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BIOMETHANE



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1 INTRODUCTION

The upgrading of biogas into biomethane has significantly gained in relevance in recent years. In contrast to “on-the-spot conversion into electricity”, there are several advantages offered by upgrading biogas into biomethane and subsequently feeding it into natural gas grids. Through the use of biomethane at a place with a high demand for heating, the upgrading of biogas into biomethane contributes to a significant increasing share of externally usable heat energy; this in turn leads to an increase in the overall efficiency of biogas use. Essential characteristics of this are the decoupling of production and use in terms of location and also of time. Aside from the advantage of efficient use at places with sufficient demand for heat, biomethane can provide an important advantage in terms of the provision of energy in accordance with demand, by means of the storage function of the natural gas grid. A further essential advantage represents the more flexible possibilities for use, as biomethane is similar to natural gas in terms of its composition – thus biomethane is partly also referred to as bio natural gas. In terms of energy, biomethane can be used in the coupled production of electricity and heat (production in combined heat and power plants – CHP), as fuel in natural gas vehicles and also as a natural gas substitute in natural gas-fired burners used for heating. In addition, there is the possibility to use biomethane as a raw material for the chemical industry.



Fig.1: Example of a biogas plant with biomethane upgrading facility [13]

On 5 December 2007, the Report on Implementation of the Integrated Energy and Climate Programme (IECP) of the German Federal Government determined that, by the year 2030, a potential can be developed for biogas which corresponds to 10% of Germany’s consumption of natural gas. In this context a target was defined, aiming at an annual feed-in of biogas equating to 6% (ca. 6 bn. m³/a) of German natural gas consumption by 2020 and 10% (ca. 10 bn. m³/a) by 2030. The legislature’s intention in doing this is to reduce import dependency on natural gas, to generate impulses aimed at environmentally friendly energy production, and also to expand both the efficient utilisation of combined heat and power production (CHP) and also the use of biogas as a vehicle fuel. Within the framework of the amendment to the Gas Grid Access Ordinance (GasNZV), this definition of goals was formally incorporated into the Ordinance. The technical primary energy potential for biogas, taking 2020 as the reference year, comprises 503 PJ/a [1]. In comparison to this, 6 bn m³/a of (upgraded) biogas (assuming a methane content of 100%) corresponds to ca. 215 PJ/a.

At the end of 2011 ca. 7,100 biogas plants were operating in Germany, with an installed electrical capacity of around 2,780 MW and thus an annual electricity production of approx. 18 m. MWh [15]. Of these, 83 facilities were upgrading biogas into biomethane. In this regard, the total upgrading capacity of the raw biogas amounted to ca. 103,000 m³/h, in terms of figures. This corresponds to a biomethane production of approx. 57,000 m³/h, assuming plants operating at the rated load and an average methane content of

the raw biogas of 55 %. With a total capacity of 4.8 bn kWh/a, this is equivalent to 8 % of the expansion target set for the year 2020 [12].

The German Biogas Association's expectation was, that by the end of 2012, growth would take capacity up to 7,400 biogas plants, providing an electrical output of 2,900 MW [15]. As of 01/2012, the status is that around 60 further biogas upgrading projects are in the construction and planning phase.

DEVELOPMENT OF BIOGAS UPGRADING PLANTS IN GERMANY

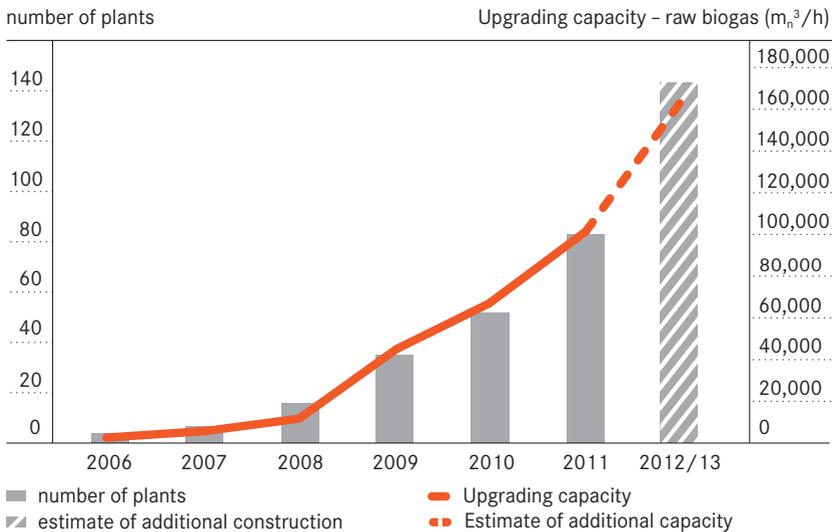


Fig. 2: Development of the upgrading capacity (raw biogas) of biogas upgrading facilities in Germany over the period 2006–2011, with an estimate of additional construction and capacity for 2012/13, as calculated in December 2011 (cumulated) [12]

2 ENVIRONMENTAL CONSIDERATION OF BIOMETHANE PRODUCTION – SUSTAINABILITY

The principle of sustainability originates from the forestry sector and was first formulated in writing at the beginning of the 18th century [3]. The definition of sustainability, still acknowledged to a large degree to this day, originates from the 1987 Brundtland Report of the World Commission on Environment and Development. This defines a development as being sustainable if the needs of the current generation are satisfied without limitations being imposed on future generations in terms of their needs [1].

Transferring this principle to the concept and operational mode of a biogas or biomethane plant, this means attaining as relevant an economic gain as possible while safeguarding compatibility with ecological and social considerations. For that reason, using animal excrements and plant residues counts as a very sustainable way of providing energy. The greatest potential is offered by the use of energy crops. However, the limitations in terms of usable agricultural land and the situation of increasing competition from the use of biomass as an energy source, results in the need for a sustainable mode of production and for the most efficient use possible.

Sustainability requirements for biofuels and electricity production from liquid biomass

In adopting the Sustainability Ordinance for Biofuels and Biomass Electricity (Biokraft-NachV) and the Biomass Electricity Sustainability Ordinance (BioSt-NachV) in 2009, the German Government defined binding sustainability criteria for liquid biomass used for producing electricity, or respectively for liquid and gaseous biomass used to produce biofuel. The intention in this was to secure a major reduction of greenhouse gas emissions through the use of biomass. Thus this legislative requirements in relation to sustainable production also apply to biomethane (upgraded biogas) used as fuel from 2011 onwards.



Fig. 3: Mixed cultivation of energy crops [14]

Reduction of greenhouse gas emissions

A central aspect of sustainability is the protection of climate and resources, resulting in the avoidance of greenhouse gas emissions. The most important greenhouse gases (GHG) include carbon dioxide (CO₂), methane (CH₄), nitrous oxide (so-called laughing gas, N₂O) and fluorinated compounds such as chlorofluorocarbons (CFC) [6].

The following factors along the value chain are crucially responsible for greenhouse-gas emissions which occurs by the energy production from biogas and biomethane (list added in accordance with [5]):

- the used biomass and its cultivation,
- the transport, storage and conservation (ensilage) of the biomass,
- the biogas plant and fermentation technology,
- the losses of biogas and biomethane into the atmosphere,
- the storage and application of fermentation residue,
- the utilisation of biogas and
- the upgrading of biogas to natural gas quality and its subsequent use;

It should be noted that, using optimum production-installation technology, the largest proportion of the emissions within the overall process emerges in producing the biomass. Accordingly, an intelligent choice of raw materials can positively influence the overall GHG balance; for this reason especially the use of plant residues and waste materials is recommendable.

Agriculture contributes to climate change with GHG emissions amounting to around 130 m tonnes of CO₂ equivalent/year (ca. 13 % of Germany's emissions). In this context, the key sources are ruminants' digestion processes (CH₄), crop production (CO₂ and N₂O), the decomposition of carbon in former fens and the energy requirements of the operating resources used [4]. At the same time, agriculture is not solely a source of greenhouse gases, it also contributes to GHG reduction. This by means of plants storing CO₂ in the process of photosynthesis.

Biogas and biomethane can also provide a decisive contribution to reducing the burden on the environment by replacing fossil-based energy sources, resulting in a reduction of CO₂ emissions. What is decisive in this regard is essentially the minimization of losses of biogas and biomethane, because methane has a more powerful effect on the climate than CO₂ does, by a factor of 21 [6] or of 25 [7] respectively.

Aside from greenhouse gas emissions generated in producing biogas and biomethane, efficient use has a major influence on reduction of greenhouses gases. In particular, producing electricity while simultaneously using the heat generated in that process achieves a noticeable reduction in greenhouse gases. Efforts to achieve efficient use of the biomass deployed are leading to more and more concepts for heat supply in villages and municipalities, based on biogas plants. If no complete and efficient use of the heat is possible at the biogas plant or within a distance of a few

kilometres, the opportunity still presents itself to convert the biogas into biomethane. That way, biomethane can be transported via the natural gas grid and used at a location with a high demand for heating.

However, additional climate-relevant emissions are produced in upgrading biogas to biomethane, mainly due to the efficiency level of the upgrading process (methane slip) and also to the energy requirement of the upgrading and feed-in installation itself. Aside from technical measures aimed at energy saving, the use of renewable energy for providing the required process energy has

a positive influence on the GHG balance of the process. These factors depend, in particular, on the chosen upgrading process and the gas pressure of the natural gas grid at the entry point. For instance, chemical absorption with organic solvents (amine scrubbing) is characterised by a very low level of methane slip [2]. Experience has also shown that larger processing capacities can lead to reduced GHG emissions because of their lower specific energy requirements. Feeding biomethane into gas grids with lower pressure levels, in turn, reduces the energy level required for increasing the pressure at the entry point.

GHG EMISSIONS IN BIOMETHANE PRODUCTION

2,000 kW_{el} (ca. 500 m_n³/h biomethane)

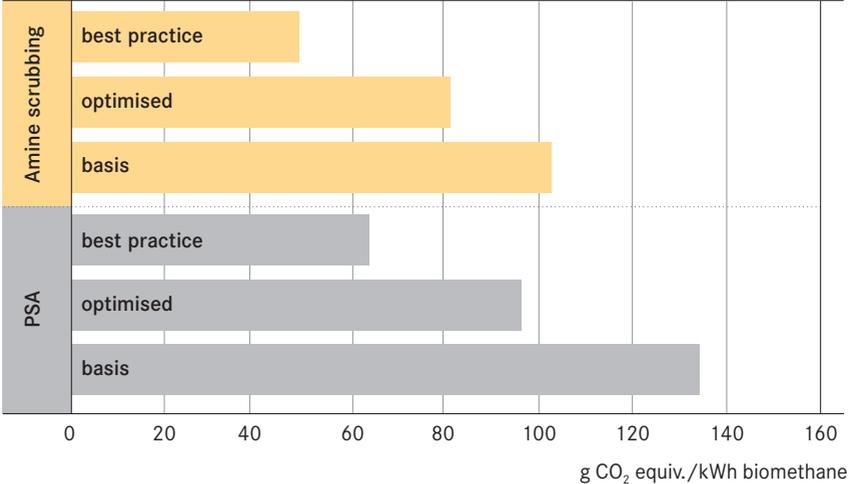


Fig. 4: GHG results for the production of biomethane, basis is a biogas plant of 2,000 kW_{el}; the equivalent corresponds to ca. 500 m_n³/h biomethane; increase of pressure up to 16 bar [21]

Figure 4 compares the greenhouse gas emissions involved in biomethane production for the following upgrading processes: pressure-swing adsorption (PSA) and amine scrubbing. Here both processes are considered based on taking into account three variations (“basic”, “optimised” and “best practice”) for the whole process chain, i.e. the greenhouse gas emissions are added together, starting from biomass production, via transportation and through to the biogas upgrading and the raising of pressure to 16 bar.

