Project: BiG>East

(EIE/07/214)

Biogas purification and assessment of the natural gas grid in Southern and Eastern Europe

Deliverable 2.5
Task 2.5

Mag. Heinz Praßl

Ing. Gerhard Agrinz GmbH
Emmerich-Assmann-Gasse 6
8430 Leibnitz, Austria

Leibnitz, 23.06.2008

Elaborated with input of the BiG>East partners
Krasin Georgiev, Denitsa Dimitrova, Biljana Kulisic, Konstantinos Sioulas, Ilze Dzene,
Augustin Ofiteru, Mihai Adamescu, Florian Bodescu, Aleks Jan, and Dominik Rutz.

With the support of:

Index

Foreword

This summary concerning the feed-in of biogas into the natural gas grid has been compiled in the framework of the Big>East project. BiG>East is supported by the European Commission in the “Intelligent Energy for Europe Programme” and coordinated by WIP Renewable Energies, Germany. The objective of BiG>East is to transfer knowledge from biogas experts of Western Europe to farmers, biogas plant operators and decision makers in Bulgaria, Croatia, Greece, Latvia, Romania, and Slovenia.

This document was elaborated by the Ing. Gerhard Agrinz GmbH, Austria, and reviewed by WIP Renaewable Energies, Germany. Input on the target countries was provided by Energy Restructuring Agency (ApE), Slovenia, Center for Renewable Energy Sources (CRES), Greece, Ekodoma Ltd., Latvia, Energoproekt jsc, Bulgaria, Energy Institute Hrvoje Pozar (EIHP), Croatia, and by SC Mangus Sol SRL, Romania.

The following literature has been used for the elaboration of this document:

Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich
Authors: DI Dr. Dieter Hornbachner, Dr. Gernot Hutter, DI Dieter Moor, HEI Hornbachner Energie Innovation; Publisher: Bundesministerium für Verkehr, Innovation und Technologie; Wien, 2005

Evaluierung der Möglichkeiten zur Einspeisung von Biogas in das Erdgasnetz – Endbericht
Authors: Institut für Energetik und Umwelt gGmbH (IE) – Frank Hofmann, André Plättner, Sönke Lulies, Dr. Frank Scholwin; Contractor: Fachagentur Nachwachsende Rohstoffe e.V. (FNR); Leipzig, 2005

Studie – Einspeisung von Biogas in das Erdgasnetz
Authors: Institut für Energetik und Umwelt gGmbH, Prof. Dr. Stefan Klinski, DBI Gas- und Umwelttechnik GmbH, Fraunhofer Institut UMSICHT (FhU) und Gaswärme-Institut e. V. Essen (GWI); Publisher: Fachagentur Nachwachsende Rohstoffe e. V.; 2. Auflage, Leipzig, 2006

Möglichkeiten einer europäischen Biogaseinspeisungsstrategie
Authors: Daniela Thrän, Michael Seiffert, Franziska Müller-Langer, André Plättner, Alexander Vogel; Publisher: Bundestagsfraktion BÜNDNIS 90/DIE GRÜNEN, Fachverband Biogas, STAWAG; Leipzig, 2007

Mit Biogas in das Erdgasnetz – Erste ö. Biogasaufbereitungs- und Einspeisungsanlage in Pucking
Authors: Franz Kirchmeyr, Johannes Kraus; Herausgeber: ARGE Kompost & Biogas Austria , Natural gas OÖ; Linz, 2005

Biomethananlage Pliening
Authors & publisher: Aufwind Schmack GmbH - Neue Energien; Regensburg, 2006

1. Introduction

Biogas is produced by the fermentation of plants, food remnants, biological wastes or animal excrement (manure) and is also found in waste treatment facilities and landfills. Biogas contains a high amount of methane that can be used to recover energy.
Biogas is therefore not a recent invention, but has been known since 1682 when the two scientists Robert Boyle and Denis Papin observed gas formation during the decomposition of plant materials. The Italian researcher Alessandro Volta discovered so-called marsh gas in 1776. At the beginning of the 20th century, theoretical knowledge was put into practice when the first digesters were built. In 1935, for example, 95 cars of the Stuttgart vehicle fleet were operated with biogas.

Low energy prices (oil) in the 1960s lead to a lull in research and construction of biogas plants. After the enegy crisis in 1973 and 1979/80, biogas technology was increasingly used in the industrialised countries. Global goals, such as those set in Kyoto Protocol, with the aim of reducing greenhouse gases, as well as the more or less ambitious national goals in this regard, have meant new impetus in the industrialised countries for this technology.

Up to now, biogas has been used almost exclusively for the production of electricity in block type thermal power plants (BTTP). The recovery of the energy contain in biogas is usually minimal since the waste heat produced by the generation of electricity is normally not used. This results in up to two thirds of the energy contained in the biogas being lost. This means that biogas-power generation is often, in terms of energy, a very inefficient process. Another, more energy efficient type of biogas utilisation is the feed-in of biogas into the public natural gas grid. The biogas is transported through the gas grid to the consumer where it is used to produce electricity, heating or as a fuel. The primary advantage of the feed-in of biogas into the natural gas grid in keeping with the concept of a future-oriented energy system is the separation of the loactions of production and utilisation. This allows the flexible, local use of the biogas with a high degree of efficiency, while at the same time replacing fossil fuels. Although the combustion of biogas releases carbon dioxide, the difference to natural gas is that this carbon dioxide comes from regenerative process cycles. This means that the carbon that is released into the atmosphere as CO_2 through the burning of biogas has been previously removed from the atmosphere by the fermented plants during their growth phase. In contrast to natural gas, therefore, there is no net increase in the concentration of CO_2 in the Earth's atmosphere and consequently no strengthening of the greenhouse effect. This is referred to as the CO_2 neutrality of biogas. The reduction in the consumption of natural gas in favour of an increased use of biogas thereby represents a significant contribution to reducing CO_2 emissions.

2. Properties of the natural gas grid

Natural gas in Europe comes from Russia, Algeria and from domestic national production like from West European sources (North Sea – The Netherlands, Norway, Great Britain). The gas is transported by the importing gas supply companies in pipelines to Europe.

As a natural product, natural gas has a variety of properties depending on the different sources. Natural gas is categorised according to the Wobbe-Index. The origin of the gas from different sources and the structure of the natural gas grid cause regional differences in the distribution of gas qualities. Due to its historical development the gas grid has to be an amorphous structure that is difficult to arrange spatially and is classified according to pressure stages and levels of supply.

The European pipeline system for the transport of natural gas consists principally of so-called long distance pipelines and distribution grids. Long distance pipelines are defined as facilities for the purpose of transporting natural gas through high pressure pipelines or grids, insofar as they are also dedicated to the transport to other long distance pipelines or distribution companies. Distribution lines are pipelines that are primarily or exclusively for the transport of natural gas directly to customers.

2.1 Classification according to grid levels

The natural gas pipeline or grid can be classified into 4 categories of supply grid:

Level 1: International long distance transport grid (international long distance pipeline)
Level 2: National transport grid (national long distance pipeline)
Level 3: Regional transport grid
Level 4: Local distribution grid

The term long distance pipelines includes transit pipelines (Level 1) and high pressure lines for national transport (Level 2) of natural gas. The necessary operational pressure in long distance pipelines reaches up to 120 bar. Transit pipelines serve primarily the transit of natural gas through the individual countries. These pipelines are also used partially for the transport of natural gas for domestic supply. In high pressure lines that fall under the definition of long distance lines, natural gas is transported exclusively for the supply of domestic consumers.

