact: Dr. Arndt von der Lage

Phone: +49 4405 238000-0

Fax: +49 4405 238000-9

E-Mail: arndt.von.der.lage@gmx.de

Required amount of feedstock: ~ 52,000 t/a

Energetic usage: electricity, heat, biomethane

Generated products: liquid digestate, solid digestate

Application of the digestate: spreading as fertilizer

Investment volume: ~ 8 Mio. €

Gas grid connection Biorefinery Niederndodeleben



Biomethane feed-in station Niederndodeleben



An efficient way to use bioenergy in the form of biogas is supplying it directly to the public gas grid. However, before biomethane can be fed into the grid, it has to be processed, which means that surplus components of the biogas are removed by pressurized water scrubbing.

The biogas plant in Niederndodeleben, which produced an energy quantity of 113 million kWh in 2016, consists of 2 separate processing plants. The processed gas of both plants is bundled and afterwards fed into the gas grid via the new established connection. In this context 2 dry-running MEHRER piston compressors, which are operated as a redundant pair, are used with volume flows between 960–1,987 Nm³/h and a drive power of 200 kW.

Also the complex requirements of the downstream feed-in process can be operated by the compressors used: In order to bring the biogas, which arrives at a pressure of 4.5 to 7 bar a, to the PN 25 required by the grid, a 2-stage compressor in V-Design is used, which has the advantage that the resulting forces are less extreme, which in turn has a positive impact on the lifespan. Furthermore, the gastight engine prevents too much methane gas loss, which, ac-

Operator & Constructor

Getec green energy AG

Magdeburg · Germany

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Fax: +49 391 2568 419

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URL: www.getec-greenenergy.de

Manufacturer:

Mehrer Compression GmbH
Streicher Anlagenbau GmbH & Co. KG

Commissioning: 2014

Types of fermentation:

mesophilic
wet digestion

Upgrading technology:

scrubbing

Gas treatment capacity: 969 – 1,987 Nm³/h



According to the Gas-NZV, is not permitted to exceed 0.2% of the production volume of the plant. The high machine availability of over 97% is ensured by extensive reserves in the layout, the use of high-quality material and structural measures to extend the lifespan.

In the case of the plant in Niederndodeleben, the plant manufacturer received a complete functional unit with precisely matched components in the form of a MEHRER compressor system based on the Plug & Play principle, which guarantees short delivery times due to its simple modular system.



Feedstock

Energy crops:
corn silage 45%
beet pulp 16%

Animal by-products:
livestock manure 15%

Vegetable by-products:
various 24%

Required amount of feedstock: 100,000 t/a

Energetic usage: biomethane

Generated products: liquid digestate

Application of the digestate: spreading as fertilizer

Biogas plant Beerfelde / Gölsdorf



View from digester roof top: High performance mixer drives for stirring up to 16% dry matter. Large-scale gas buffers on post-digesters



The biomethane power plant in Beerfelde is a product of the successful cooperation between NEVAG AG, BKW Beerfelde GmbH and RegPower GmbH (Regensburg (D), www.regpower-gmbh.de). The plant, planned by RegPower, was constructed by experienced plant manufacturers and service providers, and is now operated by RegPower and BKW Beerfelde.

Unique in the planning of this plant was the execution of a physico-chemical and technical modelling and simulation programme, which took place parallel to the planning and construction of the plant. This served both to verify the design and planning of the plant and to carry out an initial plant optimisation. A parallel evaluation of the gas measurement technology was carried out and run against the modelling results. The identified improvements to measurement technology were directly implemented in the planning and construction of the biomethane plant. This new approach of incorporating modelling from the outset led to multiple benefits. Cooperating partners in this undertaking were denvo GmbH (Munich (D), www.denvo.de),

Operator

Biogas plant Beerfelde / Gölsdorf

Beerfelder Weg 1
15518 Steinhöfel (Gölsdorf) · Germany
Contact: Cornelius Herb
Phone: +49 941 899 66 264
Fax: +49 941 46 56 306
E-Mail: info@regpower-gmbh.de
URL: www.regpower-gmbh.de

Projekt development and plant operator:

RegPower GmbH
BKW Beerfelde GmbH & Co. KG

Commissioning: 2016

Types of fermentation:

mesophilic
thermophilic
dry continuous digestion
wet digestion



Upgrading technology:

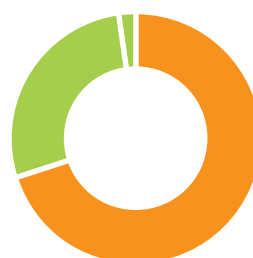
water scrubbing

Gas treatment capacity:

1,400 Nm³/h

NTB (Institute for Computational Engineering, Buchs (CH)), the Technical University of Vienna (TU Wien (AT)) and RegPower.

In the course of plant operation, plant-specific energy and feedstock data can now be continuously evaluated, interpreted and validated. Plant failures can be identified earlier and potential for optimisation exploited. Taking into consideration the costs and benefits, engineering concepts for the realisation of solutions are developed in cooperation with the plant operators.



Feedstock

- Energy crops 70%
- Animal by-products:
livestock manure dry 28%
cattle manure liquid 2%

Required amount of feedstock: 68,000 t/a

Energetic usage: electricity, biomethane

Generated products: liquid digestate, solid digestate

Application of the digestate: spreading as fertilizer

Investment volume: 15.1 Mio. €

TTV dry AD plant, AVA Augsburg GmbH



TTV AD plant AVA Augsburg



More energy – That was the aim behind the decision to build an AD plant in Augsburg. The waste recycling plant of AVA Abfallverwertung Augsburg GmbH has been operating a closed composting plant in the city since 1993. In fact the site has become a benchmark for joined-up thinking about waste, recycling, energy, resources and the environment.

The AD facility is using three Thöni TTV digesters. The process operates in the thermophilic range, maximising process rate, hygiene and biogas yield in a system that is low-rise and easy to fit into a built-environment. All of the biogas generated in the TTV digesters is first collected in a gas storage unit located on the load-bearing roof of the digesters. Since being commissioned in the fall of 2013, biogas produced by the AD facility has been upgraded to natural gas standard using a membrane plant, which is also operated by the AVA. This is a key component regarding site environmental impact and was specified with a zero tolerance of methane emissions/maximum methane recovery. The upgrading of the generated

Manufacturer:
Thöni Industriebetriebe GmbH

Commissioning: 2013

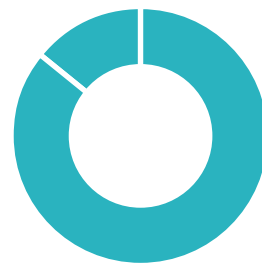
Types of fermentation:
thermophilic, dry
continuous digestion

Upgrading technology:
membrane separation

Gas treatment capacity: 1,000 m³/h



raw biogas is effected by using activated carbon filters (absorbing undesirable substances) and membranes for the separation of CH₄ and CO₂. A special feature of the plant is the retrieving of residual methane by liquefying the separated carbon dioxide stream and so reducing methane losses to a minimum. The upgraded biomethane is then fed into the network of the Augsburg public utility company (Stadtwerke Augsburg). The total annual production of 35,000,000 kWh/a of biomethane would cover the CNG requirement of 3,800 cars driving an average distance of 15,000 km or the annual heating requirement of 3,900 households.



Feedstock

Biowaste from households:
biowaste 86%
green waste 14%

Operator

TTV dry AD plant, AVA Augsburg GmbH

Am Mittleren Moos 60

86167 Augsburg - Germany

Contact: Wolfgang Veszely

Phone: +49 821 7409-125

Fax: +49 821 7409-120

E-Mail: wolfgang.veszely@ava-augsburg.de

URL: www.ava-augsburg.de

Required amount of feedstock: 105,000 t/a

Energetic usage: biomethane

Generated products: liquid digestate, solid digestate, compost

Application of the digestate: spreading as fertilizer, marketing (for gardening, landscaping, ...)