“Basic”/“optimised”

- gas-tight covered storage for fermentation residue: no methane emissions
- biogas production: methane emissions of 0.45 %
- plant energy requirement: covered by a biogas-operated combined heat and power installation (CHP); heat-led (i.e. heat requirements are the determinant of operations); 55 % of the electricity production for the biogas plant, 45 % is fed in and booked as a credit entry in the calculation system. Methane emissions of CHP: 0.5 %

“Basic”

- Processing by PSA: methane emissions and methane slip of 2 %, electricity requirement: $0.3 \text{ kWh}_{\text{el}}/\text{m}_n^3$ raw biogas
- Processing by amine scrubbing: methane emissions and methane slip of 0.1 %, electricity requirement: $0.168 \text{ kWh}_{\text{el}}/\text{m}_n^3$ raw biogas, heat requirement: $0.4 \text{ kWh}_{\text{th}}/\text{m}_n^3$ raw biogas, heat produced by a natural gas heating plant

“optimised”

- Processing by PSA: 2 % methane losses with the use of post-combustion, final methane emissions of 0.01 %, electricity requirement: $0.3 \text{ kWh}_{\text{el}}/\text{m}_n^3$ raw biogas
- Processing by amine scrubbing: methane emissions of 0.1 %, energy requirement: $0.168 \text{ kWh}_{\text{el}}/\text{m}_n^3$ raw biogas, heat requirement: $0.4 \text{ kWh}_{\text{th}}/\text{m}_n^3$ raw biogas; heat regeneratively produced by a biomass heating plant

“best practice”

- beyond the optimised installation concept: lower mass losses during the silage making process; higher gas yield; lower methane emissions from the biogas plant, the CHP installation and in the upgrading process; lower losses of nitrogen in form of ammonia and laughing gas, by means of optimised management of fermentation residues [21]

It is evident that with “best practice” assumptions, GHG emissions can be reduced by ca. 50 % compared to the basic model [21].

As a generally valid observation, legislative limits are set regarding the maximum permissible methane emissions into the atmosphere at the upgrading of biogas to biomethane: with the new Gas Grid Access Ordinance (GasNZV), in force since 2010, a biomethane supplier from a new upgrading installation must prove that, based on regular operation of the installation, the maximum methane emissions into the atmosphere do not exceed 0.5 %. In the case of installations connected to the natural gas grid after

30 April 2012, the relevant value is reduced to 0.2%. Likewise, the Renewable Energy Sources Act (EEG) 2012 limits the maximum emissions into the atmosphere to 0.2% for new installations coming into operation after 1 January 2012, and from 1 May 2012 for installations already in service. In order to be able to guarantee this, and thus to limit emissions into the atmosphere, in the case of upgrading processes which involve higher levels of methane slip, the exhaust gases are subjected to an after-treatment process.

All things considered, it is evident that, in replacing fossil fuels, biogas and biomethane can contribute decisively to the reduction of CO₂ emissions. A precondition for this is low GHG emissions along the whole value chain. The lower the GHG emissions in producing biogas and biomethane, the more relevant the effect are in climate-protection terms.



Fig. 5: Biogas plant [14]

3 PRODUCTION OF BIOGAS

Biogas arises during the microbial decomposition of organic matter, subject to the almost complete exclusion of oxygen. This process of decomposition occurs widely in nature, for example in bogs, fens and swamps or in ruminants stomachs. This process is technically performed in biogas plants.

The biogas produced is a gas mixture comprised of ca. 2/3 methane and 1/3 carbon dioxide, as well as small quantities of water, hydrogen sulphide, nitrogen, oxygen, hydrogen and other trace gases.

In principle, the biological process of decomposition (fermentation) can be subdivided into four phases, each of them involving different groups of micro-organisms. The phases themselves take place in a biogas plant in parallel and simultaneously. Within this, temperature, pH value, nutrients supply and inhibitors have a substantial influence on the fermentation process:

Use of substrates

As a general observation, biogas can be produced from a large number of substrates. The resources used in agricultural biogas plants, besides animals' excrement (such as cattle slurry and pig slurry), residues of fodder and other agricultural organic residues, are mainly renewable resources. Examples of these are maize, grasses, grain, sunflowers and sugar beets. However, other organic substrates can also be used for biogas production, such as residuals from the food industry, vegetable

or other food waste, landscaping material, green cuttings or organic waste from municipal waste disposal. The degree of degradability and the dynamics of fermentation, as well as the yield of biogas, are determined by the substrates used, together with the technical and biological performance characteristics of the production installation and of the fermentation process. [1]

Plant engineering

An agricultural biogas plant usually consists of a preliminary tank, with a feed mechanism for solid matter (where applicable), a fermenter in a horizontal or standing position with a stirring device, a gas storage, a storage for fermentation residue, and the biogas utilisation (e.g. a combined heat and power installation). In the preliminary tank, the substrates are stored on an intermediate basis, prepared and mixed; from there they go into the insulated and heated digester. The digester is the core element of the unit; it must be gas-tight, water-tight and impermeable to light. Appropriate stirring technology is used to guarantee the homogeneity of the fermentation substrate and to support the formation of gas. The gas storage takes up the biogas while the fermented substrate goes into the store for fermentation residues; the latter usually also serves as a post-digester. While the biogas is then taken to serve its designated purpose, the fermentation residue can be distributed on arable land as valuable farm fertiliser (Figure 6).

There is a great diversity of production installation concepts for obtaining biogas. These can be differentiated according to their process characteristics, such as the dry matter content of the substrates, the way in which the material is fed in, or the number of process phases. The largest number of biogas plants in Germany operates on the basis of continuous wet fermentation in the mesophilic temperature range (32–42 °C).

At present, biogas in Germany is mainly used in combined heat and power facilities for producing electricity and heat; this is due to the established feed-in tariffs for electricity from renewable resources. Because in many instances the heat cannot be used sufficiently, the upgrading of biogas to biomethane offers the possibility to raise overall efficiency by decoupling production and use in terms of location and time.

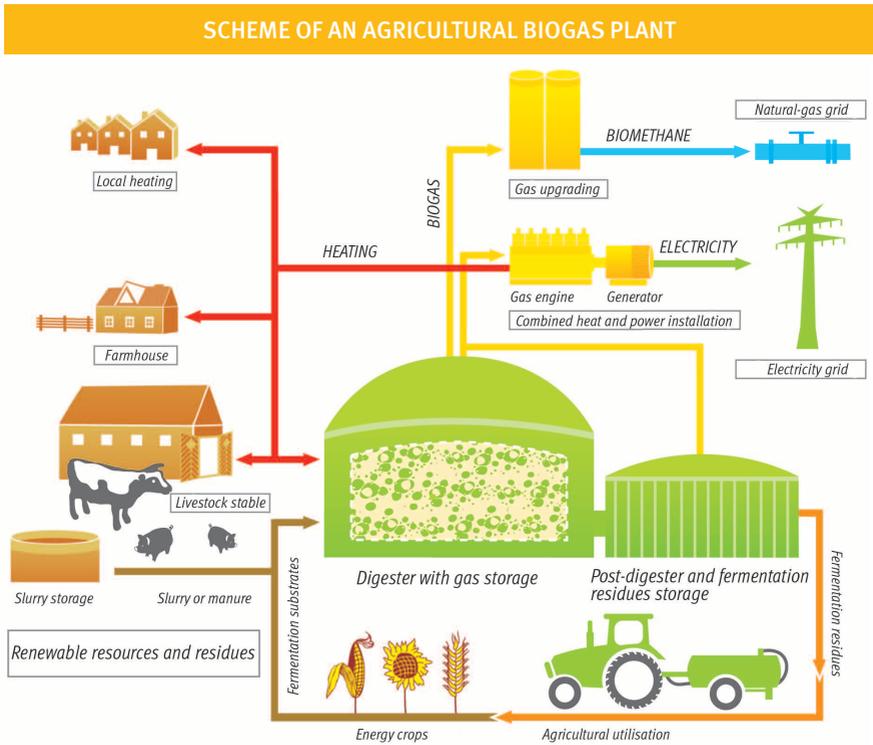


Fig. 6: Scheme of an agricultural biogas plant [14]

4 BIOMETHANE PRODUCTION AND TRANSPORT

In order to be able to feed biogas into natural gas grids or to use it as a fuel in natural gas vehicles, the gas needs to be purified of unwanted constituent elements, the methane content needs to be increased, and the CO₂ needs to be removed. This happens through the so-called upgrading of the biogas into biomethane.

At present, there are five different technologies used in Germany to remove the CO₂, for the purpose of methane enrichment: PSA – pressure swing adsorption, pressurised water scrubbing, physical absorption with organic solvents, chemical absorption with organic solvents, and membrane processes. Cryogenic procedures (in the low-temperature range) are not yet in commercial-scale use in the upgrading of biogas.

4.1 Biogas purification

In part, the need for biogas purification and the possible processes applicable in the case of biogas plants with biogas upgrading differ from those of on-site electricity conversion installations involving the direct use of raw biogas in CHP installations. The composition and origin of the biogas (renewable resources, slurry, waste material, sewage sludge, etc.), as well as the subsequent upgrading technology, define the type of purification used for the biogas. Within this, the sequence of the steps in the purification process varies according to the upgrading technology used.

Dehumidification/drying

After it leaves the fermenter, biogas is saturated with water vapour. To a large degree this water must be extracted from the gas, to prevent faults in the subsequent upgrading and also to ensure compliance with the limit values applicable to the feeding-in of biomethane. Usually dehumidification/drying takes place at two positions in the biomethane plant:

- If a compression takes place before entry into the actual CO₂ removal stage (e.g. scrubber column, molecular sieve or membrane), a cooling process extracts water from the biogas which is heated by the compression process. This happens in order to prevent an unwanted condensation of the humidity in the system further downstream.
- In the case of scrubbing processes, the biomethane is dried after it exits the scrubbing column.

Desulphurisation

Hydrogen sulphide (H₂S) can occur, depending on the origin of the biogas, in concentration ranges from ~70 mg/m_n³ up to (in some cases) over 10,000 mg/m_n³. In combination with water, sulphuric acid can be formed. In order to avoid corrosion of the parts of the production installation and to comply with the quality requirements in force for feeding the biomethane into natural gas grids (the same applies for its direct use as a fuel), the biogas needs to be desulphurised. A basic distinction is made between coarse

desulphurisation and fine desulphurisation processes. For coarse desulphurisation, the biological desulphurisation in conventional agricultural biogas plants directly using gas in CHP units is usually carried out in the fermenter by means of adding doses of air. However, in the case of biogas plants involving biogas upgrading, this process is only applicable to a limited degree and subject to particular preconditions; this is because the result is a thinning of the biogas with atmospheric nitrogen. This cannot be separated off any more by practically any of the biogas upgrading technologies. To avoid these thinning effects, it is mostly the following processes that are applied for coarse desulphurisation:

- Adding doses of iron hydroxide and/or iron salts into the fermenter,
- External biological desulphurisation outside the fermenter or
- Caustic treatment with biological regeneration of the washing agent.