In contrast, the regional distribution grid is used exclusively for the direct supply of domestic customers on two different pressure levels. Here, a differentiation is made between distribution grids with an operational pressure over 6 bar and those with operational pressure under 6 bar. The equivalent to this are the technical terms „Grid level 3" (pressure > 6 bar) and „Grid level 4" (pressure >0,1 bar and < 6 bar).

The national transport grid (Level 2) is embedded in the international transport level. Here, the international transport level is linked with regional or local supply level. It supplies either the downstream regional grid (Level 3) or the operators of the local distribution grid (Level 4), as well as individual industrial consumers. Depending on the position of the long distance pipeline, this can take place over branch lines directly or through more or less intermeshed regional grids.

The regional grids connect the long distance transport grids with the local distribution level. The local distribution grid is a closely intermeshed grid (radial distribution, branching, ring and intermeshed pipeline network), that provides local supply of natural gas. In parallel to other local supply grids, the pipeline routes are mostly located alongside the road network. The technical system of local gas supply companies can be described as a distribution grid that connects the rows of houses in the parts of city with pipelines. This geometry of this grid corresponds therefore for the most part to the geometrical structure of the rows of buildings in the community. The local gas supply companies are responsible exclusively for the supply of customers in the final distribution stage. In the existing supply chain they receive their gas typically from the regional supply companies, but direct supply from an importing regional gas supplier is also normal.

2.2 Classification according to pressure levels

The supranational main transport pipelines with nominal diameters of 400 to 1,200 mm and pressures up to 120 bar carry standard volume flows of approx. 1.0 to 2.5 million m^3/h. Regional pipelines are operated in a broad range from 1 to 70 bar. At the lowest grid level, nominal diameters of 50 to 600 mm allow flow pressures of 30 to 100 mbar. The second possibility of natural gas grid classification, in other words consists of classification in pressure and diameter levels.

High pressure pipelines:	1 bar to 120 bar
Medium pressure pipelines:	100 mbar to 1 bar
Low pressure pipelines:	up to 100 mbar

2.2.1 Low pressure grid

The transport capacity for a pipeline cross section results from the flow speed and the permissible pressure loss. Using the assumption of flow sppeds (3 to 6 m/s for supply lines, 6 to 10 m/s for main lines) these are not reached in low pressure lines due to the loss of pressure. The existing pressure gradient or transport capacity must remain large enough so that at maximum delivery quantity a supply pressure of 22 mbar is assured.

2.2.2 Medium and high pressure grids

For medium and high pressure grids as well, the available transport capacity is determined by the usable driving pressure gradient. The flow speeds are higher than in low pressure pipelines.

It should always be observed that the pressure in the downstream grid determines the lower limit. Customers in residential areas are supplied through low pressure grids up to approx. 100 mbar, medium pressure grids up to 1 bar or high pressure up to 4 bar and partly above. The grids overlap to some extent. Larger industrial customers are serviced from regional transport pipelines with pressures that can also exceed 10 bar.

In order to be able to determine the quantity of the prepared, grid compatible gas to be fed into the natural gas grid, two significant restrictions must be observed: The **grid-side restrictions** and the **restrictions due to the supplied and unsupplied gas areas**.

2.3 Technical criteria for the feed-in of biogas

Raw biogas is formed by the fermentation of renewable primary produts, fermentation impurities or from landfill and sewage gas. It is usually very impure (sulphur, water) and has a methane content of approx. 60% with a CO_2 content of about 40%. This impure raw biogas is cleaned and enriched with methane to become production biogas. The extent of methane enrichment depends on the quality of gas the is required. If biogas can be fed into the gas grid with its natural methane content, it is referred to as „admixture gas“ and can be added to the natural gas in certain quantities.

In this case no methane enrichment is necessary. If the methane content is raised to value just over 90%, it is generally referred to as „enriched admixture gas“. If the raw biogas is brought up to the quality of natural gas it is referred to as „exchange gas“. In addition to methane enrichment it can also be necessary to add liquid gas in order to achieve the prescribed fuel value for natural gas.

Technically the quantity of biogas to fed-in is determined according to the following criteria:

1. Gas side: By the type of processing and thereby its availability as exchange or admixture gas.
2. Grid side: By the capacity of the grid behind the feed-in point. This is determined in winter by the total capacity under full load.
3. Consumer side: By the base load flow rate and in summer by the minimal consumption and use.

The flow rate of feed-in biogas in the supply area of a gas supply company is calculated using the grid parameters such as pressure range, pipeline diameter and installation of additional lines, as well as the miinimal delivery of gas from the grid.

Admixture gas can only be fed-in in the amount that the downstream consumers use it. Due to the transport obligations of the grid operators there can be problems in winter if there is not enough transport capacity for the feed-in of biogas as an admixture gas in a low pressure grid.

Whereas large grids have a sufficiently high buffer capacity and the daily variation in gas consumption is not so important, the smaller grids must take these facts into consideration. A load profile such as this is dependent on the consumer structure and outside temperature. A uniform decrease in gas consumption can be established in the nighttime hours („night tarrif“). For small supply grids it can be assumed that with a continuous feed-in a reduction of 40% of the daily average may not be achieved. In larger grids, the effect of the grid buffer and a higher load profile can enable a larger feed-in quantity. To determine the minimal load, the average consumption per summer day for one hour is established and used to weight the factor „night tarrif“.

The summary of different parameters such as the annual load trend, daily load trend and grid structure yields the result that in periods of minimal gas consumption (hourly) 0.134 % of the average annual total consumption is used. This corresponds to the technical aspects (no change in grid parameters) of the continuous feed-in quantity of exchange gas into the grid level.

It should be observed here as a qualification that this base load, under certain circumstances, may be divided about several partial grids that are not connected to each other, whereby it is not taken into consideration that the end customers are already supplied by the medium pressure grid. Consequently it cannot be said about the individual gas supply company whether this flow rate can only be fed into the low pressure pipeline. This would have to be clarified with the individual gas supply company, as well as the question as to whether an increase in pressure at the low or medium level should be undertaken to achieve a higher flow rate. To prevent the pipelines from being overloaded it is advisable to carry out a grid simulation in individual cases. The higher the pressure level – from the viewpoint of the grid topology – the less the significance of the division into several grids.

2.3.1 Classification of the gas supply companies

A characteristic parameter for the size classification of a gas supplier and the associated grid is the annual delivery of gas to consumers. Approximately 35% of the gas supply companies have sales of unter 200 GWh; these are the small local supply companies. Another 50% have sales of between 200 GWh and 1,100 GWh. 15% have gas sales of over 1,100 GWh.

Another classification parameter is the ratio of average deliveries per summer day to the highest delivery per day. If the ratio is under 0.15 it can be assumed that the corresponding grid is dominated by residential construction. Medium ratios of under 0.45 characterise a mixture of residential, businesses and industries. Values above this represent sales of gas to businesses and industrial consumers. If these factors are combined a classification of the gas supplier can be made.