Investment volume: 23 Mio. €

New Horizons Energy Plant Athlone



Biogas upgrading system housed in the building in the front; CO₂ tanks in the background



New Horizons Energy officially opened the first waste-to-energy facility of its kind for Africa in Athlone, near Cape Town. The facility will process up to 600 tons/day of Wet Trade Waste (WTW), Pure Organic Waste (POW) as well as Municipal Solid Waste (MSW), which will be converted into organic fertilizer, compressed biomethane, liquid carbon dioxide (CO₂), recyclables and refuse-derived fuel (RDF). This facility creates a platform for disruption by not only solving waste management and landfill concerns, but also offering innovative energy recovery from underutilised resources.

When fully operational, the facility's digesters will turn up to 200 tons/day of separated organics from the MSW sorting process and other collected bio-waste into raw biogas and fertilizer. This will go through a process of pre-treatment, following which the biogas enters Pentair Haffmans' Advanced Plus biogas upgrading system with a raw gas capacity of 1,600 Nm³/h. Combining advanced membrane and cryogenic technology, the raw gas is split into high-purity biomethane (95,5%) without any methane slip, and liquid CO₂ as a second value stream. The produced biomethane is compressed,

Manufacturer:

Fountain Civil Engineering (EPC)
Pentair Haffmans (biogas upgrading)

Commissioning: 2017

Types of fermentation:

mesophilic
wet digestion



Upgrading technology:

membrane separation
cryogenic treatment

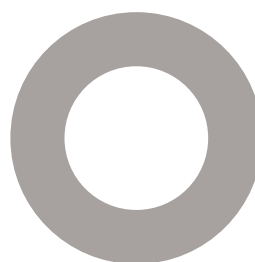
Gas treatment capacity: 1,600 Nm³/h

and distributed by gas supplier Afrox to its regional customer base as an alternative to LPG or diesel.

In addition, an estimated amount of 1,040 kg/h CO₂ will be recovered from the biogas upgrading process, liquefied and stored in a buffer tank, before it is distributed to customers in the Western Cape industry, agriculture and waste water treatment sector. CO₂ is in short supply in the region. Up to now, CO₂ for the Western Cape was predominantly sourced from Mossel Bay, which is more than 380 km away.

Feedstock

WASTE Various waste and residues 100%



Operator

New Horizons Energy Plant Athlone

301 The FIRS, Biermann Avenue

Rosebank, Johannesburg, 2196 · Republic of South Africa

Contact: Phumi Makhanya

Phone: +27 11 268 6735

E-Mail: phumi@cleanenergyafrica.co.za

URL: www.cleanenergyafrica.co.za

Required amount of feedstock: 72,000 t/a (200 t/d)

Energetic usage: biomethane, fuel

Generated products: liquid/dewatered digestate, liquid CO₂ for industrial and food-grade applications

Application of the digestate: spreading as fertilizer

Investment volume: 30 Mio. €

Kompogas Winterthur



Winterthur: The HZI BioMethan gas treatment plant operates by means of pressureless amine scrubbing



The plant processes around 23,000 metric tonnes of kitchen and green waste every year from more than 78,000 households, from municipalities and garden markets. 1,050,000 Nm³ of biomethane are produced per year.

After shredding and sieving, the substrate is fed into the digester which is part of the fully automated facility. The raw biogas produced in the digester is precleaned, i. e. desulphurized and dewatered before being fed into the HZI BioMethan gas treatment plant for pressureless, heat-led amine scrubbing to separate out the CO₂ and upgrade the CH₄ fraction to natural gas quality. This biomethane is compressed and then fed into the municipal gas grid. Part of it is made available via three local natural gas fueling stations selling a mix containing biogas. The lion's share is incorporated into various gas products consumed by private households and large customers. Two sieve screw presses are used to separate the digestate from the digester into a liquid and a solid fraction. The press cake is stored

Operator

Kompogas Winterthur

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URL: www.hz-inova.com

Manufacturer:

Hitachi Zosen Inova BioMethan GmbH

Commissioning: 2014



Types of fermentation:

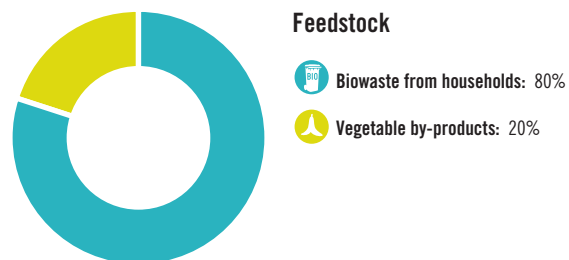
thermophilic
dry continuous digestion

Upgrading technology:

amine scrubbing

Gas treatment capacity: 300 Nm³/h

and further stabilized in subsequent composting. This process allows the material to mature into top-grade compost that is collected by nurseries, market gardens and farmers for use as fertilizer. Part of the press juice is fed back into the digester to directly initiate the fermentation process. The remainder is used in agriculture as certified organic liquid fertilizer. Exhaust air from the entire process is collected and fed into a biofilter filled with several layers of torn root wood to remove ammonia, and subsequently released into the atmosphere. This avoids the emission of unpleasant odors and means that the plant enjoys broad acceptance in the community.



Required amount of feedstock: 23,000 t/a

Energetic usage: biomethane, fuel

Generated products: liquid digestate, compost

Application of the digestate: spreading as fertilizer

Investment volume: 2.27 Mio. €

Meden Vale



Biogas plant Meden Vale biomethane feed-in plant

Manufacturer:
BioConstruct GmbH

Commissioning: 2016

Types of fermentation:
mesophilic
wet digestion

Upgrading technology:
membrane separation

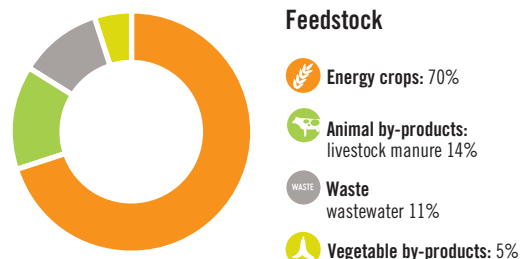
Gas treatment capacity: 800 Nm³/h



The plant is a two stage wet digestion plant with fermenter and post fermenter. Additionally, a full-stream pasteurisation takes place after which additional gas is produced after thermal opening of cells.

The plant is equipped with a CHP to produce parasitic load both thermally and electrically. The CHP is automatically controlled by the needs of electricity from the plant as there is a zero injection rule for electricity on site. The plant is additionally equipped with a power to heat module and a dual fuel burner to control the parasitic loads and ensure self-sustainability.

Approximately 800 Nm³/h of the biogas are upgraded to biomethane by membranes and injected into the public gas grid.



Operator

Meden Vale

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Phone: +49 15142222970

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URL: www.bioconstruct.de

Required amount of feedstock: 49,000 t/a

Energetic usage: electricity, heat, biomethane

Generated products: liquid digestate

Application of the digestate: spreading as fertilizer

Company directory

SYMBOL DESCRIPTION:

Pressure swing adsorption



Scubbing technologies



Membrane separation



Cryogenic treatment



Process auxiliaries



Plant components



Energy concepts



Wet continuous digestion



Dry continuous digestion



Matrix overview of the company directory

Company										Page
Turnkey system provider										
agriKomp GmbH			X			X	X	X		44
AAT Abwasser- und Abfalltechnik GmbH			X			X		X		45
BTS Biogas			X				X	X		45
BioConstruct GmbH	X	X	X	X		X	X	X		46
bwe Energiesysteme GmbH & Co. KG		X	X			X	X	X		47
Hitachi Zosen Inova BioMethan GmbH		X	X							48
EnviTec Biogas AG			X		X	X	X	X		49
ÖKOBIT GmbH		X	X					X		49
Pentair Haffmans		X	X	X		X	X			50
rovi energie AG		X	X			X	X	X	X	51
THÖNI Industriebetriebe GmbH			X			X		X	X	52
PlanET Biogas Global GmbH	X	X	X	X		X	X	X		53
Project developer										
denvo GmbH			X		X	X	X			53
CarboCycle Ingenieurbüro	X	X	X	X				X		54
Plant components										
Awite Bioenergie GmbH						X				55
Franz Eisele u. Söhne GmbH u. Co.KG						X				56
Evonik Resource Efficiency GmbH			X							56
Mehrer Compression GmbH						X				57
Konrad Pumpe GmbH						X				58
SUMA Rührtechnik GmbH						X				58
Process auxiliaries										
CarboTech AC GmbH					X					59
Schaumann BioEnergy GmbH					X		X			59
Arcanum Energy	X	X			X	X	X			60



We at **agriKomp** have been developing ground-breaking biogas systems since the middle of the 1990's. Up to now we have implemented with our customers more than 800 biogas plants with a total installed capacity of around 250 MW_{el}. It was, and is still today our goal to make it possible for agricultural businesses to enter the energy market, quickly and with minimum outlay.