For fine desulphurisation (reducing the concentration of hydrogen sulphide to $< 5 \text{ mg/m}_n^3$), the process of catalytic oxidation and adsorption with impregnated activated carbon is the state of the art; it is to be found in operation at almost all biogas-upgrading facilities.

Apart from the constituent parts described above, and depending on the origin of the raw biogas, other trace gases can also occur: these also need to be separated off. Among others, these include ammonia, organic silicon compounds, halogens and aromatic compounds. [2]

4.2 Process of carbon dioxide removal

PSA – Pressure swing adsorption

Pressure swing adsorption constitutes an adsorptive biogas upgrading process. Adsorption should be understood as the deposition of constituent parts of gas (here: CO_2) onto the surface of solid matter (adsorbents). Activated carbons, zeolites or carbon molecular sieves can be used as adsorbents. Apart from CO_2 , however, other constituent parts of gas can also be retained, such as water (H_2O) or hydrogen sulphide (H_2S) or also, to a very small degree, nitrogen (N_2) and oxygen (O_2). However, in practical application H_2O and H_2S are already removed before the biogas enters into the adsorption column. [2]

In this process, there is initially an increase of pressure up to a level of ca. 4 to 7 bar. After the subsequent separating of the water and the fine desulphurisation, the gas is guided into an adsorption column in which the molecular sieve is located. This is where the CO_2 is retained by means of deposition onto the molecular sieve. CH_4 , by contrast, passes through the column almost completely. Only a small part of the methane is also held back and ejected with the CO_2 . The adsorbed constituent parts of gas are removed (desorbed) by means of lowering the pressure. A first flow of the desorbed gas is guided into a second, non-charged column, as this gas still contains CH_4 . This CH_4 almost entirely passes through this column, whereas the other constituent parts are held back again. The complete desorption of the first column is brought about by

SCHEMATIC PROCESS DIAGRAM – PRESSURE SWING ADSORPTION

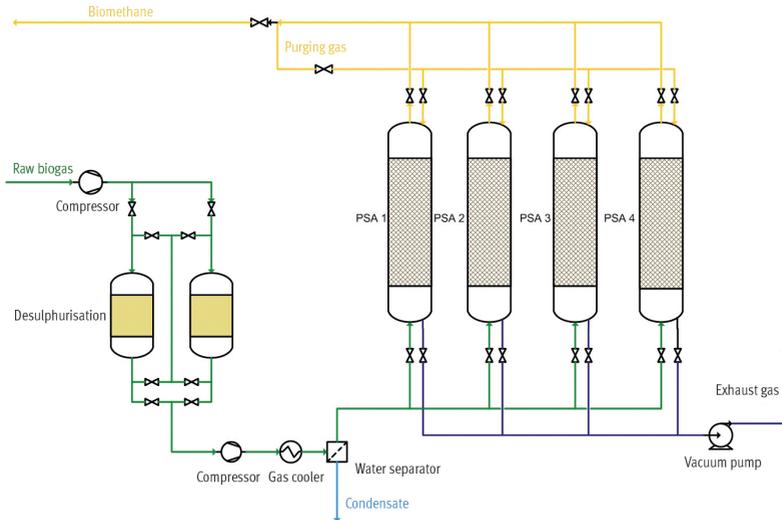


Fig. 7: Schematic process diagram – pressure swing adsorption with four adsorber units [10]

setting up a vacuum. As the flow of exhaust gas still contains residual quantities of CH_4 , the exhaust gas has to undergo an after-treatment. [2]

Pressurised water scrubbing (PWS)

Pressurised water scrubbing constitutes an absorptive biogas upgrading process. In contrast to adsorption, absorption is the dissolving of gases in fluids (absorbents). In the case of pressurised water scrubbing it is solely water that is used as an absorbent. The process is based on the reversible absorption in water (through physical bonding forces (physisorption)) of CO_2 , but also of other constituent parts of gas exerting an acidic effect (e.g. H_2S) and alkaline effect

(e.g. ammonia – NH_3). The fine desulphurisation of the biogas in the absorption column is a side effect of this process.

After compression, usually consisting of several stages and taking the pressure to levels between ca. 7 bar and 10 bar, the raw gas progresses from below into the absorption column. The water streams through the column from top to bottom and is charged with the constituent part of gas which is to be absorbed. The product gas, saturated with water, leaves the column at the upper end and subsequently it still needs to be dried. As some of the CH_4 also formed bonds with the charged water particles, initially this water is subjected to

a process of lowering of its surface tension, in a so-called “flash” column. The gas desorbed in this intermediate stage of lowering of surface-tension leaves the “flash” column at the upper end and is guided back into the flow of raw gas. The water, which above all still contains dissolved CO_2 , is guided into the desorption column from above; there its surface tension is reduced, taking it to the level of atmospheric pressure. In addition, to accelerate the expulsion of the gas from the water, air is blown into the desorption column from below. The water is now regenerated and can be used once again for the purpose of absorption in the scrubber column. The dissolved exhaust gas leaves the column at the upper end of the desorption column. As the exhaust gas flow still contains residual quantities of CH_4 , usually the exhaust gas needs to undergo an after-treatment. [2]



Fig. 8: Pressurised water scrubbing [13]

Physical absorption with organic solvents (Genosorb® scrubbing)

This process also involves a purely physical absorption (physisorption). Yet in contrast to pressurised water scrubbing, an organic reagent (e. g. polyglycol mixes) is used as the absorbent. Before the raw gas enters into the absorption column, compression is used to take the pressure level to ca. 8 bar. Through a cooling of the compressed gas, set up further downstream in the process, water is condensed and subsequently it can be expelled from the system. In the absorption column the stream of absorbent goes through the biogas in counter-flow, forming bonds with CO_2 as well as with H_2S and H_2O . Thus, as is the case with pressurised water scrubbing, the fine desulphurisation process can be omitted. The product gas, dehumidified as well as finely-desulphurised by the hygroscopic characteristics of the absorbent, exits the column at the other end. Depending on the product gas requirements or respectively on the composition of the raw gas, there is the possibility to conduct an additional fine desulphurisation process and/or adsorption drying of the product gas, for example. As in the case of pressurised water scrubbing, what happens here also is initially a lowering of surface tension of the charged washing solution in a “flash” column. The complete desorption takes place through supplying heat (ca. $50\text{--}80\text{ }^\circ\text{C}$) and also supplying stripped air in the desorption column. The provision of heat is possible due to the decoupling of waste heat from the compressor. In parallel, the process is characterised by the possibility to have parallel absorption of CO_2 ,



Fig. 9: Physical absorption with organic solvents (Genosorb® scrubbing) [13]

H_2S and H_2O in the scrubber column. In this process also, the exhaust gas flow contains residual quantities of CH_4 and thus there usually needs to be an after-treatment of the exhaust gas. [2]

Chemical absorption with organic solvents

Chemical absorption with organic solvents, often referred to in practice as “amine scrubbing”, constitutes a chemisorptive process. Depending on the production installation manufacturer, different ethanolamine-water mixtures are used (e.g. monoethanolamine or diethanolamine). In contrast to the purely physical washing processes, the scrubber column can carry out an absorption process almost without pressure (ca. 100 mbar). Depending on the manufacturer, however, processes are also used in which the gas is compressed to up to 4 bar before it enters into

the absorption column. As co-absorption of H_2S is possible in the cleaning unit, most processes involve a fine desulphurisation of the biogas. As with all other upgrading processes, N_2 and O_2 should be prevented from entering, as N_2 is not absorbed and thus the result can be a thinning of the product gas. The presence of O_2 in the raw gas exerts an additional negative effect in this process, because it can result in an unwanted oxidation of the absorbent. The regeneration of the charged absorbent takes place in the desorber, with heat being applied. Depending on the manufacturer, heat is required at a temperature of 110–160 °C. The particular features of the process are very high levels of purity of the product gas (on the precondition that no N_2 or O_2 , or very little, is contained in the raw gas) and, compared to other upgrading processes, a very low level of methane losses. An after-treatment of the

exhaust gas, as is necessary in the case of other upgrading processes, can usually be omitted. After the absorption process, the product gas is saturated with humidity, a drying operation is required. [2]

Membrane process

In the case of membrane processes, also referred to as gas permeation processes, various degrees of permeability of polymer membrane materials are used to separate unwanted constituent parts of gas from the biogas. Polymers used include, among others, cellulose acetate or aromatic polyimides. These membrane materials exhibit high permeability levels for CO_2 , H_2O , NH_3 and H_2S in comparison to their permeability for CH_4 . Particularly in order to extend the turnaround time of the membranes and to guarantee an optimum performance of the

separation activity, in practical application, apart from separating off dusts and aerosols, a drying and fine desulphurisation of raw gas is necessary before it makes contact with the membrane. Thus, before the biogas reaches the membrane modules, firstly it is dried, then it is compressed to ca. 5 to 10 bar; then (depending on choice) before or after the compression the fine desulphurisation is carried out. In the membrane module, CO_2 penetrates the membrane and the CH_4 is retained. Mostly, in practical application it is multi-stage processes that are used. Residual quantities of methane in the permeate flow material necessitate an after-treatment of the exhaust gas. Beyond this, a combination of membrane separation/cryogenic processes is possible. [2] [25]

Cryogenic separation

In the case of low-temperature processes, the lowering of the temperature of the gas flow leads to condensation or respectively to re-sublimation of the CO_2 , whereby the CO_2 is present in fluid or solid form. If the CO_2 is sufficiently pure, it can be put also to commercial use. So far there has been little commercial-scale experience of using this process. [2]

Figure 11 shows the extent of use of the different upgrading technologies in Germany.

As a general observation, most upgrading technologies are also suitable for small-sized upgrading facilities in terms of their technical aspects. This becomes evident particularly when considered the structure



Fig. 10: Membrane installation [13]

DEVELOPMENT OF THE VARIOUS UPGRADING TECHNOLOGIES

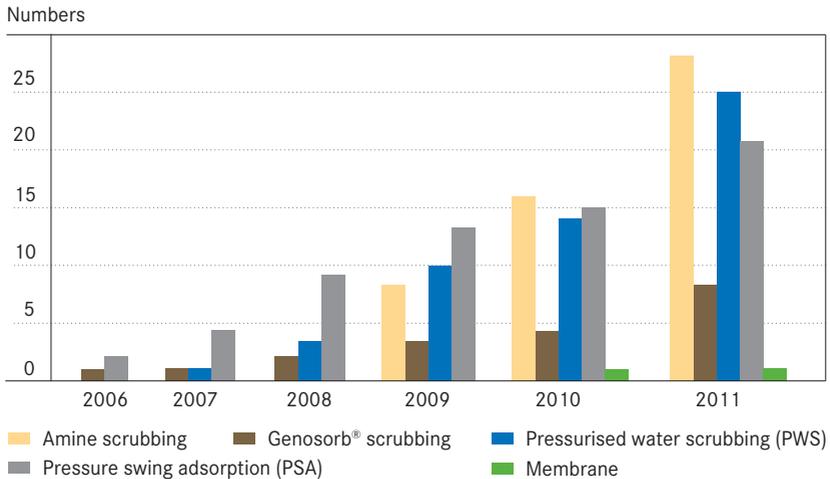


Fig. 11: Number of biogas upgrading plants, according to the upgrading technologies used, over the period 2006–2011 (cumulated) [12]

of the biogas upgrading projects in other European countries, where on average significantly smaller installation capacities are in operation. Accordingly, there are or there have been (e. g. on a pilot-project scale) upgrading installations operating with raw gas capacities of $< 150 \text{ m}_n^3/\text{h}$ for all of the currently in Germany used upgrading technologies on a commercial scale.