With regard to the feed-in of exchange gas, in addition to the values already named, the maximum transport capacity of that part of the grid where the biogas is to be fed in must be taken into consideration. The selection of an appropriate connection area is therefore of significant importance. Here, a differentiation is to be made between pipeline sections that serve only as supply lines to a residential development and business centers and those sections that have a transport function to other residential areas or business parks. The latter are preferred as connection points. Consideration must also be given here to the fact that the transport capacity of the grid with a high percentage of business customers must be at least 5 times higher.
With the smaller gas suppliers with sales of up to 200 GWh/a it can be assumed that the corresponding grid has one or several feed-in points that can be serviced from the regional supply grid. Here there must be at least one location for the feed-in of biogas, namely directly behind the transfer station, where a majority of the possible gas to be consumed is available.

2.3.2 Feed-in of admixture gas

The quantity of admixture gas to be fed in is also dependent on the exchange gas quantity, but it is only a fraction of this corresponding to the targeted mixture ratio. Here, the valid calculations are those restrictions with regard to fuel value, Wobbe-index and CO_2 concentration. Due to the minimal allowable flow rates adn the necessity of a mixer, the feed-in only comes into consideration for a few suppliers, which have to checked individually.

When the feed-in is admixture gas, the fuel value difference of the base gas to the admixture gas is decisive which, particularly in summer with minimal gas quantities is restrictive.
In ring grids, the collision of conditioned and unconditioned gases under sensitive gas applications can cause difficulties („oscillation zone“). It can therefore make sense to feed-in at higher pressure levels with large quantities of gas, since then the fuel value differences in conditioned gas can possibly be kept lower. Then, the selection of a connection point takes on an even greater importance than is the case with exchange gas. A pipeline section must be chose in which a sufficient quantity of gas can be continuously transported.

This is to be differentiated from the capacity of the corresponding pipe section to transport at a certain flow rate to other parts of the grid as may be necessary for the transport of the feed-in of exchange gas. The required quantity of base gas must also be transported, independent of the operation of the biogas plant. A detailled analysis of the respective local grid, the transport quantity in different pipeline sections and above all the daily, weekly and annual rates of transported quantity represents a significant obstacle to the feed-in.

2.4 Area restrictions of biogas feed-in

The accessibility of the natural gas grid for conditioned and grid compatible gas is determined by the gas supplied area. Here it is irrelevant whether it is a local supply line or a regional high pressure line. It can be assumed that the area restrictions are subordinate to the technical restrictions. The project planning of a feed-in station is possible nearly anywhere there is a gas supply pipeline. A particularly advantageous location is, in any case, to be determined on a case by case basis. Even areas in which the number of supply companies are low for a give area, can still be completely provided for.

3. Requirements of biogas composition

The technical requirements on the feed-in of biogas into the public natural gas grid apply to the material values, the technical combustion specifications and the condition and quantity of the gas, as well as the technical equipment that is required for the production and propagation of grid compatible gas properties. Biogas cannot be fed into the gas grid with the same chemical composition as it is formed in the fermentation process in the fermenter or as it is found in waste treatment plants or lanfills. This so-called „raw biogas" is contaminated withimpurities that could cause damage such as corrosion to the downstream equipment i.e. the gas grid and end consumer. Also the fuel value of this raw gas may be too low due to the lower percentage of methane. In other words: there are certain quality requirements for the chemical composition of the biogas (methane content, sulphur concentration, humidity) that have to be fulfilled before it can be fed into the gas grid.

A question of central importance is whether the biogas is to be fed into the grid as „admixture gas" or as „exchange gas". The term admixture gas is used when biogas with low, usually natural methane content (approx. 60%) is fed into the grid so that the natural gas is „added" to in small quantities (approx. 5 to 25%), yielding a gas mixture with a mixed quality that is slightly lower than that of pure natural gas. A so-called „mixed gas" is formed whose quality depends on the mix ratio of biogas / natural gas and the feed-in qualities of biogas and natural gas. The quality requirements of biogas as admixture gas are therefore clearly lower than those for natural gas. Methane enrichment is usually not necessary and the cleaning requirements (removal of gas contaminants) are less strict.
The necessary connection lines must be available for the feed-in, the gas must be compressed to a pressure above the pipeline pressure of the respective pressure level, adapted to the delivery and contract requirements and pressure and material values must be measured and regulated and the gas must be stored in a buffer tank. Furthermore, an odoriser and mixer may be required.

3.1 Biogas properties

Biogas consists primarily of methane and carbon dioxide and is completely saturated with water vapour. Depending on the technical design of the fermenter (leakages or internal biological de-sulphurisation), the biogas can contain appreciable quantities of nitrogen and oxygen (air). It can therefore be assumed that the gas conditioning process will have to compensate for fluctuating contamination loads.

Component	Content	Effect
CH_4	50 to 75 Vol.%	Combustible biogas components
CO_2	25 to 50 Vol.%	Reduces the fuel value; raises the methane content and thereby the anti-knock properties of motors; promotes corrosion (weak carbonic acid); if the gas is also damp it damages alkaline fuel cells
H_2S	0,005 to 0,5 mg S/m³	Corrosive in aggregates and pipelines (stress corrosion); SO_2 emissions after combustion or H_2S emissions if combustion is incomplete; catalytic converter poison
NH_3	0 to 1 Vol.%	NO_x emissions after combustion; harmful for fuel cells; increases the anti-knocking properties of motors
Water vapour	1 to 5 Vol.%	Contributes to corrosion in aggregates and pipelines; condensate damages instruments and aggregate; danger of icing of pipelines and vents at frost temperatures
Dust	> 5 µm	Clogs vents and damages fuel cells
N_2	0 to 5 Vol.%	Reduces the fuel value; raises the anti-knock properties of motors
Siloxane	0 to 50 mg/m^3	Only forms in sewage and landfill gas from cosmetics, wash powder, printing inks etc.; acts as a quartz grinding medium and damages motors

Table 1: Components of raw biogas
Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

The most important minor component in biogas is sulphur hydroxide, whereby the quantity can fluctuate strongly depending on the input substrates. The range of fluctuation for H_2S can be from 200 to 10,000 ppm in various biogas plants. Even within the same biogas plant there can be strong fluctuations in H_2S load over a certain period of time. It can generally be assumed that biogas from plants with high use of liquid manure will have a significantly higher level of sulphur than plants with renewable raw material substrates. Another factor influencing the quantity of H_2S in biogas when using liquid manure is also the quallity of the livestock's drinking water.

Depending on the input substrate, the biogas can also contain higher minor components of hydrocarbons (touluene, benzene, or xylene) or organic silicon (siloxane). The concentrations of benzene, touluene, ethylbenzene, xylene and cumene in biogas are very small and are generally below the limit of detection of 1 mg/m^3. Only a touluene load of up to 5 mg/m^3 can be detected in individual cases (use of co-substrates). Concentrations of chlorine and fluorine in biogas are also below the limit of detection of 0.1 mg/m^3 with individual exceptions (chlorine up to 0.15 mg/m^3). Organic sulphur components such as methane or ethantiol can be present in a very few exceptional cases in biogas. Siloxane can be present in biogas in very small quantities through the use of foodstuff waste. There have only been a very few individual cases of siloxan compounds measured in the range of < 5 mg/m^3.