The holistic and visionary thinking of the company founders, Robert Bugar and Michael Engelhardt decisively characterizes the development of the business to the present day. agriKomp's name stands not only for efficient technology and reliable service, but also for innovation, conviction and a great deal of entrepreneurial courage: ground-breaking systems, such as the first mobile biogas plant, the Güllewerk®, or the Paddelgigant® agitator, are just a few examples of brilliant engineering from the agriKomp R&D department.

The continuous effort in research and development has led to an outstanding CHP portfolio, which is expanding since 2009. Together with tried and tested partners, agriKomp develops optimized CHPs with modern engine technology in the small and medium performance range. Our CHPs are characterized by their robustness and reliability. This results in low maintenance costs, which are unrivaled in the industry.

Furthermore agriKomp has installed its first biogas upgrading system located in France. It converts biogas produced by anaerobic digestion into biomethane by using special membranes. The membrane system has excellent separating properties and is based on the different flow-through speed and solution behavior of the gases.



agriKomp Headquarters – Merkendorf



agriPure – Gas-to-Grid Plant System by agriKomp GmbH

All the essential components of the biogas plant are developed and manufactured within the agriKomp group of companies. This guarantees absolute reliability and continuous excellent quality. Key components, such as the flexible gas store (Biolene®), the paddle agitator (Paddelgigant®) and the robust feeding technology (Vielfraß®) have set international standards with respect to stability, reliability and energy efficiency.

It only takes a few weeks to build a biogas plant, our service partnership lasts for decades. This is what a biogas plant manufacturer should be able to offer in all events. Essential parameters which decide long-term the profitability of your plant are stable technology, reliable service and, above all, continuous further development. We are always researching and developing, so that you remain ahead in the future.

„If you wish to stay ahead you must be innovative, have reliable and efficient products in your portfolio and also provide a secure service. This requires dedicated people and solid engineering“, says Robert Bugar.



- ▶ Agitator technology
- ▶ Gas storage
- ▶ CHPs
- ▶ Service and maintenance
- ▶ Grid injection technologies

Year of foundation **2000**
Number of employees **400**

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- ▶ Agitator technology
- ▶ Gas storage
- ▶ Gas drying
- ▶ Desulfurisation
- ▶ Biogas plants

Year of foundation **1993**
 Number of employees **11**

AAT Abwasser- und Abfalltechnik GmbH

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 URL: www.aat-biogas.at



Pump room of the biogas plant Recycling Energie AG

Reliable solutions for commercial success.

AAT is not only well known for its background of highly-specialized knowledge and state-of-the-art biogas plants but also for successful operation of these during their entire lifespan. More than 1,000 biogas plants built and operating in more than 30 countries verify AAT's success; the result of 30 years of experience and ongoing in-house research and development by highly motivated staff.



Low operating, service and maintenance costs coupled with high availability are the main design targets for each individual AAT biogas plant, achieved by focusing on the customer's specific demands and input material requirements and supported by reliable in-house developed components and hands-on technology together with profound know-how and efficient service. An excellent example of the application of such expertise is to be found in the AAT-designed maintenance-free digester.



- ▶ Anaerobic digestion
- ▶ Digestate treatment
- ▶ Gas drying
- ▶ Grid injection technologies
- ▶ Feedstock preparation

Year of foundation **2008**
 Number of employees **80**

BTS Biogas

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Ridge Road, UK 2016

BTS Biogas is a Pioneer in the construction of Biogas Power Plants with more than 80 employees and has already built 190 plants worldwide. BTS offers waste to biogas/biomethane plants in the range from 8,000 to more than 30,000 tons of organic waste per year, corresponding to an electrical power from 250 kW to more than 1.5 MW. In this case a pre-treatment is necessary and includes:

- organic material collection unit
- solid organic waste crushing and separation unit to break-up the waste and sort the plastic residue



- sedimentation unit to separate the inorganic sediments (like sand, glass, etc.)
- pumping unit.

The organic part comes out as a pulp, while the inert materials are unloaded in a special collection container. The biomethane plant is assembled and placed in containers and consists of:

- Gas-dryer unit
- Activated-Carbon Filters
- Membrane modules.

The upgrading system is engineered by BTS Biogas and it is successfully working in various UK plants.



A view on BioConstruct's Headquarter and own operated anaerobic digestion plant



Biogas plant Vettweiß biomethane feed-in plant



Since its incorporation, **BioConstruct** has successfully commissioned more than 400 plants with an installed capacity of more than 250 MW. Our portfolio of realised projects ranges from:

- agricultural plants processing energy crops or co-fermentation plants with liquid or solid manure
- plants with difficult/more complex input materials such as > 90 % grass silage, dung, slaughterhouse waste and food waste
- biogas plants with biomethane upgrading and gas-to-grid technology
- high-end industrial biogas plants up to 5.1 MW
- high-efficiency plants with heat usages for industry, local heating distribution companies and greenhouses as well as for electricity providers
- industrial waste fermentation systems

BioConstruct has international experience in the realisation of projects in Italy, France, Czech Republic, the Netherlands, Turkey, Estonia, Latvia, Greece and the UK.

Only materials able to withstand the strain of continuous operation are used in our plants. BioConstruct technology meets the most rigorous standards and is permanently monitored by a fault management system that is continuously improving due to our broad experience in the operation of 20 biogas plants, most of which are majority-owned by BioConstruct. The plants are meticulously planned, exceedingly low-maintenance and furnish the highest yields as a result.

For BioConstruct, turnkey plant construction means performing – profitability forecasts, individual plant designing, obtaining necessary approvals, service and maintenance and even operation of the plants.

In a nutshell, BioConstruct's involvement does not end with the handover of a plant. BioConstruct sees itself as a partner, not only during the construction phase but rather throughout the whole lifetime of a biogas plant, and supports clients in matters pertaining to the biological process, technology and financial ways of optimising the plants.



- ▶ CHPs
- ▶ Heating technology
- ▶ Service and maintenance
- ▶ Grid injection technologies
- ▶ Feedstock preparation

Year of foundation **2001**
Number of employees **90**

BioConstruct GmbH

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Building one of bwe's headquarter in Friesoythe



West London facility with bwe anaerobic digestion technology has been awarded two times in a succession as the best merchant waste AD project



Heat recovery systems: We design and optimise the heat recovery system to achieve a high annual utilisation level of the biogas plant. Moreover, we develop projects for industrial heat processes and drying systems.

Micro gas network: We offer micro gas network option installing the CHP units close to the consumers. A gas drying unit and compressor system at the biogas plant feed the gas into the micro grid.

Electrical installation and automation: We design the automation and electrical systems in order to guarantee continuous operation. Moreover, retrofitting existing electrical installations, programming and interfaces are also part of our scope.


Biological supervision: We offer biological process supervision including sampling and digestate analysis.