Fig. 12: Pressure swing adsorption [13]

Table 1 provides the most important characteristic values for the various biogas upgrading technologies.

Tab. 1: Characteristic values of various biogas upgrading technologies (IWES, completed in accordance with [2])

		PSA	Pressurised water scrubbing (PWS)	Physical absorption with organic solvents	Chemical absorption with organic solvents	Membrane processes	Cryogenic separation
Electricity requirement	[kWh/ m_n^3 BG]	0.20– 0.25	0.20– 0.30	0.23– 0.33	0.06– 0.15	0.18– 0.25	0.18– 0.33
Heat requirement	[kWh/ m_n^3 BG]	0	0	~ 0.3	0.5– 0.8	0	0
Temperature process heat	[°C]	–	–	55– 80	110– 160	–	–
Process pressure	[bar]	4–7	5–10	4–7	0.1–4	5–10	
Methane loss	[%]	1–5	0.5–2	1–4	0.1	2–8	
After-treatment of exhaust gas necessary? (legislation: EEG & GasNZV)		Yes	Yes	Yes	No	Yes	Yes
Fine desulphurisation of the raw gas necessary?		Yes	No	No	Yes	Recommended	Yes
Water requirement		No	Yes	No	Yes	No	No
Chemicals requirement		No	No	Yes	Yes	No	No

4.3 Exhaust gas treatment

In order to comply with the limit values set by the Renewable Energy Sources Act (EEG), the Gas Grid Access Ordinance (Gas-NZV) and the Technical Instructions on Air Quality Control (TA Luft), an after-treatment of exhaust gas can be necessary for some biogas upgrading technologies [2].

As a matter of principle, distinctions should be made between the following terms:

- **Methane slip (methane losses)**
Relationship between the volume of methane which does not get into the flow of product gas (on the one hand), to the volume of methane in the raw gas as it enters the biogas upgrading installation (on the other).
- **Maximum methane emissions into the atmosphere**
Relationship between the volume of methane escaping unoxidised into the atmosphere and the volume of methane in the raw gas as it enters the biogas upgrading installation. What this means is the part of the methane slip which escapes unoxidised into the atmosphere.

For treating the exhaust gas, various processes are available for reducing the methane emissions. The most relevant processes are stated as follows:

- **Regenerative thermal oxidation (RTO)**
This process is suitable particularly for flows of exhaust gas with low concentrations of methane, as is typically the case with pressure water scrubbing or Geno-

sorb® scrubbing. Beyond this, compared to other processes for after-treatment of exhaust gases it is insensitive to corrosive constituent parts (H_2S) in the flow of exhaust gas. An auto-thermal operation (without a supporting gas being added) is possible, starting from a methane concentration level of ca. $2 \text{ g CH}_4/\text{m}^3$. In this process the exhaust gas is warmed to oxidation temperature. The substance is guided through several chambers (mostly 2–3); a flow reversal is used. Heat accumulators are located in the system; through these, the heat energy is cyclically recovered, making possible the auto-thermal operation of the system. [2]

- **Catalytic post-combustion**
By means of catalytic oxidation processes, in a similar way to RTO, residual quantities of CH_4 are oxidised in the exhaust gas flow of the biogas upgrading process. Platinum, palladium or cobalt are used as catalysts. Essential differences to RTO consist in the lower temperature level and the degree of sensitivity to catalyst poisons (e.g. H_2S). The process can likewise operate at very low concentrations of methane, whereas by contrast too high concentrations of methane are to be avoided, because they can lead to an overheating of the catalyst bed. [2] The process is to be found occasionally at PSA installations.
- **Low calorific gas burner**
For the utilisation of low-calorific gas, it is also possible to use special burners which can be operated with low levels

of methane content. However, the necessary minimum methane content is ca. 4 to 5 %, presenting an essential difference to the two processes previously described. As most biogas upgrading processes reach significantly lower methane concentrations in the exhaust-gas flow, either the level of methane slip must be deliberately set high or it is necessary to add a quantity of higher calorific gas (e. g. raw biogas). So-called Flox® burners have commercial-scale relevance (flameless oxidation). In this process, the mixed gas is burned without a flame, using pre-warmed air and, where applicable, pre-warming of the exhaust gas. The burner's exhaust gas has a temperature of 600 to 700 °C. [2] Low calorific gas burners are used primarily at PSA and also membrane installations.

4.4 Structure of the German natural gas grid [20]

The German natural gas grid is around 495,000 km [34] in length, ranking among the world's best-developed networks. It enables biomethane not only to be transported but also to be stored outstandingly well. Due to its historical development, it is hard to characterise the gas grid in terms of a system. A subdivision is made based on levels of pressure, levels of supply and combustion characteristics.

The grid levels can be divided as follows:

- Level 1: International long-distance transport grid
- Level 2: Trans-regional transport grid
- Level 3: Regional transport grid
- Level 4: Local distribution grid

The pressure stages are differentiated as follows:

- High-pressure grid (HP): 1–120 bar
- Medium-pressure grid (MP): 0.1–1 bar
- Low-pressure grid (LP): up to 0.1 bar

Natural gas is subdivided according to its combustion characteristics, based on the following terms of reference:

- H-gas grid (high calorific value, from 11.1–12.5 kWh/m³)
- L-gas grid (low calorific value, from ca. 9.1–11.0 kWh/m³)

The natural gases are differentiated according to their geographical origin (see Table 2) and the result is regionally different qualities of the gas. The gas quality in the respective



Fig. 13: After-treatment installation for exhaust gas (here: RTO) for the cleaning of exhaust air (here ca. 2,000 m³/h) of a PWS-facility [13]

Tab. 2: Compositions of gas for natural gases sourced from different areas of origin [8]

	Methane vol. %	Ethane vol. %	Propane vol. %	Butane vol. %	Carbondioxide vol. %	Nitrogen vol. %
H-gas						
Russia	98.3	0.5	0.2	0.1	0.1	0.8
North Sea I	88.6	8.4	1.7	0.7	0	0.6
North Sea II	83.0	11.6	3.1	0.5	0.3	1.5
L-gas						
Holland I	81.3	2.8	0.4	0.3	1.0	14.2
Holland II	82.9	3.7	0.7	0.3	1.3	11.1
East Hannover	79.5	1.1	0.1	0	0.7	18.6

natural gas grid, into which the upgraded biogas is to be fed, the composition of the biomethane and the feed-in method (replacement gas or supplementary gas), have a decisive influence on the kind and the scope of conditioning applied (conditioning is the adaptation of the gas being fed in, by means of adding liquid gas and/or air, to match the combustion characteristics of the natural gas in the natural gas grid).

4.5 Biogas conditioning and feed-in installations

According to Article 32 of the Gas Grid Access Ordinance (GasNZV) the grid connection consists of the connecting pipeline between biogas upgrading plant and gas grid, the gas pressure control and measurement system, the installation used for increasing pressure, and the verifiable measurement of the biogas (biomethane) to be fed in. Despite the division of costs between supplier

(operator of the biomethane plant) and the grid operator, when the grid connection is installed, the grid operator is the owner and operator of the grid connection. The costs for operation and maintenance are borne entirely by the grid operator.

Essential functions of the feed-in installation are stated as follows:

- Creation of a structural connection between the biogas upgrading installation and the gas grid
- Verifiable measurement of the biomethane (measurements relevant to billing, such as measurement of gas quantities and calorific parameters)
- Measurement of the gas composition
- Conditioning of the biomethane (adaptation of the combustion characteristics of the biomethane to those of the natural gas in the gas grid)
- Odourisation of the biomethane in accordance with the DVGW G 280-1 and G 281 ordinances (DVGW is the German

Technical and Scientific Association for Gas and Water); this requirement is omitted in the case of high pressure levels

- Increasing the pressure of the biomethane to match the grid pressure

Structural connection to the natural gas grid

In most cases, the feed-in station is located directly next to the upgrading plant (mostly on the same site). Depending on the location, the connecting pipeline to the natural gas grid can be several kilometres in length. Nevertheless, for the most part biogas upgrading installations are planned in direct proximity to natural gas grids, usually at distances below 2 km. Because in most cases replacement gas is fed in, the biomethane in this connecting pipeline already corresponds to the requirements of DVGW G 260/262, is conditioned, compressed to match grid pressure and, if necessary, odourised.

Measurement technology

The measurement technology at the feed-in station has several functions to fulfil. It serves the purpose of monitoring the limit values for various parameters, as stated in the DVGW Worksheets G 260 and G 262. In order to be able to determine the energy content of the biomethane quantity being fed in, a measurement of both the calorific value and of volume (gas quantity) must be carried out. In order to determine the calorific value relevant for billing, the following are used: process gas chromatographs (PGC) and also combustion calorimeters suitably authorised in terms of the law governing verification of measurements. Like-

wise, PGCs serve the purpose of measuring the composition of gas, in order to monitor data in relation to the limit values stated in the Worksheets G 260 and G 262.

Conditioning

A conditioning process is necessary when replacement gas is fed in, in order to adapt the biomethane's combustion characteristics (calorific value and Wobbe Index) to match those of the natural gas in the natural gas grid. This is usually done by adding liquid gas. Depending on the gas composition of the natural gas, a reduction of the calorific value can also be necessary, by air (L-gas grid areas) or respectively by a proportional addition of liquid gas and air (certain H-gas grid areas).

Odourisation

In accordance with the DVGW G 280-1 ordinance, gases used for public gas supply must be equipped with a sufficient warning smell. This is done by adding an odourising agent. In the case of feeding gas into transport grids, usually no odourisation takes place. Similarly, in the case of feeding-in only small quantities (low proportion of the flow of biomethane volume to the flow of natural gas volume) odourisation can be omitted.

Increase of pressure

Usually, pressure is increased to grid-pressure level by means of piston compressors and/or rotary screw compressors. Compressors are used either in single-stage or also multi-stage versions: this depends on the supply pressure (the outlet pressure from the biogas upgrading installation), which

ranges from a few mbar up to ca. 8 bar (with different upgrading processes using different levels), and also depends on the necessary outlet pressure (pressure in the natural gas grid). In most cases, feed-in projects entail a feeding-in of gas in stages of grid-pressure going up to 16 bar. In these cases, the process of compression to reach grid pressure is usually carried out in only one compression stage (depending on the level of pressure at the outset).