Due to the very minimal contamination of biogas plants with BTX (benzene, toulene, xylene), siloxane, ammonia and organic sulphur compounds, they are usually neglected when designing the gas cleaning process. There are three reasons for this: One is that the contaminants are below the requirements of the natural gas grid, the minor components are generally not detectable in the biogas and finally the minor components can usually be removed as part of the normal gas cleaning process without additional process steps. Generally, gas cleaning and conditioning process are limited in their ability to be used in other biogas plants and should in any case be optimised for the concrete biogas composition and adapted to the local properties.

3.2 Gas property requirements for feed-in into the grid

The defined quality requirements were originally specified for natural gas to assure its safe transport within the gas grid without causing lasting damage to the pipeline system. Some of the impurities contained in natural gas such as hydrocarbons, water, oxygen or carbon dioxide can, in larger concentrations cause significant corrosiion in aggregates and pipelines. The condensate from these impurities can also damage instruments and aggregates and, at freezing temperatures lead to the icing of the pipelines.

Another important aspect concerns the establishment of certain combustion specifications of the gas. This has nothing to do with safety considerations, but is rather meant to assure a defined energy content of the gas at the consumer's end. These combustion specifications make up the properties of the imported gas.

The components of natural gas and its associated impurities are primarily hydrocarbons in a gas state. Furthermore, there can be impurities that are gaseous, fluid or solid. They are either already in the transported natural gas, stem from some possibly used conditioning process, are purposely added to the gas as effective substances or are formed during the transport of the gas.

Combustion specifications		
1.	Wobbe-Index	13,3 – 15,7 kWh/m^3
2.	Fuel value	10,7 – 12,8 kWh/m^3
3.	Relative density	0,55 – 0,65
Gas impurities		
4.	Hydrocarbons: Condensation point	maximum 0° at operation pressure
5.	Water: Condensation point	maximum -8° at a pressure of 40 bar
6.	Oxygen (O_2)	≤ 0,5 Vol. %
8.	Carbon dioxide (CO_2)	≤ 2 Vol. %
9.	Nitrogen (N_2)	≤ 5 Vol. %
10.	Hydrogen (H_2)	≤ 4 Vol. %
11.	Total sulphur	10 mg S/m^3 (longterm) 30 mg S/m^3 (representative)
12.	Mercaptan sulphur	≤ 6 mg S/m^3
13.	Hydrogen sulphide (H_2S)	≤ 5 mg/m^3
14.	Carbonyl sulphide (COS)	≤ 5 mg/m^3
15.	Halogen compounds	0 mg/m^3
16.	Ammonia (NH_3)	Technically free
17.	Solid and fluid components	Technically free
Other components that could endanger the operational safety and contents of the grid are not allowed.		

Table 2: Austrian qualitystandards of ÖVGW Richtlinie G 31
Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

3.2.1 Definition of gas labels

Fuel gas for the public gas supply are gases that are distributed via a supply grid to households, businesses, industries and public institiutions. They are categorised according to their technical fuel specifications into families and into groups according to device specific reasons (see table 3).
Base gas is the term given to the gas provided by the gas supply companies in the respective supply region. The gas of the 2nd gas family is divided into L-Gas (Low) and H-Gas (High) (see table 3).

Conditioning gas is used to adjust the technical fuel specifications. Gases or gas mixtures for conditioning can be added to the base gas to adust the fuel specifications (heat value, fuel value, density, Wobbe-index, connection pressure). Conditioning gases that are allowed are: air, nitrogen, gases from gas family 1 (town gas, synthesis gas), natural gases with different properties or liquid gases. The mixed gas may not exceed 1% CO and 12% Hydrogen. Under certain circumstances , depending on the supply region and gas supply companies, these limit values may not be utilised.

For base gases of gas family 2, the following gases or gas mixtures for conditioning may be used:

1. **Air.** The use of air is limited due to the oxygen content in the mixed gas that may not exceed 4% temporarily in dry grids (3% in dry grids, 0.5% in damp grids). Furthermore, the relative humidity may not exceed a value of 60% in high and medium pressure lines.
2. **Nitrogen.** There are no additional restrictions (nitrogen must be dry).
3. **Gases of gas family 1.** The use of gases from gas family 1 is limited by the values for gas impurities, CO-Vol. 6 %, O_2-Vol. 3 % in dry grids and 0.5 % in damp grids. For mixed gas the values are: CO-Vol. ≤ 1 %, H_2-Vol. ≤ 12 % (lower contents may be necessary), the methane count must be observed, annual average value of total sulphur (without odorising) ≤ 30 mg/m^3.
4. **Natural gases with different properties.** These can be used without additional restrictions for the production of regular H or L gas.
5. **Liquid gases.**

The addition of liquid gas can make sense, for example to raise the technical fuel properties of the feed-in gas to the level of natural gas L or H (carburisation). The amount added gas is oriented to the fuel value of the gas normally distributed. The addition of propane is therefore less critical due to its recessive combustion quality than the addition of butane. With a fuel value setting of up to 11,1 kWh/m^3 there are no time or technical limitations (liquid gas composition, propane-butane-ratio). With a fuel value setting over 12.1 kWh/m^3 propane is to be used exclusively and its use should be limited to exceptional situations and time limited. At pressures above 5 bar, changes in the condensation behaviour should be carefully observed.

Admixture gas

Admixture gases are gas mixtures that differ from bases gas in their composition and in their technical fuel specifications. They can be added in limited quantity to supplement gas properties or for the utilisation of locally available gases. Allowable admixture gases are: Gases of gas family 1 in a mixture with liquid gas, liquid gas/air mixture, exchange gas (propane-air mixture, waste gas, biogas, marsh gas) and other methane rich gases, as the case may be as a mixture with liquid gas.

1. **Liquid gas-air-mixture** The gas impurities may not exceed the guidelines with the exception of the liquid gas-air-mixture. The values for propane, butane and admixtures with an olefin content of max. 10% by weight. The same characteristics must be assure for the combustion. At more than 10% admixture the relative density of d = 0,75 may be exceeded. The same fuel value admixture of more than 20% can lead to a shortfall in the Wobbe-Index lower value limit. For the operation of gas engines a lowering of the methane count should be observed.
2. **Gases of gas family 1 in a mixture with liquid gas.** The limits are based on the guidelines for gas impurities CO-Vol. 6 %, O_2-Vol. 3 % in dry and 0.5 % in damp grids. For the mixed gas the limists are CO-Vol. $\leq$ 1 %, H_2-Vol. $\leq$ 12 % (lower contents may be necessary). The methane count must be paid attention to; the annual average of total sulphur (without odorisation) ≤ 30 mg/m^3.
3. **Exchange gas.**
   a. **Propane** is limited by the maximum olefin content of 10% by weight, the setting of the propane-air-mixture on a reduced Wobbe-Index from experience of 12,5 kWh/m^3 for natural gas H. On a time limited basis the Wobbe-Index can be lowered to 11 kWh/m^3 for natural gas L.
   b. **Waste gas and Biogas** as well as marsh gas. Appropriate conditioning is necessary. The problem of corrosion due to the CO_2- content should be observed. Gas from coal gasification and splitting should have a CO content under 3 %.
   c. **Methane gases e.g. in a mixture with liquid gases.** The fuel value should be oriented to the normal conditions in the supply region.