Repair and maintenance: In order to avoid the reduction of the availability of the plant, bwe offers a range of maintenance contracts following health and safety standards.

Emergency service 24/7: Should you have an unexpected situation you can upgrade your service package to 24/7 assistance and personal contact number.

Project management and planning: Before starting the construction, our development team tailors the concept to your needs and if necessary leaves the possibility for future expansion of the facility.

Repowering, expansion and retrofitting: We are also happy to take over an existing biogas plant and maximise its production, retrofit it or re-power its capacity.



- ▶ Gas storage
- ▶ Heating technology
- ▶ Pipe installation
- ▶ Pumping technology
- ▶ waste treatment technology

Year of foundation **2000**
Number of employees **106**

bwe Energiesysteme GmbH & Co. KG
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URL: www.bwe-energie.de

bwe Energiesysteme GmbH & Co. KG was founded in 2000 in Friesoythe, Germany. Since then BWE has grown into one of the leading biogas technology providers in the EU. With more than 390 operating plants, we have gained extensive experience in biogas technology both in Germany and abroad, e.g. Spain, Italy, Czech Republic, the UK, Hungary and Turkey. BWE organic waste treatment plants are characterised by the high level of profitability and efficiency. For the second year in row the biogas plants with BWE AD technology had the first three positions in the highest load factor (> 95%) among the top 30 food waste AD facilities in the UK in 2014 and 2015.

In the last years the company offers wider range of services in energy sector including heating concepts, electrical installations and maintenance of combined heat and power (CHP) units. In order to reflect the expansion of the service package, starting from 2016 BWE is going to be known under the name bwe Energiesysteme GmbH & Co. KG. Our service package includes inter alia:

Hitachi Zosen INOVA



Heat-led gas upgrading process – Plant for biomethane production with pressureless amine scrubbing in Bruchhausen-Vilsen



Production in Zeven – Assembly of a plant using membrane-based gas permeation



Gas Upgrading und Carbon Capture

Hitachi Zosen Inova BioMethan GmbH offers innovative, comprehensive solutions for the upgrading of biogenic gases such as biogas, landfill or sewage gas and of flue gases. We develop and manufacture:

- Gas upgrading plants that treat and refine raw biogas to deliver biomethane of a quality equivalent to natural gas
- Facilities for feeding biomethane into the existing natural gas infrastructure
- Carbon capture plants for separating CO₂ out of flue gas for use as product gas or in liquid form for use in glasshouses as an example
- Optional modules for the production of vehicle fuels and the use of CO₂ built in compact container form

With our pressureless amine scrubbing – heat-led gas upgrading process – as well as our pressure-controlled technology using membrane-based gas permeation we have the right technology to suit any client requirement.

This enables us to choose the process best suited in terms of the desired performance, the operator, and the requirements of the market. Both of these upgrading processes excel by high technical availability and ensure minimal methane slip while delivering a high degree of purity.

Stand-alone components for gas conditioning, compression, drying, volumetric measurement, quality control, and odourisation as well as gas transport units complete our product portfolio.



- ▶ Carbon capture technologies
- ▶ Fuel technologies
- ▶ Service and maintenance
- ▶ Grid injection technologies
- ▶ Upgrading technologies

Year of foundation **2015**
Number of employees **65**

Hitachi Zosen Inova BioMethan GmbH

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- ▶ Service and maintenance
- ▶ Full AD plant equipment
- ▶ Preparation of approval applications
- ▶ Full project execution
- ▶ Waste- and agricultural AD plants

Year of foundation **2002**
 Number of employees **440**

EnviTec Biogas AG
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 E-Mail: info@envitec-biogas.com
 URL: www.envitec-biogas.com



EnviThan gas upgrading – the container-based design is especially cost-effective and environmentally friendly

Biogas to Biomethane

As a technology leader and biogas all-rounder, the wealth of expertise held by its engineers is the key of **EnviTec Biogas**. The high efficient EnviThan gas upgrading system is currently enjoying particularly strong demand. By using highly selective membranes, the methane yield is outstanding high by remarkable low power consumption. Developed jointly with Evonik Industries, the system requires neither chemicals nor water or other resources, which makes it more environment-friendly than other methods –



and significantly more cost-effective. Worldwide, 20 EnviThan plants have already been built and/or expanded, 6 projects are now in planning or construction (as of June 2017).

Background EnviTec Biogas AG

The German based EnviTec Biogas is active in more than 20 countries worldwide. So far, EnviTec installed more than 390 MW_{el} and 630 modules worldwide and has a wide experience in processing agricultural, agro-industrial by-products and many other kind of organic waste.



- ▶ Agitator technology
- ▶ Gas storage
- ▶ Feedstock preparation
- ▶ Desulfurisation
- ▶ Pumping technology

Year of foundation **2000**
 Number of employees **35**

ÖKOBIT – The Biogas Experts
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 URL: www.oekobit-biogas.com



Biomethane plant Semd - Germany

As a major manufacturer and planner of biogas plants with over 175 projects worldwide, **ÖKOBIT** is one of the most sought-after full-service suppliers within the biogas industry. We develop and build technically intelligent, substrate-flexible biogas and biomethane plants which perfectly correspond to the specific local conditions of our clients.

ÖKOBIT is an owner-operated and exceptionally wide range of services and expertise. Our biogas expert team of experienced engineers, business experts, as well as energy and environ-



mental engineers works with full commitment on the implementation of environmentally compatible biogas concepts operating on the highest level of economic efficiency.

ÖKOBIT relies on established and exceptionally flexible technology concepts and ensures their effective and safe implementation. As a general contractor, in addition to expert advice and profitability calculations, we take on all tasks from planning and approval to turnkey plant construction.



**MAXIMIZE YIELD.
MINIMIZE ENVIRONMENTAL IMPACT.**

Today's biomethane producers want both – an efficient methane recovery process and an effective carbon dioxide (CO₂) management.

Biogas produced through anaerobic digestion consists of roughly 55 percent methane and 45 percent CO₂. With conventional biogas upgrading techniques the CO₂ by-product and with it a considerable amount of methane is expelled into the air and is lost. This means not only economic loss but also environmental damage.

Pentair with its world-class brands Haffmans and Union Engineering offers a wide range of solutions for biogas upgrading and/or CO₂ recovery. To provide each customer with a technical solution that perfectly fits the specific requirements, a choice will be made between a membrane, cryogenic or chemical absorption (e.g. amine) process. Capacities range from 100 to 2,500 Nm³/h using the membrane solution (Standard, Advanced and AdvancedPlus System) and 1,000 to 20,000 Nm³/h with the chemical absorption process (BioCO₂n System).

Eliminating any methane slip

Pentair goes beyond the borders of conventional biogas upgrading systems. Using an advanced combination of technologies, Pentair's biogas upgrading systems completely eliminate any methane slip. This results in a significantly higher methane yield, and optionally provides liquid CO₂ as a second value stream. The portion of environmentally-harmful greenhouse gases released to the atmosphere is reduced to almost zero, which makes these systems a future-proof investment. As an additional advantage of the chemical absorption



Biogas plant and CO₂ buffer tank



Turnkey biogas upgrading system

process (BioCO₂n System), this operates without activated carbon to remove H₂S from the gas stream, leading to substantial savings in OPEX.

Advanced service concepts

Our dedication to your system continues after the sale. Through comprehensive lifecycle management, Pentair ensures that an installation operates at optimal performance. Regardless of where your plant is located, our global network of service engineers is ready to serve you. In addition, a team of product specialists provides technical support, including 24/7 remote service.

A proven track record

Since entering the biogas upgrading market in 2010, Pentair has experienced amazing success with its innovative technology. To date, 40+ biogas upgrading projects have been realized or are set to be completed, including projects in the Netherlands, Germany, France, the UK, Norway, Denmark, South Africa, the Philippines and the USA.