Fig. 14: Biogas feed-in station [13]

DEFINITIONS [8]

Basic gases are the gases usually distributed in a given supply area. (→ natural gas in the natural gas grid)

Supplementary gases are gas mixtures which are substantially different to the basic gas in terms of composition and combustion characteristics. They can be added to the basic gas in a limited quantity. The demand for homogeneous combustion performance of the mixture determines the possible extent of the addition. (→ non-conditioned biomethane)

Replacement gases are gas mixtures which display the same kind of combustion performance as the basic gas, although their composition differs from that of the basic gas, and also (where applicable) from characteristic data. This is subject to the same gas pressure and unchanged setting of the equipment (e.g. of a natural gas burner). (→ conditioned biomethane)

4.6 Safety of installations

In order not to restrict the technical safety of the gas grids and the supply safety for gas customers, the DVGW Worksheets G 260 and G 262 state the requirements for the gas characteristics. In addition, the DVGW Basis for Testing VP 265-1 regulates the minimum requirements in terms of safety for upgrading, including compression, pressure regulation, conditioning and measurement, through to the feed-in of biomethane into natural gas grids. It applies to the planning, manufacture, building, testing and commissioning of installations for biogas upgrading and feed-in; among other things, it refers to various laws and ordinances, DIN norms and DVGW regulations. [9]

For end-users, the same security stipulations apply to the use of biomethane as apply to the use of natural gas.

5 POSSIBILITIES FOR USE OF BIOMETHANE

To secure the supply of energy for the future and to make it more independent of fossil-based and nuclear sources, huge efforts are necessary to achieve energy savings, but also to develop renewable energy sources.

Biomethane is a very valuable renewable energy source and an important element of viable energy concepts for the future. It is produced on a commercial scale, transported, stored and distributed via existing natural gas grids, and can be used efficiently and in accordance with demand. [11] Biomethane is usable both for industry and also for public and private energy consumers; according to choice, it can be used for producing electricity and heat, but also as a fuel.

5.1 Biomethane utilisation

According to the Biogas Monitoring Report 2011 by the Federal Network Agency (BNetzA), in 2010 the quantities of biomethane traded (and allocated to a specific use) were allocated to the following three areas of use: “CHP – combined heat and power”, “fuel” and “domestic, industry, commercial uses”. According to the Report, CHP use accounted for the largest proportion. [19]

Biomethane in combined heat and power operations

A crucial area of use for biomethane is the coupled production of electrical and ther-

mal energy in combined heat and power installations, suitable to operate on natural gas. The performance range is from $\sim 1 \text{ kW}_{\text{el}}$ up to $> 10 \text{ MW}_{\text{el}}$. For most CHP-plants on the market, spark ignition engines are used. In the very low output range, expansion steam engines and Stirling engines are also used in individual instances. In the MW range, there are also cases of gas diesel engines and jet-ignition engines being used. [24] Up to now, relevant installation sizes for biomethane-based-CHP plants have been in the performance range from $< 100 \text{ kW}_{\text{el}}$ to $\sim 1 \text{ MW}_{\text{el}}$, with typical orders of magnitude being in the range of $500 \text{ kW}_{\text{el}}$. Now more and more CHP installations are becoming available on the market, even in the small-scale segment (mini-CHP plants); they are also suitable for the coupled production of electricity and heat powered by natural gas or biomethane in single-family or multifamily residential buildings.

Biomethane as a fuel

Biomethane can be used as a fuel for natural gas vehicles without any problems. One possibility is to feed the biomethane into the natural gas network and subsequently to make it available on a virtual basis at natural gas fuelling stations. This is already happening at many fuelling stations in Germany, at which mostly natural gas/biomethane mixtures are offered. An alternative to this is the direct linking of a biogas fuelling station to a biogas upgrading plant, with the vehicle being fuelled using methane obtained from bio-

gas. But, to date there are few references for this in Germany; the biogas fuelling station in Jameln acts as a pioneer project and has by now been established for several years. However, the future market development of biogas as a fuel is crucially dependent on the degree of market take-up for natural gas vehicles. At present there are around 90,000 natural gas vehicles in Germany. For now the market for biogas as a fuel in Germany should rather be viewed as a niche market.

Biomethane for heating

Biomethane can also be used as a substitute for natural gas in conventional natural gas burners and condensing boilers. There is no need for homeowners to replace their existing heating system for this. Traditional gas-powered domestic appliances, such as gas ovens

or gas driers can also be powered by biomethane. Many utility companies offer biomethane/natural gas mixed products with various proportions of biomethane (5, 10 or 20% biomethane); these are also available for private users. 100% biomethane products are rather rare and are usually significantly more expensive than pure natural gas products with the same energy content.

Biomethane for material use

Biomethane offers, due to the high methane content, similar product characteristics as natural gas. In principle it is also an option for material use in the chemical industry as natural gas substitute. In the chemical industry, approx. 3% of the total volume of natural gas consumed in Germany is used as an ingredient in chemical processes.



Fig. 15: Biogas fuelling station in Jameln [13]

What mostly happens is that natural gas is converted into synthetic gas (a mixture of carbon monoxide and hydrogen). Synthetic gas is a significant source for basic chemicals and thus one of the most important basis for many chemical products. [18]

5.2 Biomethane trading and record keeping

Biomethane trading

Aside from the possibility to conclude a contract directly between the biomethane producer (supplier) and biomethane user (e.g. CHP plant operator), the supplier also has the possibility to use a trader to market the biomethane. Biomethane traders purchase biomethane from various producers and market it to a variety of customers/consumers. The trader thus covers the need in terms of transport, and potentially also the keeping of records, as well as the associated contracts.

Keeping of records

In contrast to trading natural gas, when trading biomethane it is required to create a document proving product origin. This documentation includes the specific “characteristics” of the biomethane, which in turn serve as proof for the use of the biomethane, for instance in order to obtain the corresponding remuneration based on the Renewable Energy Sources Act (EEG) at the point when the product is converted in a biomethane CHP installation. In Germany these proof records, stating origin and characteristics for biomethane fed into the natural gas grid, can be documented in the biogas register of dena, the German Energy Agency. For this purpose, producers, traders, consumers, environmental auditors and other subject-area experts can get themselves registered at the internet platform www.biogasregister.de. In principle, the register works as follows:

The biomethane producer books into the biogas register the quantities of biomethane fed into the natural gas grid. In situ, an environmental auditor or relevant subject-area expert checks the details given and confirms them in the biogas register. After this, the biogas quantities can be distributed and traded.

6 LEGISLATIVE FRAMEWORK AND ECONOMIC EFFICIENCY

6.1 Legislative framework

The legislative framework for feeding biomethane into the natural gas grid is established on a Europe-wide basis in the Directive 2003/55/EC, adopted by the European Parliament and the Council on 26 June 2003, concerning joint stipulations that govern the internal market for natural gas. However, a uniform standard for the feed-in of biomethane does not yet exist in Europe.

In Germany, the legislative framework for feed-in biomethane is stated in the Integrated Energy and Climate Programme (IECP) adopted by the Federal Government in 2007, and definitively implemented by the Renewable Energy Sources Act (EEG), the Renewable Energy Heating Act (EE-WärmeG), the Gas Grid Access Ordinance (GasNZV) and the Gas Grid Charges Ordinance (GasNEV).

Renewable Energy Sources Act (EEG)

The basic goal of the Renewable Energy Sources Act (EEG) is to raise renewable energies' proportion of electricity supply to at least 30% by the year 2020 and thereafter to continually increase that share. For this purpose, the Act guarantees a remuneration for feeding-in electricity from renewable resources, for the year in which the respective installation was commissioned and for a further 20 years.

A precondition applying to remuneration for electricity sourced from biogas is the use of biomass in accordance with the Ordinance on the Generation of Electricity from Biomass (BiomasseV).

When upgrading and feeding biogas into the natural gas grid, what is needed to obtain remuneration according to the Renewable Energy Sources Act, is for the quantity of gas removed from the gas grid to correspond in heat-equivalent terms to the quantity of biogas fed into the gas grid, prior to that, at another location. In this regard it is sufficient if the quantities match at the end of a given calendar year and proof is provided by means of a mass-balance system. What is then actually remunerated is the electricity which has been produced from the gas obtained. That way, at locations with sufficient demand for heating, the biomethane can be converted into electricity in CHP installations. As a generally applicable principle, CHP plants using biomethane must be heat-led (i.e. must take demand for heating as the determinant factor in their operations).

Starting from 2012, the amendment of the Renewable Energy Sources Act (EEG) introduces a bonus for gas processing (biogas upgrading), taking the installation's installed nominal capacity as its reference point:

1. "Entitlement to the bonus for gas processing pursuant to Section 27c (2) shall apply to electricity generated in

installations with including maximum rated average annual capacity of 5 Megawatts, provided the gas was fed-in pursuant to Section 27c (1) and was processed before being fed into the natural gas grid, and it is proved that the following preconditions were met:

- a) Methane emissions into the atmosphere during processing do not exceed 0.2%,
 - b) Electricity consumption during processing does not exceed 0.5 kilowatt hours per standard cubic metre of raw gas,
 - c) Supply of the process heat for processing and generation of landfill gas, sewage treatment gas or biogas is from renewable energies, mine gas or from the waste heat of the gas processing installation or feed-in installation, without the use of additional fossil energies and
 - d) Installed rated gas output of the gas processing installation not exceeding 1,400 standard cubic metres of processed landfill gas, sewage treatment gas or biogas per hour.” [16]
2. “The amount of the bonus for gas processing is:
- a) 3.0 cents per kilowatt hour for a gas processing installation with a nominal capacity of 700 standard cubic metres of upgraded landfill gas, sewage treatment gas or biogas per hour,
 - b) 2.0 cents per kilowatt hour for a gas processing installation with a nominal capacity of 1,000 standard cubic metres of upgraded landfill gas, sewage treatment gas or biogas per hour and
 - c) 1.0 cents per kilowatt hour for a gas processing installation with a nominal capacity of 1,400 standard cubic metres of upgraded landfill gas, sewage treatment gas or biogas per hour.” [16]



Fig. 16: Natural gas grid; sign drawing attention to an underground pipeline [13]

For the use of biomethane, reference is made to Section 27 (3) of the Renewable Energy Sources Act (EEG) 2012, according to which new installations with an installed capacity of $>750 \text{ kW}_{el}$, entering into service from 2014 onwards, must participate in Direct marketing and can then obtain the market premium. The possibility to make avail of the fixed remuneration according to the Renewable Energy Sources Act (EEG) is then discontinued for this type of installation. Up to the size of installation stated above, operators have the possibility, even after that cut-off date, to choose between the EEG fixed remuneration or the EEG market premium model.

Renewable Energy Heat Act (EEWärmeG)

With the goal of raising the renewable energies' proportion of final energy consumption for heating to 14% by the year 2020, the Renewable Energy Heat Act (EEWärmeG) stipulates a heating supply sourced from renewable energy for owners of buildings constructed after 1 January 2009.

When using biogas, here is a 30 % share of the total heating energy requirement for the building in question. A precondition is use of the biogas in a CHP installation.

In addition, when using gas from the natural gas grid there are requirements concerning biogas upgrading and feed-in:

- Compliance with the quality requirements for receipt of the bonus for gas processing, in accordance with the Renewable Energy Sources Act (EEG) (namely limits on methane emissions and electricity requirement of the upgrading plant, regeneratively-produced process heat for the upgrading and feed-in)
- Documentary proof of origin via the mass-balance system [33]

Gas Grid Access Ordinance (GasNZV)

Stating the goal of making it possible for 6 billion cubic metres of biomethane to be fed in annually by the year 2020, and 10 billion cubic metres by 2030, the Gas Grid Access Ordinance establishes the conditions according to which the grid operators grant the transport customers access to their output grids.