The liquid gas/air-mixture should be limited to a maximum olefin content of 10%. Higher olefin content can cause problems (upon exceeding the relative density of 0.75 or upon undershooting the Wobbe-Index by more than 20%). The maximum allowable relative density with liquid gas dosage, the feed-in must not exceed 13,5 kWh/m^3 for natural gas-H and 11,6 kWh/m^3 for natural gas-L. It may be necessary to maintain more narrow limits for certain consumers.

When gases from gas family 1 (hydrogen rich gases, synthesis gases) are fed into a mixture with liquid gases as an admixture gas, the same conditions must be observed as with the feed-in or addition of conditioned gases.

Exchange gas

Exchange gases are gases that can differ in composition and combustion specifications from base gas, but that have the same combustion behaviour.

1. **Propane:** The limit here is an olefin content of 10% max. by weight. The setting of the propane-air-mixture on a reduced Wobbe-index from practical experience is limited to 12,5 kWh/m^3 for natural gas H and 1 kWh/m^3 for natural gas L.
2. **Waste gas and biogas** as well as marsh gas. Appropriate conditioning is necessary. The problem of corrosion due to the CO_2- content should be observed. Gas from coal gasification and splitting should have a CO content under 3 %.

Gases that belong to the same group are in principle exchangeable, whereby the locally permissible Wobbe-index fluctuations must be paid attention to (approx. +5 %, –10 % of the nominal value of the respective Wobbe-index nominal values 12,4 and 15,0 kWh/m^3).

3.2.2 Discussion of technical combustion data

Wobbe-Index

The Wobbe-Index is a specification for the exchangeability of gases with regard to thermal load of gas equipment. This index should enable evaluations to be made as to whether a gas can be exchanged for another gas without changes having to be made to the burner. Its numerical value is derived from the division of the fuel value by the root of the relative density. The Wobbe-Index is an important specification in the filed of so-called „gas families". In the public gas supply, fuel gases with conformable combustion properties are grouped into gas families. To the extent necessary due to equipment specifications, gas families are also divided into groups.

Gas family	Main components	Group
1	Hydrogen (H_2)	A: Town gas B: Coke-(grid gas)
2	Methane (CH_4)	L: Natural gas L & Exchange gas H: Natural gas H & Austauschgase
3	Propane (C_3H_8), Butane (C_4H_{10}) (liquid gases)	1. Propane 2. Propane/Butane-mixture
4	Hydrocarbon/air-mixture	1. Liquid gas/air 2. Natural gas/air

Table 3: Gas families according to DVGW-G260/1
Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

For the different gas families and their groups, total ranges, nominal values and fluctuation ranges are established for the Wobbe-index, that are oriented primarily to the combustion behaviour of the gases in gas equipment or normal construction.

- The total range of a gas family is determined by the upper and lower limits. Exceeding the upper limit is not permissible in any case and an undershooting of the lower limit values is only permissible under certain conditions (e.g. to avoid supply bottlenecks) for limited period of time.
- The nominal value is a characteristic Wobbe-index depending on the gas family. In gas family 2 of the methane rich gases, the nominal value for the adjustment of gas equipment is used as the basis.
- The fluctuation range describes the range in which the Wobbe-index can normally fluctuate. The fluctuation range in the local supply area is derived from the nominal value.

To provide an overview of possible specification for the total range and the fluctuation range for the Wobbe-index, the following table lists the figures from the DVGW-G260.

WOBBE-INDEX	Unit	1. Gas family		2. Gas family		4. Gas family	
		A	B	L	H	Liquid gas/Air	Natural gas/ Air
Total range	kWh/m³	6,4 - 7,8	7,8 - 9,3	10,5 - 13,0	12,8 - 15,7	6,8 - 7,0	7,0
Nominal value	kWh/m³	n.s.	n.s.	12,4	15,0	n.s.	n.s.
Fluctuation range	kWh/m³	n.s.	n.s.	+0,6/-1,2	+0,7/-1,4	n.s.	+/-0,2

Table 4: Total range, Nominal value and fluctuation range of theWobbe-Index acc. DVGB 260/1
Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

In Germany the Wobbe-index can vary within the fluctuation range with regard to the nominal value. The fluctuation range is established in such a way that the upper limit of the total range may not be exceeded unded any circumstances. In such a case, the gas equipment and the burner must be readjusted in order to be able to compensate for the increased thermal load. In any case, however, a temporary overshooting of the nominal Wobbe-index value within the fluctuation range is possible without having to modify the burner nettings; a short-term overload with normal devices is considered to be harmless.

As listed above, a limited undershooting of the Wobbe-index-range for gas family 2 is, in practice, possible in the following cases.

- For the operation of appropriate gas equipment for Group H, the lower limit of 12,8 kWh/m³ can undershot for a limited time by 0,8 kWh/m³ to 12,0 kWh/m³ without having to change the equipment settings (nominal value 15 kWh/m³).
- For the operation of appropriate gas equipment for Group L, the lower limit of 10,5 kWh/m³ can be undershot for a limited time by 0,5 kWh/m³ to 10,0 kWh/m³ without having to change the equipment settings (nominal value 12,4 kWh/m³).

In contrast to Germany, in Austria only a range of the Wobbe-index corresponding to the total range of 13,3 to 15,7 kWh/m³ is prescribed that must be maintained under all circumstances within the Austrian gas market. A definition of the nominal value or a fluctuation range for the nominal value is not defined and there is no accomodation made for short-term undershooting of the Wobbe-index limit of 13,3 kWh/m³.

It is also decisive for the treatment of modified requirements of gas quality for the consumer that a change of the Wobbe-index be technically possible in principle. If comprehensive changes are made (change of „gas family“), the burner in the gas equipment will have to readjusted as would be the case during regular maintenance work.

Fuel value
Currently in Austria a fuel value in the range of 10,7 to 12,8 kWh/m³ for natural gas is prescribed. The fuel value is the sum of the values of the so-called combustion heat and the condensation heat. The complete combustion of a standard cubic metre of gas yields the combustion heat. The combustion products that result such as exhaust fumes and water vapour are cooled at a pressure of 1.013,25 bar and an output temperature of 25° C. At a certain temperature, the so-called dew point temperature, the water vapour begins to condense; the heat released is called condensation heat. This condensation heat is added to the combustion heat and the resulting total heat is called the fuel value.

In contrast to the fuel value, the heat value of a gas represents only the combustion heat as described above. However the combustion by-products are cooled to the output temperature of 25° C and the combustion water that is formed remains in a vapour state. The condensation heat is lost as so-called exhaust gas loss.

There is no compelling technical reason that a gas must posses a defined fuel value. Even lower fuel values are technically possible. Falling fuel values per cubic meter gas however means an increase in the quantity of gas in order to transport a given quantity of energy. This can cause problems in pipelines under heavy load.