- ▶ CO₂ recovery
- ▶ Desulfurisation
- ▶ Gas drying
- ▶ Gas quality measurement
- ▶ Service and maintenance

Year of foundation **1947**
Number of employees **19,000 (globally for Pentair plc.)**

Pentair Haffmans
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Indoor installation of membranes for CO₂ separation



Outdoor installation of raw biogas pre-conditioning and exhaust gas treatment



As rovi we care about your project. Maybe more than others. That's why we focus on the right biogas upgrading technology for your waste streams right from the very beginning. We want technology to adapt to your project conditions no matter if this is biogas generation, biogas upgrading, effluent treatment or heat generation. Your needs and our expertise build the foundation for a thoughtful concept.

Our consultancy services include:

- Pre-studies to develop a basic concept
- Feasibility-studies for evaluating technical and economic indicators
- Bidder comparison to identify the optimum technology
- Overall project development
- Project management from contract signature to take over
- Development of customized and manufacturer independent service contracts
- Biomethane distribution concepts

Our scope of delivery includes:

- Biogas conditioning systems for drying, cooling, H₂S-removal, pre-compression
- Biogas upgrading plants based on membrane technology
- Biogas upgrading plants based on amine scrubbing
- Gas grid injection systems
- CNG filling stations and storage solutions
- Compressor units and pipeline construction
- Manufacturer-independent after sales service



- ▶ Project development
- ▶ Consulting services
- ▶ Biogas pre-conditioning
- ▶ CNG components
- ▶ Service and maintenance

Year of foundation **2010**
Number of employees **3**

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rovi energie AG is a specialised and flexible consultancy company supporting customers on their way to a successful waste to energy project. In concert with our partner network we are able to offer turn-key solutions for any part of the project from biogas generation to biomethane injection systems. Since 2010 we have been involved in more than 20 waste to energy projects throughout Europe. Our focus lies on source separated biowaste and the organic fraction from municipal solid waste (OFMSW).

Together with the **Friedrich Vorwerk Group** we are your strong partner from project development to service and maintenance of your biogas upgrading plant. With over 50 years of experience Friedrich Vorwerk has a remarkable reputation in the gas industry. In 2015 Friedrich Vorwerk started its renewable energy business and has built and commissioned its first biogas upgrading plant based on membrane technology the same year. At the end of 2017 four upgrading plants will be in operation in Germany (2), France (1) and Switzerland (1) with another 20 upgrading plants in Germany and Switzerland being serviced.



THÖNI Industriebetriebe GmbH is an Austrian based provider of biogas plants for treating organic waste and agricultural by-products. With track record of more than 25 years, Thöni provides highly-efficient plant solutions offering an excellent price-performance ratio. These systems are planned and designed by Thöni's own engineering division, the key plant components are manufactured by the in-house metalworking facility. To date, THÖNI currently has more than 90 biogas plants in operation in Europe.

Put waste in, draw energy out – Thöni AD dry digestion TTV

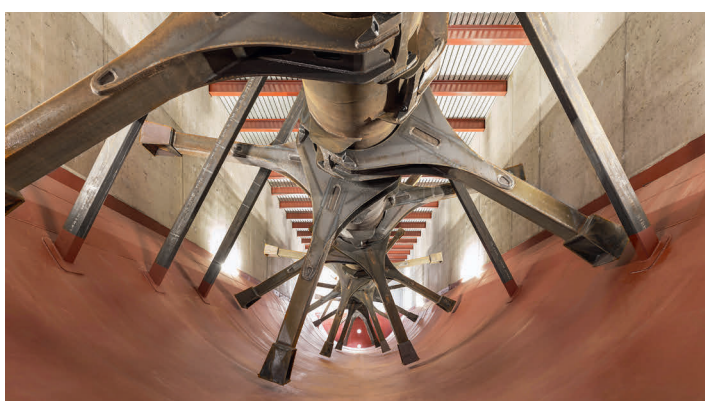
Waste has enormous potential. Thöni Environmental Energy Engineering uses it to produce clean energy and valuable resources. Thöni TTV is a dry digestion process that is especially well suited for organic waste because it has a higher insensibility against impurities than other processes. The heart of the Thöni TTV process is the plug-flow digester equipped with a slow rotating paddle agitator ensuring the optimum mixing of the substrate and thus a high biogas yield. The Thöni paddle stirrer ensures highly efficient stirring as well as optimum prevention of swim layers and sediments. The dewatering of the digestion residues is effected by Thöni screw presses which are particularly characterised by low energy consumption and durability.

Turnkey systems for the agricultural sector – Thöni NATURGAS

Thöni NATURGAS technology is based on the wet digester which is continuously filled with liquid and solid input material via a special feed hopper system. The patented Thöni paddle agitator creates the conditions for stirring input mixtures with high content of dry matter so efficiently that no floating layers arise and ensuring at the same time high gas yields.



Headquarter Thöni in Telfs



TTV paddle stirrer

Outstanding features of Thöni biogas plants
Robust system technology and the operational reliable design of critical components ensure maximum availability. Thöni delivers turnkey, ultra-efficient plants offering an excellent and trend-setting price-performance ratio:

- High system and input flexibility, robust and durable plant technology
- Operational efficiency, low operating costs and maximum availability
- High biogas yields due to efficient stirring technology

The company has its headquarters in the town of Telfs in the western Austrian province of Tyrol and has further facilities in Landeck, also in Tyrol, and in Kempten in the southern German region of Allgäu and in Rovereto, Italy. Besides Environmental Energy Engineering, the Thöni Group is also active in the following business divisions: aluminum extrusion, automotive components, plant engineering, hose production and machining.




- ▶ Agitator technology
- ▶ Dewatering units for digestate
- ▶ Service and maintenance
- ▶ Heating technology

Year of foundation **1964**
Number of employees **600**

THÖNI Industriebetriebe GmbH

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- ▶ Agitator technology
- ▶ CHPs
- ▶ Grid injection technologies
- ▶ Gas upgrading technologies
- ▶ Desulfurisation

Year of foundation **1998**
 Number of employees **200**

PlanET Biogas Global GmbH
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Example of a PlanET biomethane plant

PlanET belongs to the worldwide leading manufacturers of turnkey-ready anaerobic digestion (AD) plants and technology suppliers. Our portfolio covers the whole digestion line and provides you with independent consultation to select the best technology to use the produced biogas – whether it is used for electricity production via a CHP or upgraded to biomethane. Especially with regards to upgrading technology we rely on a broad selection of suppliers to match it to your needs. We are familiar with all

kinds of available processes including pressure swing adsorption and membrane technologies. With the experience of nearly 20 years and over 400 successfully operating AD and biomethane plants in Europe, North America and Asia we are keen to create a feasible concept for every need. Additionally, our own laboratory and R&D department give us the knowledge and possibility to individualize our products to match your inquiry. Convince yourself: Biogas. The Future – Your Benefit.



Project developer



- ▶ Gas quality measurement
- ▶ Gas grid management
- ▶ Data mining/analysis
- ▶ Business development
- ▶ H₂ injection technologies

Year of foundation **2011**
 Number of employees **2**

denvo GmbH
 Dollmannstrasse 15
 81541 Munich · Germany
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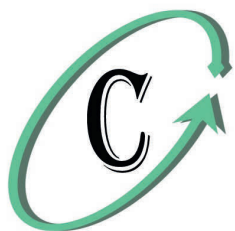
Technical competence, economic intelligence and business/project development – excellence made by denvo

denvo is the successful partner of more than 20 biomethane and energy plants with a total investment volume of over €135 million. We provide services in the areas of project planning, technical design, modelling and simulation, plant optimisation and data mining. We also provide support during contract allocation, plant construction and commissioning. Gas upgrading and injection, and gas measurement and control technology belong to our core competencies. As participants since 2007, we are amongst the most experienced in the German

biogas upgrading and injection industry. In addition, we have extensive know-how in the areas of fuel cell, reformer, and H₂ technology, and wood distillation.