Within this, the following are key rulings for linking up a biomethane plant to the output grids when feeding biomethane into the system: [17]

- Priority grid connection for biomethane plants
 - Grid operators' obligation to link up biomethane plants to the gas grid on a priority basis.
 - Cost-sharing for the link-up to the grid: the grid operator bears 75 % of costs,

the supplier bears 25 %, up to a connecting pipeline length of 10 km. If the connecting pipeline has a maximum length of 1 km, the supplier's share of the costs is capped at 250,000 €.

- The grid operator guarantees at least 96 % availability of the grid connection.
- The drawing-up of a plan concerning content, time sequencing and responsibility (a road-map of implementation) by grid operator and supplier, aimed at avoiding delays to the grid connection. [17]
- Priority grid access awarded to transport customers for biogas
 - The obligation on the part of the grid operators to conclude entry contracts and exit contracts with transport customers for biogas on a priority basis, and also to transport product for them on a priority basis, subject to the biogas being compatible with the network.
- Extended balancing of transactions, including a framework of flexibility
 - The offer of an extended balancing of transactions for the feed-in and feed-out of biogas by the party responsible for the market area, including a flexibility framework of 25 % in the case of accounting grid for which the product in the transactions balanced is solely biogas.
- Quality requirements for biogas
 - Limiting to 0.5 % the permissible maximum methane emissions into the atmosphere when processing biogas into methane, up to 30 April 2012; after that, the limit is 0.2 % for new installations.

The supplier must ensure that, at the entry point and during the feed-in process, the gas corresponds to the requirements of the DVGW Worksheets G 260 and G 262 (status: 2007). By contrast, the grid operator is responsible for ensuring that the gas at the exit-point corresponds to the verification stipulations stated in DVGW Worksheet G 685 (status: 2007). The grid operator also bears the costs for this. Beyond this, the grid operator is responsible for odourisation and measurement of the gas's composition, also bears the costs for this. [2]

Gas Grid Charges Ordinance (GasNEV)

The Gas Grid Charges Ordinance establishes the method used for determining remunerations to be paid for access to the grids for long-distance gas transportation and gas distribution. It regulates that transport customers for biogas currently receive from the grid operator – into whose grid the product is fed – a fixed sum of 0.7 Euro cents per kilowatt hour of biogas fed in; this is for ten years from the initial operation of the corresponding grid connection. The grid operator can allocate these additional costs among all grids in that particular grid area.

Funding

The Directive for the Promotion of Activities for the Use of Renewable Energies in the Heat Market, dated 11 March 2011, is intended to raise the volume of business for renewable energy technologies in the market for heating; in turn, this is intended to contribute to the cutting of costs and improved commercial viability. Financial assistance is given to this process via the Federal Office of Economics

and Export Control (BAFA), by means of grants for investment costs, and via the Renewable Energies Programme (run by the KfW promotional bank of the federal republic and the federal states); it is provided with the help of favourable interest rate arrangements, and also loan-redemption grants, whereby loans granted on favourable interest rate terms are partially redeemed ahead of schedule.

For biogas upgrading plants producing a maximum of 350 m_n³/h of biomethane, the loan-redemption grant comprises up to 30 % of the net investment costs qualifying to be taken into account for financial assistance eligibility. A precondition for this is that the methane emissions into the atmosphere caused by the upgrading do not exceed max. 0.5 %, with a maximum electricity requirement of 0.5 kWh/m_n³ of raw gas for upgrading and, feed-in and making available the required process heat from renewable resources, mine gas or waste heat from the gas upgrading and feed-in installation. Until now, this financial assistance has had a time limit, expiring on 31 December 2012; it can-



Fig. 17: Biogas pipe [14]

not be claimed cumulatively together with other financial assistance schemes funded by public money [26].

A further opportunity for financial assistance for biomethane users is afforded by the Directive for the Promotion of CHP Installations of up to 20 kW_{el} (for this also, the programme administrator is the Federal Office of Economics and Export Control (BAFA)). The financial assistance, provided in staged levels depending on the size of the installation, is provided through grants that do not require repayment.

6.2 Technical regulations

This section describes the technical rules relevant for the upgrading and feed-in of biogas, as set by the DVGW German Technical and Scientific Association for Gas and Water and also by DIN norms relevant to the use of biogas as a fuel. At this point it is noted that, in the most up-to-date version of the Gas Grid Access Ordinance (GasNZV), the Worksheets G 260, 262 and 685 of the DVGW Regulations (status: 2007) are taken as a point of reference. This means that the application of these technical regulations on biogas feed-in projects also takes the 2007 status as the point of reference, even in the event of additions being made to the body of rules established.

Worksheet DVGW G 260 “Composition of gas”

This set of technical rules states the requirements for the composition of flammable gases. Furthermore, a regulatory framework is put in place for the supply of gas, the

transportation of gas, the operation of gas installations and gas appliances or respectively industrial gas applications, as well as the basis for development and for establishing norms and testing. [8]

Worksheet DVGW G 262 “Use of gases from regenerative sources in public gas supply”

This Worksheet applies to the use of gases from thermal and fermentative processes involved in the public gas supply. [31]

In the context of ‘upgraded gases’, the previous version of this Worksheet (11/2004) essentially referred to the maximum concentrations of CO₂ and H₂. The most current (09/2011) version states substantially more parameters. Among the details that it stipulates are limit values for water content and water dew point, methane content in the upgraded biogas, carbon dioxide, oxygen, ammonia and amines, silicon organic compounds and hydrogen. [32]

Worksheet DVGW G 280-1 “Gas odourisation”

Gases used in public gas supply must have an adequate warning smell. As natural gases and also upgraded biogases are mostly odourless, an odour substance – a so-called odourant – needs to be added. Among other things, this Worksheet includes information about general requirements for odourants, commonly used odourants, safety measures, and techniques used for odourisation.

Worksheet DVGW G 685 “Billing of gas”

This Worksheet establishes the processes for measurement and ascertainment of the

data required for gas billing, in accordance with the DVGW Worksheet G 260 “Composition of gas”.

DVGW Basis for Testing VP 265-1: Installations for upgrading and feed-in of biogas into the natural gas grid – Part 1: Gases produced by fermentative process; planning, production, construction, testing and initial operation.

The VP 265-1 Basis for Testing “applies to the planning, production, construction, testing and initial operation of installations used for upgrading of fermentatively produced biogases to reach natural gas quality, and also for installations used for feed-in of these gases into gas transport and distribution systems operated with gases in accordance with G 260. The minimum requirements for technical safety of the installation and its components, necessary for using biogas, are stated here in summary – from the upgrading installation and via the compression, pressure regulation, conditioning and measuring, through to the feed-in into the gas grid as a supplementary gas or replacement gas.” [9]

DIN 51624 “Fuels for vehicles – natural gas – requirement and testing procedures”

This norm establishes the characteristics and limit values for the use of natural gas as a fuel in vehicles equipped for operation using natural gas, together with the testing procedures to be applied for these characteristics. It is permissible to admix biogas, provided that it is ensured that the finished mixture complies with this norm’s requirements. The

norm applies both for natural gas and for biogas as a fuel in natural gas vehicles.

DIN EN ISO 15403-1 “Natural gas – natural gas as a compressed fuel for vehicles – Part 1: Determining the composition”

The objective of this norm is to ensure provision of data concerning the composition of fuel for natural gas vehicles, needed by manufacturers, vehicle operators, fuelling station operators, and other involved parties in the industry for vehicles driven by compressed natural gas (CNG), in order to develop and operate equipment for these vehicles successfully.

6.3 Contract structures and project arrangements

Contract structures

It is a requirement that the implementation of a biogas upgrading project is contractually secured for the entire value chain. The focus is on contractual rulings for the cultivation of biomass; this includes the production and upgrading of biogas, as well as feed-in into the natural gas grid and marketing of the biomethane. Depending on the business model used, various contracts are of relevance in this regard:

Supply contract for raw biogas: If the production and upgrading of biogas are operated by different companies, it is purposeful to conclude a supply contract for raw biogas. Concluding a supply contract for raw biogas guarantees the operator of a

biogas upgrading installation the provision of a defined quantity and quality at agreed prices, over a fixed time period.

Biomethane supplier contract: The biomethane supplier contract is concluded for the marketing of the biomethane fed into the natural gas grid, between the supplier or the biomethane producer respectively, and the biomethane trader or the final consumer (e.g. the operator of the CHP installation). Apart from the supply quantity and the determination of the point of product handover, the biomethane contract also establishes the “characteristics” of the biomethane to be supplied (e.g. substrates used in the biogas production, capacity, electricity consumption and the biomethane installation’s maximum methane emissions into the atmosphere, etc.). [30]

Grid connection contract: The grid connection contract is concluded between the connectee or respectively the connection user and, on the other hand, the feed-in grid operator. [27] The contract determines technical parameters (particularly in accordance with the Worksheets DVGW G 260 and G 262) [30], as well as rules on liability and notice periods for termination of the arrangement.

Entry contract: The entry contract is concluded between the transport customer and the feed-in network operator. It ‘entitles the transport customer to use the grid from the entry point up to the virtual trading point’ [17]; among other things, it serves as a foundation for being able to allocate the fed-in biomethane quantities to a specific accounting grid. [28]

Exit contract: The exit contract is concluded between the transport customer and the exit grid operator. [17] The exit contract regulates the use of the grid as far as the exit point; it is identical for end customers using biomethane and for end customers using fossil-based natural gas.

Supplier framework contract: The supplier framework contract is concluded between the transport customer and the exit grid operator; it “entitles transport customers in a market area to use the grids from the virtual trading point and also to withdraw the gas at exit points of the local gas-distributor grids.” [17]

Biogas accounting grid contract: Transport customers of biomethane in the natural gas grid are obliged to conclude a biogas accounting grid contract for transactions with the grid operator responsible for the relevant (geographical) market area. This contract



Fig. 18: Biogas upgrading plant [13]

DEFINITIONS

Connectee

Connectee is the term used for “each legal or natural person who, as a project developer, constructor or operator of a biogas upgrading installation, lays claim to use of the grid connection of this installation”. [17]

Connection user

In the cooperation agreement, connection user is the term used for the person/organisation “who uses the grid connection for the purpose of feed-in of the biogas upgraded to natural gas quality in the biogas upgrading installation, by making the biogas available for transport” [27].

Accounting grid

An accounting grid summarises the entry points and exit points, in order to produce account balances of feed-in and feed-out quantities and in order to make it possible to finalise commercial transactions [17].

Supplier

Supplier of biogas is the term given for “each legal or natural person who, at the entry point as defined in Section 3 (13b) of the Energy Industry Act (EnWG), feeds-in biogas into a grid operator’s grid or partial grid” [17]. Usually the injector is also the operator of the biogas upgrading installation.

Transport customer

Transport customers in the gas sector is the term given in the German Energy Act (EnWG) to “wholesalers and gas suppliers, including the Trading department of a vertically-integrated company, and final consumer” [29].

“The transport customer takes over the biogas made available by the connection user, in order to have it transported by the grid operator on the basis of the entry contract concluded between the transport customer and the grid operator” [27], e. g. biomethane trader.