Relative density
The relative density is the ratio of the density of the dry gas to the density of dry air under the same conditions. The density ratio is therefore an indicator as to how much the gas is heavier or lighter than the air. Furthermore, it is also an expression of the interdependance of methane and carbon dioxide.

3.2.3 Discussion of gas impurities

Hydrocarbons
Gases, depending on their origin and conditioning process, can under operating conditons contain condensable and aromatic hydrocarbons. During the expansion of the gas under the pressure of the conditioning process, they can under certain operating conditions drop out (retrograde condensation). The condensation of hydrocarbons is influenced by the type and quantity of the condensable components in the gas, as well as the pressure and respective temperature. With hydrocarbons, condensation can cause the formation of oils that can lead to sooting and clogging in gas burners. A further danger of condensation lies in the deflagration within a burner in which it come to a build up of pressure in the combustion chamber and then to explosive dispersion of pressure. The limitation is generally set by establishing a condensation point, i.e. of a temperature above which no condensation of hydrocarbons should occur at operating pressure. Currently in Austria a condensation point of 0° Celsius max. is prescribed for hydrocarbons at operating pressure.

Water

In order to avoid lasting damage to the gas grid, the feed-in gas should also be as dry as possible to prevent corrosion and gas hydrate formation. The condensation of water is influenced by the quantity contained in the gas as well as the pressure and temperature. The limitation results in general through the establishment of a condesnation point (dew point), i.e. of a temperature above which no condensation of water should occur at set pressure. In Austria the condensation point for water must be a maximum of -8 ° C at a pressure of 40 bar.

Oxygen

Oxygen in gases containing water vapour has a corrosive effect and therefore can attack the gas grid. For this reason the percentage of oxygen in the feed-in gases in Austria is defined with a maximum value of ≤ 0,5 % Mol.

Carbon dioxide

Carbon dioxide can either be available as a result of the gas production process or as a natural part of the gases. Carbon dioxide fosters corrosion in damp gases. Due to the danger of corrosion and the related danger of damaging the gas grid, Austia allows a maximum value of carbon dioxide in feed-in gases of ≤ 2% Mol.

Nitrogen

In Austria an upper limit of 5% Mol of nitrogen is prescribed. A minimal mixing of nitrogen is principally possible, but it reduces the fuel value of the gas since nitrogen does not contain any utilisable energy content.

Hydrogen

In Austria an upper limit of ≤ 4 % Mol of hydrogen is defined. This limit corresponds to the ignition threshold of hydrogen in air. There are no reproducible explanations that can be found as to why hydrogen in gases containing methane is limited to 4% and there are also no limits in the DVGW-G260 in Germany that would lead to the reason why there is such a limit in Austria.

Sulphur compounds

The term „sulphur compounds“ includes gas impurities containing sulphur compounds such as sulphur hydroxide, carbon oxide sulphide, other organic sulphides, disulphides, mercaptane and thiophene. The content of sulphur compounds in produced gases depends on the raw materials used and on the gas cleaning. In fossil gases the content depends on the respective storage site of the gases and the conditioning process. The sulphur content of gases (e.g. total sulphur and mercapatan sulphur) can negatively impact the life of pipes and consumable equipment and must therefore be limited. For this reason, in Austria, a total sulphur limit of 150 mg S/m³ in case of disruptions, 30 mg S/m³ as an annual average and 10 mg S/m³ long term. Total sulphur can, in corresponding concentration, lead to corrosion in the conditioning plants and of course in the downstream grids. Furhtermore, for the reasons named, a maximum of 6 mg S/m³ mercaptan sulphur in the feed-in gas is allowed.

Halogen compounds

As a result of the combustion of halogen compounds, acids can be formed, which in combination with humidity or water vapour can lead to corrosion and therefore to damage to the gas grid. For this reason, in Austria 0 mg/m³ is defined as the limit for halogen compounds in the feed-in gas.

Ammonium

In gases containing water vapour ammonium has a corrosive effect and therefore must be avoided in feed-in gases. The requirement „technically free“ means that ammonium has to be removed to such an extent that the continuous operation of gas devices and equipment of standard construction is assured. If this is not the case, there is the danger of deflagration as described unter „hydrocarbons“.

Solids and liquid components

The appearance of mist (oil, glycol or other low volatile liquids) in gas depends on the conditioning process used. Compressor equipment can also, under certain circumstances (liquid hydrocarbons) cause oil mist to form. Since mist and dust can form during production and conditioning and dust formation due to corrosion in the pipelines cannot be avoided completely, measures have to be taken to separate or bind it in the required scope. If, for example, liquids in the form of mist is added to the gas in low pressure grids to prevent leakages in socket joints and to bind dust in the pipeline grid, its addition must be limited so that the combustion properties of the gas and the function of the gas equipment is not negatively impacted. For these reasons the mixture of solid and liquid components in gases must be avoided, so, as with ammonium, in Austria the criterion „technically free“ is listed in order to assure the continuous operation of gas equipment.

3.2.4 Conditioned gases from renewable sources for the public gas supply

Biogas, waste gas, and landfill gas are considered to be gases from renewable sources. The last of these are not allowed into the public gas supply since they can contain halogenated hydrocarbons. The raw gases are classified into gases from fermentation or thermal processes. The combustion specifications are in fermentation gases are derived from the inert components and in the thermal processes by the hydrogen and CO content.

The main components of fermentation gases depend significantly on the production conditions and the fermentation mass. For CH_4 (ca. 45 to 60 Vol.-%) and CO_2 (ca. 40 to 55 Vol.-%); in unstable plant operations, less than 45 % CH_4 may be possible. Gas impurities are mainly hydrogen sulphide (H_2S), but also other sulphur compounds. The concentration of H_2S is generally around several thousand ppm/m^3. Depending on the co-substrates, siloxane, other sulphur compounds, halogenated hydrocarbons (particularly in waste and landfill gas), methanol (from rapeseed oil), as well as ammonium can be present.

Biogenous exchange or admixture gases must keep to the limitations with regard to impurities and are not allowed to cause any hygienic, health risks or problems to facilities of the public gas supply.

For use in the public gas supply, the raw gas is cleaned, conditioned and compressed to the grid pressure of the grid operator. In no case may there be any health risks stemming from the conditioned gas. For the feed-in into the distribution grid of a local gas supply company, the gas must be odorised. Furthermore, regular monitoring must be carried out for the appearance of certain gas impurities such as H_2S. To assure a time and heat equivalent transfer, the settlement fuel value must also be known.

After the conditioning of the raw gas for the public gas supply it can be used as exchange gas or admixture gas (gas for conditioning) and made available to the grid operator at the transfer station.
The maximum CO_2-content is limited to 6% in fuel gas (applies to exchange gas and admixture gas feed-in for the fuel gas mixture after the mix point). The maximum admixture rate for hydrogen in fuel gas is limited to 5%., whereby this sometimes cannot be exploited.

Exchange gas: For use as exchange gas the transferred energy quantity must be determined. The average Wobbe-index of a fermented gas is placed at 60% methane at approx. 7 kWh/m^3 and therefore clearly under that of L and H gas. This means that the CO_2 percentage must be reduced if the gas is to be used as an exchange gas.