We combine this know-how with our experience since 1997 in the fields of technical business development, marketing, innovation management and start-ups, making us unique in the industry. The same is true if you are interested in the combining of different energy forms (biomethane, H₂ and electricity)





CarboCycle

Ingenieurbüro Lars Klinkmüller



Biogas plant Wolnowacha with an installed electrical power of 1.5 MW, Donetsk region, Ukraine



Biogas treatment plant Neudorf (Brandenburg-Germany), 700 Nm³ per h BioMethan, amine wash process



CarboCycle Ingenieurbüro has had more than 30 years of experience in the production of biogas. We are planning complete industrial biogas plants for the fermentation of animal excrements, organic waste and renewable raw materials. In doing so, we implement our own process know-how. Ultimately, the selection of plant components depends on the substrates and the site-specific requirements.

Our range of services covers the design and approval planning, execution planning, supply of goods and services up to commissioning. Together with local partners, we are able to offer complete plants also turnkey. We attach great importance to the reliability, longevity and safety of our systems.

In addition to plants in Germany, we have just completed the first biogas plant in Ukraine. This is a plant for the fermentation of animal excrements and renewable raw materials for the production of electricity with a capacity of 1,500 kW. It is planned to double the plant capacity in a second stage of construction. The

biogas produced is then to be processed to BioMethan and fed into the gas network.

Since 2006, we have been working on the processing of biogas for BioMethan. Practical experience has been gained especially with chemical washes.

In addition, we were involved in Germany and at the EU level on the introduction of legal and technical framework for the processing of biogas and the feeding of biomethane into natural gas networks. There are already first contacts in Ukraine to allow even there legally and technically the injection of biomethane into natural gas networks.



- ▶ Gas drying
- ▶ Biogasproduction
- ▶ Desulfurisation

Year of foundation **2003**
Number of employees **4**

CarboCycle Ingenieurbüro

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13127 Berlin · Germany

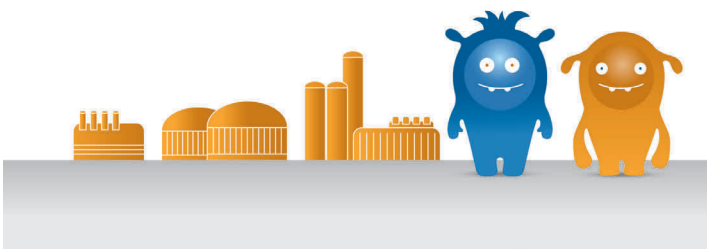
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Tailor made solutions for satisfied customers



Configuration of a gas analysis system



ing peripheral equipment. When developing our own automation solution in house, we also had a view to maximum operational reliability. We are committed to developing products on an open-source basis. This enables us to protect our customers from hidden costs. Of course, AwiCONTROL like all our other products enables you to control your systems from a distance. Using a smart phone or tablet. At any time.

Desulfurization – never too much O₂ in the system

The AwiDESULF microbiological desulphurisation system with fuzzy logic gives you full control over hydrogen sulphide. Sounds complicated? It's actually rather simple: simply switch on. The gas analysis system measures the oxygen content and the hydrogen sulphide concentration and uses this data to regulate the air supply. Your benefits? Easy to use, low costs, highly reliable process and low substrate losses.

Flow measurement – more precise measuring

AwiFLOW can be used anywhere – thanks to low pressure loss and wide temperature range – to determine water content, standard flow and energy flow. No pressure? No problem! It measures precise at gas velocities from 0.3 m/s with minimal pressure loss.

Service – you can rely on us

The assembly, startup and maintenance of our process analysis systems is carried out by our trained staff on site at your plant. We monitor the service intervals for you and on request can offer you full-service maintenance contracts. Maintenance comprises a full check of your systems, including calibration with certified gases. At any time.

Awite is specialised in gas analysis systems, automation and measuring technology in the area of biogas plants. Since 2001, Awite has been manufacturing according to individual customer requirements and to the highest standards of quality at its facility in Langenbach.

Awite offers gas analysis systems for biogas plants, for monitoring the feeding in of biogas into the natural gas grid, controlling fuel cell applications, for raw biogas distribution and also for handling other control tasks.

The range of products and services also includes the automation and visualisation of biogas plants, wastewater treatment plants and lab-scale plants with the company's own software.

Gas analysis – the right system for every process

AwiECO and AwiFLEX our gas analysis systems use extensive process controls to ensure smooth workflows and above all the economic use of energy in your plants. Constantly. The more accurate and continuous the measurements, the more they prove to be time and cost-saving factors.

Automation – full support

Our AwiCONTROL automation solution gives you complete control of your system, includ-



- ▶ Gas quality measurement
- ▶ Automation
- ▶ Desulfurisation

Year of foundation **2000**
Number of employees **34**

Awite Bioenergie GmbH
Grünseiboldsdorfer Weg 5
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E-Mail: info@awite.de
URL: www.awite.de



Franz Eisele u. Söhne is specialised in the development and manufacturing of machinery and equipment for efficient manure management and biogas plants. Quality prevails – this has been the corporate philosophy of EISELE all along and EISELE products have proven their advanced quality and reliability time and time again under harshest conditions:

The stationary vertical pump with a capacity of up to 6,000 l/min., submersible motor-driv-



EISELE submersible mixer GTWSB in concrete tank with cover membrane and side operation

en pumps AT for wet and dry operations and feature capacities of up to 6,700 l/min. The submersible motor-driven agitators GTWSB are available with gas-tight operation and partly in ex-protected versions. Lobe pumps DK have proven to be extremely quiet running and they require only minimum maintenance.

All electrical motors for pumps and mixers are manufactured by EISELE, the Ex-protected versions as well.



- ▶ Agitator technology
- ▶ Service and maintenance
- ▶ Pumping technology

Year of foundation **1887**
Number of employees **85**

Franz Eisele u. Söhne GmbH u. Co.KG

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Evonik, the creative industrial group from Germany, is one of the world leaders in specialty chemicals, operating in the Nutrition & Care, Resource Efficiency and Performance Materials segments.

The Resource Efficiency segment supplies high performance materials for environmentally friendly as well as energy-efficient system solutions ensuring sustainability – for business as well as everyday life.

SEPURAN® Green stands for innovative membrane technology for efficient biogas upgrading.



SEPURAN® Green membranes for efficient biogas upgrading

Our aim is to support the turn of organic waste into green energy source like biofuel simply and sustainably.

SEPURAN® Green membranes have the highest CO₂/CH₄ selectivity and are therefore a superior technology for upgrading biogas. This selectivity of the membranes enables the production of high purity biomethane with superior methane recovery. Due to a simple modular setup the technology is applicable for small, medium and large scale installations.



- ▶ Gas cleaning, gas processing
- ▶ Washing and cleaning systems

Year of foundation **2007**
Number of employees **33,500**

Evonik Resource Efficiency GmbH

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Compressor Package TRZ 1000 used for raw biogas, CO₂ and all common process and toxic gases



Compressor Package TVZ 900-200 Ex for e.g. grid injection



Whether biogas processing or biomethane injection – Mehrer's compressors always guarantee reliable, efficient, fail-safe plant operation. Headquartered in Balingen, Southern Germany, and a family-run enterprise since its foundation in 1889, Mehrer is one of the world's oldest compressor manufacturer, and one that is steeped in tradition. Production, design and development take place exclusively at the company's headquarters, thus ensuring that the high production quality of the plants is sustained. Mehrer has been renowned since the 1970s for the design and manufacture of dry cylinder piston compressors and compressor units in particular.


Our machines can be acquired in three different scope of supply: as compressor block, which is integrated into the overall system by the packager itself, as lean compressor package including drive, piping and monitoring or as complete compressor plant.

The latter consists of the compressor package including the control system and can be provided with components such as, for example, a dryer, a water-cooling unit or a noise hood.

The scope of supply is optimally adapted to the application case according to the Mehrer's mission statement „Customized Compression“.