Virtual trading point

The virtual trading point is “a point in the market area at which gas can be transferred between accounting grids, but does not correspond to a physical entry point or exit point in the market area” [17].

states the rules for setting up an accounting grid, and also the registration, balancing, and billing of deviations between the quantities of biomethane fed in and fed out. [17]

Project arrangements

In the upgrading and feed-in of biogas into the natural gas grid, various project arrangements are possible along the value chain (raw material supply – biogas production – biogas upgrading – feed-in – biomethane transport – feed-out – use of biomethane). In this context, the structuring of such a project arrangement takes as its orientation point the takeover of individual links in the value chain by various project participants. Usually several project partners participate in a biogas upgrading project. For instance, these include: farmers, investors, utility groups, municipal utility companies, grid operators, biomethane traders and biomethane customers.

In this context, it is a general principle that the feed-in installation is operated by the respective feed-in grid operator.

For example, the following models of co-operation are conceivable:

Operator company: There are numerous examples of operator companies who plan, implement and operate biogas installations or also biogas upgrading installations. The partners participate in the profits earned by such an operator company, on a basis proportional to their respective company stakeholding. At the same time, where there are several par-

ties involved, the individual risk and the financial expenditure for the individual investor are reduced, in the case of planning and building a project for upgrading biogas.

Farmer as raw material supplier: On the basis of a raw material supplier contract, the farmer (or several farmers) supplies the raw materials for the operator company of the biogas plant, which is for instance, just like the upgrading installation, planned, implemented and operated by an utility group.

Co-operation between farmer and municipal utility company: In this arrangement, often found in Germany, the farmer (or a co-operation of farmers) take on the role of raw material supplier and also biogas plant operator. The municipal utility company operate the biogas upgrading installation, function as transport customer and operate their biomethane-based CHP installation, or respectively take over the marketing of the quantities of biomethane. This arrangement can also be used on a trans-regional basis between several municipal utility companies and a larger group of farmers.

Farmer as operator of the upgrading and feed-in installation: A somewhat rarely used option is for the farmer to take over the complete value chain. In this, the farmer's advantage is that of having sole commercial coverage. The clear disadvantage is the high level of financial risk and the technical know-how needed.

COST FACTORS OF BIOMETHANE PROVISION

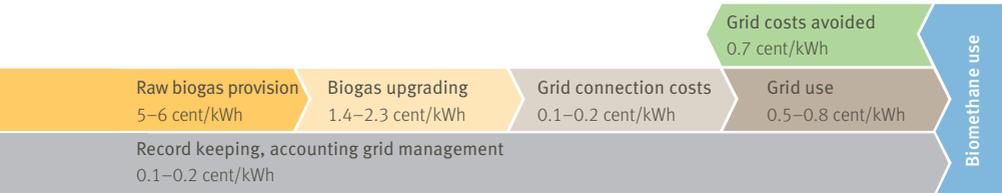


Fig. 19: Cost factors of biomethane provision in eurocent/kWh_{H₂} [IWES, 2011]

6.4 Economic efficiency

By way of an example, this section states the costs for biomethane production and for biomethane use in CHP installation.

Figure 19 provides an overview of average costs for provision of biomethane, along the value chain. The average costs for provision of biomethane are in the range from 6.8 eurocents/kWh_{H₂} (biogas upgrading plant with 2,000 m_n³/h of raw gas capacity) up to 8.3 eurocents/kWh_{H₂} (biogas upgrading plant with 500 m_n³/h of raw gas capacity).

On average, when renewable raw materials are used, the provision costs of raw biogas are in the range between 5–6 cents/kWh_{H₂} (averaged for the respective size class in the range from 5.25–5.75 cents/kWh_{H₂}). Depending on the biomethane plant capacity, the costs of biogas upgrading to form biomethane equal 1.4 to 2.3 cents/kWh_{H₂}. The proportionally-based costs of grid connection for the supplier (operator of the biogas upgrading installation) amount to 0.1–0.2 cents/kWh_{H₂}; they thus prove to be

substantially lower than the costs for upgrading. This results from the rules stated in the Gas Grid Access Ordinance (GasNZV), among other things. The transport customer for biomethane is remunerated for avoided grid costs: this amounts to 0.7 cents/kWh_{H₂} from the grid operator into whose grid the biomethane is fed-in. Charges are made for the use of the grid; these are made by the grid operators through whose grids the biomethane is transported and fed-out, and they amount to ca. 0.45–0.8 cents/kWh_{H₂}. Beyond this, costs are incurred for management of the accounting grid and for maintaining documentary proof of the biomethane; this amounts to around 0.12 to 0.22 cents/kWh_{H₂}. [22] [23]

Fig. 20 shows the economics of biomethane use in CHP plants (remuneration basis: Renewable Energy Sources Act (EEG) 2012), exemplary for three CHP sizes (200 kW_{eI}, 500 kW_{eI} and 1,000 kW_{eI}). A biogas was taken as the basis which was produced from 60% maize and 40% whole-plant grain silage. The biogas is upgraded to form biomethane in a biogas upgrading plant with

Tab. 3: Selection of relevant technical data of the three examples of natural gas based CHP plants

Electrical power	[kW]	200	500	1,000
Efficiency, electrical	[%]	37.2	39.5	41.7
Efficiency, thermal	[%]	47.8	49.4	45.9
Hours of full use	[h/a]	6,000	6,000	6,000

a rated output – biomethane volume flow of 800 m_n³/h. In addition, all Renewable Energy Source Act (EEG) requirements were complied with, in order to be eligible for the gas-processing bonus of 2 cents/kWh_{el}. For operating the biomethane-based CHP installation, the estimate basis taken is 6,000 hours of full use. The respective assumed

electrical and thermal efficiencies of the CHP installation serving as an example can be obtained from Table 3. These are technical data for CHP installations available on the market: these data do not have general validity for the respective output class but rather should be seen as being specific to the example installation selected here.

HEAT PROVISION COSTS FOR BIOMETHANE-BASED CHP INSTALLATION

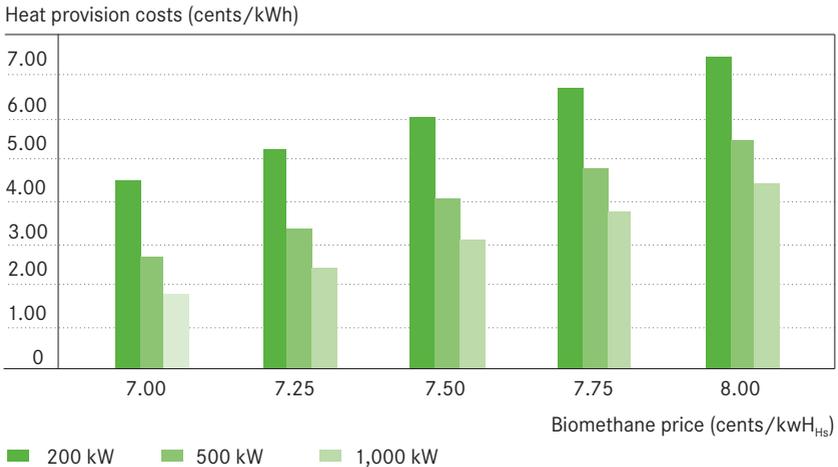


Fig. 20: Heat provision costs for biomethane-based CHP installation as function of the biomethane price [IWES, 2011]

In order to calculate the capital related costs, the assumption made was an interest rate of 7.5% (averaged from the interest rate for own and external capital) and a 10-year period was assumed for depreciation of the CHP installation. The biomethane purchase price varied within a range from 7.0 to 8.0 cents/kWh_{H₂}. Revenues are generated through the feed-in of electricity in accordance with the Renewable Energy Sources Act (EEG 2012).

The result is presented as costs for the heat provision, stated in cents/kWh (taking as reference point the outlet flange of the CHP plant – downstream periphery and potential peak-load heat provision were not taken into account).

Example 1

In case of the peripheral conditions described above, when operating a biomethane-based CHP installation, with an electrical output of 200 kW and taking as the basis a biomethane price of 7.5 cents/kWh_{H₂} the heat provision costs are 6.0 cents/kWh.

Example 2

At a location with a heat requirement which is higher by a factor of 2.5, compared to Example 1, costs generated for heat provision can be 4.1 cents/kWh (with a biomethane-based CHP installation providing an electrical output of 500 kW, and also taking as the basis a biomethane price of 7.5 cent/kWh_{H₂}).

7 ANNEX

7.1 General notice on matters of law

All law-related topics on which information has been given in this publication exclusively serve the purpose of general information; they do not serve as a basis in the event of a specific matter of law. The authors and other participating parties assume no liability with regard to usability, correctness, completeness and the up-to-date nature of the information presented: the assertion of claims of any kind is ruled out.

7.2 Further information

www.fnr.de

www.iwes.fraunhofer.de

www.dena.de

www.iea-biogas.net

www.sgc.se

www.urbanbiogas.eu

www.biogasportal.info

www.dbfz.de

www.biogaspartner.de

www.dvgw.de

www.biogasmax.eu

www.greengasgrids.eu

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7.5 List of literature

- [1] Agency for Renewable Resources (FNR): Biogas. Gülzow, 2011.
- [2] Deutsche Vereinigung für Wasserwirtschaft, Abwasser, Abfall e. V. – DWA. DWA-Regelwerk: Worksheet DWA-M 361: Aufbereitung von Biogas. (German Association for Water, Wastewater and Waste: upgrading biogas). Hennef, 2011.
- [3] URL: [http://www.nachhaltigkeit.info/artikel/hans_carl_von_carlowitz_1713_1393.htm]; accessed on 18 November 2011.
- [4] Federal Ministry of Food, Agriculture and Consumer Protection (BMELV): Nachhaltigkeit konkret – Nachhaltigkeitskonzept des Bundesministeriums für Ernährung, Landwirtschaft und Verbraucherschutz (Specifics on sustainability – sustainability concept of the Federal Ministry of Food, Agriculture and Consumer Protection). Berlin, 2008.
- [5] ifeu – Institut für Energie- und Umweltforschung Heidelberg GmbH/Becker Büttner Held – Rechtsanwälte Wirtschaftsprüfer Steuerberater (ifeu is an energy and environmental research institute operating as a limited company; Becker Büttner Held is a practice of lawyers, auditors and tax advisers): Biomethan als Kraftstoff: Eine Handlungsempfehlung für die Anwendung der BioKraft-NachV in der Praxis (Biomethane as a fuel: action recommendations for applying the BioKraft-NachV in practice) (BioKraft-NachV: see glossary below). Heidelberg/Berlin, 2010.
- [6] URL: [<http://www.umweltbundesamt-daten-zur-umwelt.de/umweltdaten/public/theme.do?nodeldent=2346>] accessed on 22 November 2011