Admixture gas: For use as an admixture gas to the base gas the energy quantity must also be determined. Additionally a gas mixer is necessary and the requirements concerning the use and billing behind the mixing point must be fulfilled. The CO_2 percentage does not have to be reduced when the specifications of the gas grid operator can be maintained. When fed-in as admixture gas the fuel value difference of the base gas to the admixture gas is decisive, which, particularly in summer with minimal gas quantities can have a limiting effect. In ring grids, the encounter of conditioned and non-conditioned gases can lead to problems in sensitive gas applications („pendulum zone problem“). It can therefore make sense to carry out the feed-in at a higher pressure level with larger quantities of gas, since then the difference in fuel values in conditioned gases may possibly be kept lower. For gas family 1, 6% CO and for split and coal gasification 3% CO is allowed. Taking into consideration the Wobbe-index limits for CO_2 of 6 Vol.-% and for H_2 of 5 Vol.-% are prescribed. In any case, disturbances of the equipment of the public gas supply are to be excluded.

Usage in L-Gas areas
Exchange gas: Usage as exchange gas is possible, if CO_2 is removed to within all but a few percent.
Admixture gas: Usage as admixture gas is possible but limited and dependent on the grid properties..

Usage in H-Gas areas
Exchange gas: In supply areas with GUS-Gas-quality (Russian-Gas-quality) the unlimited use as exchange gas is possible if CO_2 has been removed to a great extent. In supply aeras with North Sea quality (high fuel value near 12 kWh/m^3) and a nearly complete removal of CO_2, it can only be used as admixture gas.

Admixture gas: Partially conditioned admixture gas with a large percentage of CO_2 , the amount of admixture gas must be oriented to maintain the Wobbezahlgrenzen and the locally allowed fuel value fluctuations (2 % thermic, 1 % volumetric billing).

3.2.5 Gas odorisation

When conditioned biogases are used in the public gas supply they must be appropriately odorised i.e. provided a warning odor. The gas odorisation is to be carried out by the biogas producer before it is fed into the grid as exchange gas or it can be system service provided by the grid operator in the area of the regional and end-distribution. The gas requirements at the feed-in point are to be clarified with the grid operator.

3.2.6 Gas billing

A mean value of changes in the feed-in fuel value over time or in the distribution of gases with different fuel values (arithmetic or quantity weighted mean of daily gas delivery and the feed-in fuel value in a grid with possible deduction of large consumers) in a spatially separated grid of a gas supply company, is to be established and applied.

For the distribution of gases with different fuel values in a spatially connected grid (meshed grid) a substitute process is to be used at the feed-in location. This would apply, for example, to the feed-in of conditioned biogas (exchange as well as admixture gas) in the medium or high pressure level with a downstream feed-in location in the low or medium pressure supply grid (supply of end customers). In these cases, the fuel value of the mixed gases is either to be measured or calculated on the basis of the quantity flow and fuel value to the gases to mixed.

During the distribution of gases at several feed-in locations with different fuel values in a spatially connected grid (meshed grid), pendulum zones can form. In this case the following applies: The fuel value billing unit is to be determined for each individual customer on the basis of their regional situation in the supply area. The aim should be that base fuel value billing for a supply area should not deviate more than 2% from the median fuel value of the customer during the billing period for the delivered gas.
For monitoring purposes therefore, the median value (fuel value) should be calculated for every feed-in point and a quantity weighted median value determined for the downstream grid. The feed-in value should not deviate more than 2% from the base fuel value billing unit.

On the basis of these determinations it can be assumed that the feed-in of conditioned biogas directly into the low and medium pressure supply levels (end customer supply) through an additional feed-in point must assure to a great extent that the feed-in fuel value will be equal to that available locally; this means that an adjustment of the fuel value of the conditioned gas using air or liquid addition of gas is required. The feed-in of biogas into the supply grid through a feed-in point – mixture of base gas from the higher-level gas distribution level with biogenous exchange or admixture gas – simplifies the billing process and the time and expense required for biogas conditioning.

3.3 Comparison of international quality requirements

Although the regulations of the EU Gas Guidelines (98/30/EG) [EG-RL 1998] apply to all EU nations, the regulations for biogas-grid-feed-in can vary greatly.

3.3.1. Quality requirements in Germany

In principle biogas producers in Germany are also permitted access to the gas grid. However, the biogas quality must meet the demands of the DVGW-Regelwerken G260 and G262 (gas specifications).

1.	Oxygen (O_2)	< 0,5 Vol. %
2.	Hydrogen (H_2)	< 5 mg/Nm^3
3.	Carbon dioxide (CO_2)	No upper limit
4.	Nitrogen (N_2)	No upper limit
5.	Total sulphur	≤ 30mg/m^3
6.	Methane content	n.s.
7.	Water vapour-dew point	ts > ground temperature
8.	Relative density	n.s.
9.	Feed-in pressure	n.s.
10.	Wobbe-Index (kWh/m^3)	n.s.
11.	Fuel value	8,4 –13,1 kWh/m^3

Table 5: Quality criteria in Germany
Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

These criteria apply to the quality of biogas at the feed-in point. In comparison to the criteria in Austria it should be noted that the regulations in Germany, while not optimal, are nevertheless significantly more „biogas friendly“. For carbon dioxide and nitrogen, Germany has no upper limits. The Wobbe-Index is not defined. The fuel value at 8,4 kWh/m^3 is clearly lower than the limit (10,7 kWh/m^3) in Austria.

3.3.2. Quality requirements in Austria

The following table illustrates the quality requirements listed in the ÖVGW-Richtlinie G31, classified according to their fuel specifications and impurities.

Fuel specifications		
1.	Wobbe-Index	13,3 – 15,7 kWh/m^3
2.	Fuel value	10,7 – 12,8 kWh/m^3
3.	Relative density	0,55 – 0,65
Gas impurities		
4.	KohlenHydrogene: Kondensationspunkt	maximum 0° at operating pressure
5.	Wasser: Kondensationspunkt	maximum -8° at a pressure of 40 bar
6.	Oxygen (O_2)	≤ 0,5 Vol. %
8.	Carbon dioxide (CO_2)	≤ 2 Vol. %
9.	Nitrogen (N_2)	≤ 5 Vol. %
10.	Hydrogen (H_2)	≤ 4 Vol. %
11.	Total sulphur	10 mg S/m^3 (long-term) 30 mg S/m^3 (average)
12.	Mercaptane sulphur	≤ 6 mg S/m^3
13.	Hydrogen sulphide (H_2S)	≤ 5 mg/m^3
14.	Carbonyl sulphide (COS)	≤ 5 mg/m^3
15.	Halogen compounds	0 mg/m^3
16.	Ammonium (NH_3)	technically free
17.	Solid and liquid components	technically free
Other components that could endanger the operational safety and contents of the grid are not allowed.		

Table 6: Quality criteria in Austria
Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

The gas components and impurities contained in natural gas are primarily hydrocarbons in a gaseous state. Furthermore, gas impurities may be present that are gaseous, liquid or solid. They are either already present in natural gas, stem from a conditioning process, are added intentionally as effective substances, or are formed during the transport of the gas.