Mehrer compressors can be used in the fields of environment, machine construction, chemistry, petrochemistry, raw materials and food, for example for gas recovery systems.

Mehrer will continue to promote resource-saving, media-independent gas compression, and in future will also provide outstanding tailored servicing solutions and manageable, secure operation costs.



- ▶ Gas storage
- ▶ Service and maintenance
- ▶ Grid injection technologies
- ▶ Compressors

Year of foundation **1889**
Number of employees **110**

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Mehrer Compression GmbH

Mehrer Compression GmbH is synonymous for quality and reliability.

The company ranks among the world's leading manufacturers of oil-free piston compressors and diaphragm compressor packages for process gas applications with an output range of 2.2 to 250 kW and pressures of up to 1,000 bar (absolute pressure).

They are primarily used in the media-independent deposition, grid injection, extraction, purification, storage and drying of gas.

In addition to its activities in various sectors and areas of application, Mehrer also produces environmentally friendly compressor solutions. In this field, Mehrer units make an important contribution to the permanent treatment of potable water. The company devotes particular attention to designing solution-oriented biogas compressors, which are chiefly characterised by their ease of installation and reliable operation in container stations.



BIG-Mix dosing system for difficult to convey substrates



Konrad Pumpe GmbH has over 15 years of experience in designing and developing storing, processing, and dosing equipment for biomass. More than 3,000 screw feeders and solid matter dosing units supplied provide proof of our performance capabilities. Rapid delivery of all spare parts is guaranteed because customer service is provided 7 days a week.

Our solid dosing units of stainless steel are especially developed for difficult substrate materials such as 100% grass silage, solid

manure, green and food waste. Our intelligent process control and continued design and development reduce the energy consumption and system wear and tear. Capacity volumes from 8 – 210 m³ are available to suit your plant.

Direct feed to digesters or downstream equipment such as crushing and liquid feeding systems are provided by our screw technology. Flexibility, future modernization and repowering are our specialties'. On site advice is gladly given.



- ▶ Feedstock preparation
- ▶ Loading systems
- ▶ Conveying technology
- ▶ Dosing technology
- ▶ Economical transport – worldwide

Year of foundation **1830**
Number of employees **50**

Konrad Pumpe GmbH

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SUMA Agitator FT



Stirring needs to be effective, efficient and sustainable.

SUMA has been specializing in biogas, liquid manure and waste water agitators since 1957. At SUMA, we produce high performance, modular and custom solutions to fit unique biogas and liquid manure needs. Our dedication, knowledge and experience coupled with our in-house manufacturing and production facility make us capable of adapting to the customers' specific needs, industry standards and technical certifications. Therefore we are one of the most agile companies in the business worldwide.

We are working on further developments and improved processes with our own engineering department. The propellers are accurately tested in our own test basin for efficiency, effectiveness and performance.

Our latest product is a result of this innovative-driven attitude. The new long-axis agitator Giantmix AMX was especially developed for biogas plants with higher dry matter content up to 16%.



- ▶ Agitator technology
- ▶ Service and maintenance

Year of foundation **1957**
Number of employees **80**

SUMA Rührtechnik GmbH

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- ▶ Activated carbon
- ▶ Desulfurization
- ▶ Gas quality measurement
- ▶ PSA

Year of foundation **1938**
 Number of employees **60**

CarboTech AC GmbH

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Economical solutions for your technical challenges

CarboTech is Germany's leading supplier of powdered, granular & extruded activated carbons. In the very heart of the Ruhr industrial area, CarboTech operates integrated production plants for the manufacture, processing and packaging of customised activated carbons, activated cokes and Carbon Molecular Sieves produced from bituminous coal, coconut shell coke and charcoal.

CarboTech has its roots in the German mining industry and is the leading manufacturer



of activated carbons in Germany today. CarboTech's strength is the development of tailor-made products, one of them are impregnated activated carbons "Made in Germany" for desulphurization of Biogas.

In addition, 40 years of experience in the production and development of Carbon Molecular Sieves (CMS) make CarboTech worldwide the partner of choice in the area of PSA-based nitrogen generation/Biogas upgrading.



- ▶ Trace elements
- ▶ Silage additives
- ▶ Process biological advice
- ▶ Enzymes
- ▶ Analytics

Year of foundation **2007**
 Number of employees **30**

Schaumann BioEnergy GmbH

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 E-Mail: info@schaumann-bioenergy.eu
 URL: www.schaumann-bioenergy.eu



Continuous biogas fermenters – from basic research in batch fermenters and trials in continuous fermenters through to field studies in parallel working commercial fermenters, the ISF Schaumann Research has created outstanding facilities for resolving complex issues relating to biogas production.

Schaumann BioEnergy – Competence in Biogas
 Schaumann BioEnergy GmbH offers know-how and tailor-made additives for the increasing biogas market.

Schaumann BioEnergy is the leading company concerning the optimisation of anaerobic digestion facilities and conservation of organic substrates. Next to the profound process consultancy and accredited lab services, Schaumann BioEnergy offers tailor-made additives to

increase efficiency of AD processes. The portfolio of Schaumann BioEnergy comprises trace elements mixtures, several specific additives to reduce inhibition effects, enzymes and bacterial products for conservation purposes.

With the high degree of experience Schaumann BioEnergy also supports investors during the realisation of their projects through neutral/independent project evaluation, opinion letters, market studies and training courses.





Specialist for trading and portfolio management biomethane



ARCANUM Energy is an owner-operated, independent group of two companies. As a service provider, advisor and partner that particularly caters to energy utility companies, farmers and municipalities, we deliver tailor-made strategies and business models in the renewable energies, energy efficiency and agriculture fields with a focus on energy, gas and carbon reduction. In the biomethane segment, ARCANUM Energy is Germany's leading expert for project development, operation, trading, handling and consulting.

Project development and plant services:

We provide manufacturer-independent project development services in the renewable energies sector (biogas, biomethane, wind, PV) to guarantee the long-term supply of sustainable electrical and thermal energy. Based on our independent function as project developers, we will ensure that the project is realised to your individual expectations in an optimal and economic manner.

As a medium-sized company, we provide services independent of plant and component manufacturers. Our investments in recent years have enabled us to establish a specialist full-service team that operates contracts to the full satisfaction of customers. Our dedicated management with highly qualified personnel ensures minimal downtimes for the biogas upgrading plants maintained and operated by us.



Supplier of project development and plant service

Portfolio management, trade and mass balancing:

ARCANUM sources and markets your biomethane at fair market conditions. We offer optimised selling and buying opportunities thanks to our independent access to the market, optionally to complement your own sales activities with a direct contractual relationship between the supplier and buyer. You can also access the biomethane market at any time using our online trading platform (www.biomechanmarkt.de), which lets you purchase or sell biomethane in a convenient and cost-efficient manner for a range of applications.

Furthermore, we offer our know-how to support you in managing and optimising your biomethane product portfolio. As part of our range of services, we deal with the obligatory mass balancing documentation for the biomethane quality assessments, for example in accordance with EEG, EEWärmeG and Biokraft-NachV/RED. In addition to using other mass balancing systems, ARCANUM also operates its own certified mass balancing system, BiMaS.



- ▶ Service and maintenance
- ▶ Gas transport
- ▶ Gas grid management
- ▶ Gas grid connection
- ▶ Biomethane trading

Year of foundation **2001**
Number of employees **50**

Arcanum Energy

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BIOGAS Convention & Trade Fair

Save the date!

- » Current lectures from the industry for the industry
- » Exclusive workshops
- » Main topics: security, efficiency, legal requirements for biogas plants, use of digestate as fertiliser, biomass production, repowering and future projects
- » Biogas worldwide: Case studies and best practice, climate protection and finance, innovative approaches, regulations, market drivers from all corners of the world

Worldwide the biggest meeting of the biogas industry

November – every even year
at Hanover
together with the Trade Fair:



December – every uneven year
at Nuremberg
BIOGAS Convention & Trade Fair:



Joint
plenary session
Exklusive workshops
Key topics



Presentations in German or English
or with simultaneous translation



Current information:
www.biogas-convention.com

Organisations

Fachverband Biogas e.V.