- [7] Liebetrau, J./J. Daniel-Gromke/C. Reuschel et. al.: Bewertung klimarelevanter Gase aus landwirtschaftlichen Biogasanlagen auf der Basis von Emissionsmessungen. Beitrag beim FNR/KTBL-Biogaskongress 2011. (Assessment of climate-relevant gases from agricultural biogas plants, based on measurements of emissions). Contribution at the FNR/KTBL Biogas Congress 2011) (KTBL is the Association for Technologies and Structure in Agriculture).
- [8] DVGW Deutsche Vereinigung des Gas- und Wasserfaches e. V.: Technische Regel Arbeitsblatt G 260.: (German Technical and Scientific Association for Gas and Water: Technical Rules – Worksheet G 260). Bonn, 2008.
- [9] DVGW Deutsche Vereinigung des Gas- und Wasserfaches e. V.: Technische Regel Prüfgrundlage VP 265-1 (German Technical and Scientific Association for Gas and Water: Technical Rules – Basis for Testing / VP 265-1). Bonn, 2008.
- [10] Institut für Solare Energieversorgungstechnik ISET, 2008. (Institute for solar energy-supply technology).
- [11] Holzhammer, U./Beyrich, W.: Die steuerbare und am Bedarf orientierte Stromerzeugung aus Biogas. Tagungsband: OTTI-Anwenderforum Biogasanlagen – 23. November 2011 (The controllable and demand-oriented production of electricity from biogas. Publication at: OTTI-forum for biogas plant operators, 23 November 2011). Regensburg, 2011.
- [12] Fraunhofer IWES/Fraunhofer UMSICHT/DBFZ: mit einer Zuwendung des BMU: 3. Zwischenbericht BIOMON: BIOMON – Evaluierung der Biomethanbereitstellung, -verteilung und -nutzung in Deutschland durch ein Marktmonitoring, 2012 unveröffentlicht (Fraunhofer IWES/Fraunhofer UMSICHT/DBFZ: with a grant from the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety: 3rd Intermediate BIOMON Report: BIOMON – Evaluation of the provision, distribution and use of biomethane in Germany by means of market monitoring, 2012, unpublished.)
- [13] Nachweis: Fraunhofer-Institut für Windenergie und Energiesystemtechnik (Proof: IWES – Fraunhofer Institute for Wind Energy and Energy System Technology)
- [14] Nachweis: FNR (Proof: Agency for Renewable Resources)
- [15] Fachverband Biogas e. V.: Biogasbranchenzahlen 2011 – Entwicklung der Anzahl Biogasanlagen und der gesamten elektrischen Leistung in Megawatt [MW] Stand 11/2011. (German Biogas Association: Figures – biogas sector 2011 – Development of the number of biogas plants and of installed electrical capacity in Megawatt (MW). Status 11/2011). URL: [[http://www.biogas.org/edcom/webfvb.nsf/id/DE_Branchenzahlen/\\$file/11-11-15_Biogas%20Branchenzahlen%202011.pdf](http://www.biogas.org/edcom/webfvb.nsf/id/DE_Branchenzahlen/$file/11-11-15_Biogas%20Branchenzahlen%202011.pdf)] accessed on 30 November 2011

- [16] BMU: Gesetz für den Vorrang Erneuerbarer Energien (Erneuerbare-Energien-Gesetz – EEG). Fassung des Gesetzestextes in der ab 1. Januar 2012 geltenden Fassung (Federal Ministry for the Environment, Nature Protection and Nuclear Safety: Act on granting priority to renewable energy sources (Renewable Energy Sources Act – EEG). Consolidated (non-binding) version of the Act in the version applicable as of 1 January 2012).
- [17] BMWi: Verordnung über den Zugang zu Gasversorgungsnetzen (Gasnetzzugangsverordnung – GasNZV) (Federal Ministry of Economics and Technology: Gas Grid Access Ordinance; date of entry into force: 9 September 2010)
- [18] DECHEMA et al: Positionspapier – Rohstoffbasis im Wandel (Position paper. Changing of the raw material base.) Frankfurt, 2010.
- [19] Bundesnetzagentur. Biogas-Monitoringbericht 2011. (Federal Network Agency: Biogas monitoring report 2011). Bonn, 2011.
- [20] Fachagentur Nachwachsende Rohstoffe e. V. (Herausgeber): Einspeisung von Biogas in das Erdgasnetz (Agency for Renewable Resources (publisher): Feeding biogas into the natural gas grid). Gülzow, 2006.
- [21] ifeu – Institut für Energie- und Umweltforschung Heidelberg GmbH: Basisdaten zu THG-Bilanzen für Biogas-Prozessketten und Erstellung neuer THG-Bilanzen. (ifeu: (see [5] above): Basic data on the GHG balance for biogas process chains and calculation of new GHG balances). Heidelberg, 2008.
- [22] Hölder, D.: Aus Biomethan das Beste erlösen? Biomethan (-KWK) im Wärmemarkt (Redeeming the best from biomethane? Biomethane (CHP) in the heating market). Oberhausen, 2010.
- [23] Beil, M./Scholwin, F./Urban, W.: Biomethan in Deutschland: Ein Branchenüberblick – Ergebnisse aus dem BMU-Projekt „BIOMON“. 1. VDI-Kongress Biogas – Aufbereitung und Einspeisung. (Biomethane in Germany: A sector overview – results from the German Environment Ministry’s “BIOMON” project. 1st VDI Congress: Biogas – upgrading and feed-in). Düsseldorf, 2010.
- [24] ASUE (Herausgeber/publisher): BHKW-Kenndaten 2011 (CHP installations – key data 2011). Berlin, 2011.
- [25] Harasek, M.: Biogasaufbereitung für die Einspeisung ins öffentliche Netz am Beispiel der Biogasanlage Bruck a. d. Leitha. Tagungsband 6. Hanauer Dialog „Biogasaufbereitung zu Biomethan“ (Upgrading of biogas for feed-in into the public grid, using the example of the Bruck a. d. Leitha biogas plant. Volume of convention papers – 6th Hanau Dialogue “Upgrading of biogas into biomethane”). Kassel/Hanau, 2008.
- [26] BMU: Richtlinien zur Förderung von Maßnahmen zur Nutzung erneuerbarer Energien im Wärmemarkt (Federal Ministry for the Environment, Nature Protection and Nuclear Safety: Directives for promoting measures conducive to the use of renewable energies in the market for heating). March 2011

- [27] Kooperationsvereinbarung zwischen den Betreibern von in Deutschland gelegenen Gasversorgungsnetzen. Änderungsfassung vom 30. Juni 2011. Inkrafttreten am 1. Oktober 2011 (Co-operation agreement between the operators of gas supply grids located in Germany. Amended constitution dated 30 June 2011. Entry into force: 1 October 2011).
- [28] URL: [<http://www.biogaspartner.de/index.php?id=10095>] Zugriff am 13. Januar 2012 (accessed on 13 January 2012).
- [29] BMWi: Gesetz über die Elektrizitäts- und Gasversorgung. Ausfertigungsdatum: 7. Juli 2005, zuletzt geändert durch Art. 1 G vom 22. Dezember 2011 I 3034 (Federal Ministry of Economics and Technology: German Energy Act – (EnWG). Date of issue: 7 July 2005, last amended by Art. 1 G, dated 22 December 2011 I 3034).
- [30] Valentin, F.: Biogasanlagen – Analyse von Bau und Betrieb aus vertragsrechtlicher Sicht. Gülzower Fachgespräche, Band 32: Biogas in der Landwirtschaft – Stand und Perspektiven. Tagungsband zum KTBL/FNR-Biogas-Kongress vom 15. bis 16. September 2009 in Weimar (Biogas plants – analysis of construction and operation from the contractual-law perspective). Gülzower Dialogues, Volume 32: Biogas in agriculture – status and prospects. Volume of convention papers on the KTBL/FNR biogas congress, 15–16 September 2009 in Weimar).
- [31] DVGW: Technische Regel Arbeitsblatt G 262 Technische Regel Arbeitsblatt G 262 (German Technical and Scientific Association for Gas and Water: Technical Rules – Worksheet G 260). Bonn, 2004.
- [32] DVGW: Technische Regel Arbeitsblatt G 262(A) (German Technical and Scientific Association for Gas and Water: Technical Rules – Worksheet G 262 (A)). Bonn, 2011.
- [33] BMU: Gesetz zur Förderung Erneuerbarer Energien im Wärmebereich (EEWärmeG) in der seit 1. Mai 2011 geltenden Fassung (Federal Ministry for the Environment, Nature Protection and Nuclear Safety: Renewable Energy Heat Act, in the version in force since 1 May 2011).
- [34] Bundesnetzagentur: Monitoringbericht 2011. (Federal Network Agency: Monitoring report 2011). Bonn, 2011.

7.6 List of abbreviations

BAFA	Bundesamt für Wirtschaft und Ausfuhrkontrolle (Federal Office of Economics and Export Control)
BG	Biogas
BioKraft-NachV	Biokraftstoff-Nachhaltigkeitsverordnung (Sustainability Ordinance for Biofuels and Biomass Electricity)
BioSt-NachV	Biomassestrom-Nachhaltigkeitsverordnung (Biomass Electricity Sustainability Ordinance)
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)
BNetzA	Bundesnetzagentur (Federal Network Agency)
CFC	Chlorfluorocarbons
CH ₄	Methane
CHP	Combined heat and power
CNG	Compressed natural gas
CO ₂	Carbon dioxide
dena	Deutsche Energie-Agentur GmbH (German Energy Agency)
DIN	Deutsches Institut für Normung e. V. (German Institute for Standardization)
DVGW	Deutscher Verein des Gas- und Wasserfaches e. V. Technisch Wissenschaftlicher Verein (German Technical and Scientific Association for Gas and Water)
EEG	Gesetz zum Vorrang von Erneuerbaren Energien, Erneuerbare-Energien-Gesetz (Renewable Energy Resources Act)
EEWärmeG	Gesetz zur Förderung Erneuerbarer Energien im Wärmebereich, Erneuerbare-Energien. Wärme-Gesetz (Renewable Energy Heat Act)
EnWG	Gesetz über die Elektrizitäts- und Gasversorgung, Energiewirtschaftsgesetz (Energy Industry Act)
EU	European Union
GasNEV	Gasnetzentgeltverordnung (Gas Grid Charges Ordinance)
GasNZV	Gasnetzzugangsverordnung (Gas Grid Access Ordinance)
GHG	Greenhouse gas
H ₂ O	Water
H ₂ S	Hydrogen sulphide
IEKP	Integriertes Energie- und Klimaprogramm (Integrated Energy and Climate Programme)
IWES	Fraunhofer-Institut für Windenergie und Energiesystemtechnik (Fraunhofer Institute for Wind Energy and Energy System Technology)
KfW	Kreditanstalt für Wiederaufbau (Promotional Bank of the Federal Republic and the Federal States)
N ₂	Nitrogen

NH ₃	Ammonia
N ₂ O	Nitrous oxide
O ₂	Oxygen
PGC	Process gas chromatograph
PSA	Pressure Swing Adsorption
PWS	Pressurised Water Scrubbing
RTO	Regenerative thermal oxidation
TA Luft	Technische Anleitung zur Reinhaltung der Luft (Technical Instructions on Air Quality Control)

7.7 Units of measurement used

a	year
°C	degrees Celsius
g	gramme
h	hour
kg	kilogramme
km	kilometre
kW	kilowatt
kWh	kilowatt hour
kWh _{HS}	kilowatt hour, related to a calorific value
kW _{el}	kilowatt, electrical
kWh _{el}	kilowatt hour, electrical
kW _{th}	kilowatt, thermal
kWh _{th}	kilowatt hour, thermal
mg	milligramme
MJ	megajoule
MW	megawatt
MWh	megawatt hour
m ³	cubic metre
m _n ³	cubic metre (under norm conditions: 0 °C; 1.01325 bar)
PJ	petajoule
ppm	parts per million
t	tonne

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