Fachverband Biogas (German Biogas Association) brings together operators, manufacturers and planners of biogas plants, representatives from science and research and all those interested in the industry. Since its establishment in 1992, the association, which currently has more than 4,900 members, has become the most influential independent organisation in the field of biogas worldwide. It campaigns for the increased use of biogas and biomethane technology through political lobbying at EU, national and state levels. Furthermore, it encourages the exchange of biogas-related information and knowledge, for instance by collecting, evaluating and spreading knowledge of scientific findings and practical experience, or by means of conferences, exhibitions and other events.

Fachverband Biogas e.V. works closely with international organizations such as the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the United Nations Industrial Development Organization (UNIDO), the International Solid Waste Association (ISWA) as well as the European Biogas Association (EBA), where it also acts as a founding member. As a consequence, Fachverband Biogas e.V. actively promotes and stimulates the exchange of international experience.

Fachverband Biogas e.V. has excellent expertise and knowledge in all biogas-related topics and cooperates with almost all official German bodies as well as many international ones where standards for biogas plants are discussed, developed and defined.

Year of foundation **1992** | Number of employees **41**



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United Nations Industrial Development Organization

United Nations Industrial Development Organization (UNIDO) is the specialized agency of the United Nations that promotes and accelerates sustainable industrial development, inclusive globalization and environmental sustainability. The mandate of the Organization is to eradicate poverty through inclusive and sustainable industrial development (ISID) in developing countries and economies in transition.

To achieve industrial development while safeguarding the environment, UNIDO recognizes that fossil fuels must be replaced with renewable energy technologies. To facilitate the uptake of renewable energy, the Renewable and Rural Energy Division - within UNIDO's Department of Energy- actively promotes renewable energy as a source of multiple benefits for Member States. Renewable energy has a great potential to help countries become less dependent on energy imports, to mitigate the effects of climate change, to create jobs and to enhance people's livelihoods. A significant component of the global renewable energy mix is biogas which is produced using waste products like manure, food scraps and crop residue. UNIDO firmly promotes the use of biogas for productive purposes as a renewable solution that brings significant social and economic benefits to rural and urban areas alike. Currently, UNIDO manages over 25 biogas projects in Africa, Asia, Europe and Latin America and the Caribbean.

Year of foundation **1966** | Number of employees **2,206**



UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

United Nations Industrial Development Organization

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European Biogas Association (EBA)

Founded in February 2009, EBA is the leading European association in the field of biogas and biomethane production, covering the anaerobic digestion and gasification industries.

Committed to the active promotion of the deployment of sustainable biogas and biomethane production and use throughout Europe, EBA has created a perfect network of established national organisations, scientific institutes and companies.

In 2016, the association counted 38 National Organisations as full members and 58 Companies as associated members from all over Europe, and had established cooperation with biogas associations from outside Europe.

Year of foundation **2009** | Number of employees **7**



European Biogas Association (EBA)

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Deutscher Verein des Gas- und Wasserfaches e.V. – Technisch-wissenschaftlicher Verein (DVGW)

DVGW (German Technical and Scientific Association for Gas and Water – Technical-scientific association) has worked successfully in the gas and water industry for more than 150 years.

Safety, hygiene and environmental protection are the main focuses of all the association's activities. DVGW is an association with about 13,700 members, which establishes the generally accepted rules of technology for gas and water systems, initiates research projects and provides training on a full range of gas and water industry topics. Moreover, DVGW provides an inspection and certification unit for products, individuals and companies. DVGW codes of practice lay the foundation for technical self-regulation and for the responsibility of the gas and water industry in Germany. They ensure safe gas and water supplies to the highest international standards. The non-profit organization was established in Frankfurt am Main in 1859. DVGW is economically independent and politically impartial.

Year of foundation **1859** | Number of employees **175**



Deutscher Verein des Gas- und Wasserfaches e.V. – Technisch-wissenschaftlicher Verein (DVGW)

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Glossary

Biogas, from ISO/AWI 20675: *“Gas produced by anaerobic digestion of organic matter, gasification of biomass or power to gas from biomass sources and without further upgrading or purification.”* It consists mainly of methane (CH_4 : 50 to 70 vol%) and carbon dioxide (CO_2 : 30 to 45 vol%). Biogas can also contain small amounts of secondary gas substances. These include hydrogen sulphide (H_2S : up to 10 g/m³), water vapour (H_2O : up to 50 g/m³), oxygen (O_2 : up to 2 vol%), nitrogen (N_2 : up to 5 vol%), and ammonia (NH_3 : up to 1 vol%), as well as organic silicon compounds (siloxanes: up to 10 mg/m³).

Biomethane, from CEN TC 408 : *“Gas comprising principally methane, obtained from either upgrading of biogas or methanation of biosyngas.”* As a rule, biogas upgrading includes the removal of CO_2 , the separation of sulphur and other trace molecules, and drying.

Natural gas is a gas mixture occurring in subterranean deposits consisting mainly of methane (CH_4 : 75 to 99 vol%) and other hydrocarbons (ethane: 1 to 15 vol%, propane: 1 to 10 vol%, butane, ethane and pentane). Secondary gas substances may include water vapour, hydrogen sulphide (H_2S : 0 to 35 vol%), nitrogen (N_2 : 0 to 15 vol%) and carbon dioxide (CO_2 : 0 to 10 vol%). The secondary gas substances are already separated during extraction.



Nm³ is a unit for the measurement of gas under standardized conditions of temperature (273 kelvin) and pressure (1,013 hectopascal).

Parts per million (ppm) is a way of quantifying small concentrations.

Example: 5 ppm X means: that from 1 million molecules, 5 of them are molecule X.

Power-to-Gas is a chemical process in which a fuel gas is produced by means of water electrolysis with partial downstream methanation using green electricity.

Regenerative thermal oxidation (RTO) is a process for thermal exhaust gas purification. This method is preferred in order to reduce hydrocarbon emissions. It is characteristic of the method that no stationary state is reached.

The **Wobbe Index** is an indicator for burning characteristics and the interchangeability of fuel gases such as natural gas and biomethane. It is defined as heating value divided by the square root of the specific gas density. The specific gas density is the density of the gas divided by the density of air.

$$I_w = \frac{VC}{\sqrt{\rho}}$$



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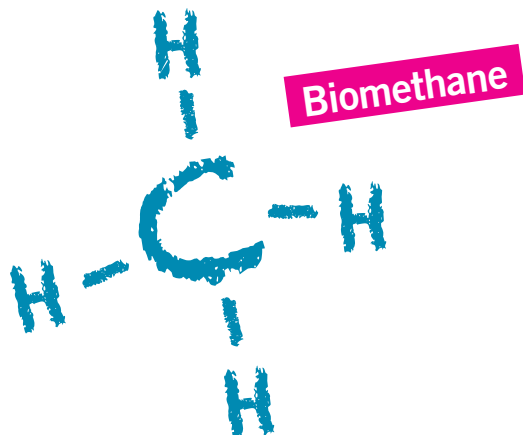
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www.biogas-to-biomethane.com

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SYMBOL DESCRIPTION:

Animal by-products		Fuel	
Vegetable by-products		Heat	
Biowaste from households		Biomethane	
Industrial and commercial wastes		Electricity	
Energy crops		Digestate	
Wet continuous digestion		Carbon dioxide	
Dry continuous digestion		Process auxiliaries	
Dry batch digestion		Plant components	
Pressure swing adsorption		Energy concepts	
Scubbing technologies			
Membrane separation			
Cryogenic treatment			

The depicted symbols are consistently used throughout the booklet and as a classification system of the different companies in the directory.



Fachverband
BIOGAS

German Biogas Association
www.biogas.org

www.biogas-to-biomethane.com