3.3.3. Quality requirements in Sweden

In Sweden, the feed-in of biogas has, up to now played a rather subordinate role. However, biogas was introduced in the 1990s as a motor vehicle fuel and in September of 1999 prescriptive limits were established that have since then had to be maintained for the use of biogas as a vehicle fuel, as well as for the feed-in into the public gas grid. These quality criteria refer to the quality of gas in the public grid.

With regard to the feed-in of gas into the gas grid, the Swedish gas supply companies can place additional requirements for the fuel value of the biogas in order to assure the correct measurement of gas consumption at the end customer. In contrast to Austria and Germany however, it is the quality of the mixed gas „in the grid“ that is important for the suitability of feed-in gas into the gas grid and not the quality at the feed-in point. The experience in Sweden up to now has shown that there is, in principle, no upper limit for the feed-in of biogas into the public gas grid. A comparison of the quality criteria listed above for Sweden with those of Austria shows that the percentage of oxygen, as well carbon dioxide is 50% higher in Sweden than in Austria and the percentage of total sulphur at 23 mg S/m^3 in Sweden is, considered over the long term, also greater than in Austria with a long term value of 10 mg S/m^3. A significant difference is also that the quality of the mixed gas is defined and not the feed-in gas.

1.	Oxygen (O_2)	≤ 1 Vol. %
2.	Hydrogen (H_2)	n.s.
3.	Carbon dioxide (CO_2)	≤ 3 Vol. %
4.	Nitrogen (N_2)	n.s.
5.	Total sulphur	< 23 mg S/m^3
6.	Methane content	> 96 %
7.	Water vapour - dewpoint	n.s.
8.	Relative density	n.s.
9.	Feed-in pressure	n.s.
10.	Wobbe-Index (kWh/m^3)	n.s.
11.	Fuel value (kWh/m^3)	n.s.

Table 7: Quality requirements for gas in the Swedish public gas grid
Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

3.3.4. Quality requirements in Denmark

In Denmark, as in Sweden, it is the quality of the mixed gas in the gas grid that is important for the feed-in of biogas into the gas grid and not the quality at the feed-in point. Investigations have brought to light no clear legal regulations for the quality of natural gas. Nevertheless, the quality criteria listed here, based on corresponding measurements, should serve as a reference point for the quality in the Danish gas grid. Due to the high percentage of propane and ethane, the natural gas in Denmark has a high fuel value with relatively low methane content.

1.	Oxygen (O_2)	n.s.
2.	Hydrogen (H_2)	n.s.
3.	Carbon dioxide (CO_2)	1,4 %
4.	Nitrogen (N_2)	0,3 %
5.	Total sulphur	n.s.
6.	Methane content (CH_4)	87,2 – 91 %
7.	Water vapour - dewpoint	< -5° C
8.	Relative density	0,625
9.	Feed-in pressure	n.s.
10.	Wobbe-Index	14,42 – 15,25 kWh/m^3
11.	Fuel value	11,1 – 12,3 kWh/m^3

Table 8: Quality of Danish gas
Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

In order to comply with the quality requirements in Denmark, up to 25% of biogas enriched with a methane content of e.g. 90% can be fed into the public grid. If no methane enrichment is carried out, the biogas (with 65% methane content) and a volume percentage of 8% can generally be fed into the grid. If biogas in natural gas quality is fed into the grid as an exchange gas, then there is of course no upper limit for the quantity of the feed-in gas. If the the biogas quality does completely meet that of natural gas, then the maximum volume of biogas the can be fed in is determined by the Wobbe-Index (14,42 – 15,25 kWh/m^3) of the resulting mixed gas.

In comparison to the current quality criteria in Austria,it can be seen that the combustion specifications of Danish gas is about on the same level as in Austria, whereby there is a conspicuous difference in the percentage of methane content of approx. 87 – 91% compared to that in Austria of 96 – 98%. This difference is based in the different production areas of the two contries; Denmark obtains its natural gas from the North Sea and Austria receives it from Russia.

3.3.5. Quality requirements in Switzerland

In Switzerland the feed-in of biogas can be as exchange or admixture gas. With regard to the quality of natural gas there is only a technical bulletin issued by the Swiss Gas and Water Association that describes the properties of the distributed natural gas based on measurements of the customs measurement station for dry gas at 0° and 1.013 mbar. This bulletin is not binding and values contracted by importers can deviate from these criteria. The bulletin does, however, provide a good overview of the natural gas quality available in Switzerland.

1.	Oxygen (O_2)	n.s.
2.	Hydrogen (H_2)	n.s.
3.	Carbon dioxide (CO_2)	n.s.
4.	Nitrogen (N_2)	n.s.
5.	Total sulphur (in odourisedGas)	8,1 – 11,1 mg/m^3
6.	Methane content (CH_4)	88,41 – 98,12 %
7.	Water vapour - dewpoint	n.s.
8.	Relative density	0,566 – 0,630
9.	Feed-in pressure	n.s.
10.	Wobbe-Index	14,47 – 14,79 kWh/m^3
11.	Fuel value	11,10 – 11,61 kWh/m^3

Table 9: Properties of distributed natural gas in Switzerland
Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

In order to allow the feed-in of only partially conditioned biogas as admixture gas, in Switzerland a maximum volume of 5% of the current natural gas flow volume has been set and the requirements for conditioning lowered correspondingly. This option for biogas feed-in has not however been used up to now. The following table shows the criteria for the feed-in of biogas (defined as waste gas) as an admixture gas or exchange gas.

	Property	Exchange gas	Admixture gas
1.	CH_4-Content	min. 96 Vol.-%	natural. CH_4-Content of waste gas
2.	CO_2-Content	n.s.	natural. CO_2-Content of waste gas
3.	O_2-Content	less than 0,5 Vol.-%	less than 0,5 Vol.-%
4.	H_2S-Content	max. 5 mg/Nm³	max. 5 mg/Nm³
5.	Water vapour - dewpoint	Saturation temperature under the average ground temperature of the gas supply region	Saturation temperature under the average ground temperature of the gas supply region
6.	relative Humidity	max. 60 %	max. 60 %
7.	Zumischung	Unlimited mixture possible	max. 5 Vol.-% Waste gas of the current natural gas flow volume

Table 10: Quality requirements for exchange and admixture gas in Switzerland
Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

The prescribed odorisation of both gases can take place either directly after gas conditioning or the gas supply company must assure sufficient odorisation of the entire mixed gas (fed-in biogas and natural gas) centrally. In order to comply with the criteria listed above the following process steps are prescribed:

- Filtration of the gas (to remove accompanying particles or droplets)
- Desulphurisation
- Drying (by cooling the gas to 5° C)
- Oxygen-elimination (as necessary)
- Methanane enrichment/CO_2-reduction (only for unlimited mixture as exchange gas)

In the case of unlimited mixture as exchange gas, the biogas conditioning must be monitored by quantitative gas analysis that is visualised graphically. The CH_4- und CO_2-content and the H_2S-content are to be determined regularly.

In comparing the Swiss and Austrian quality requirements it can be seen that in Switzerland there already exist quality criteria for the feed-in of admixture gas. Biogas with a natural methane content of approx. 60% and carbon dioxide content of approx. 40% (CO_2) can be fed in up to 5% of flow volume. If conditioned biogas is fed in as exchange gas into the public gas grid, higher quality criteria must be complied with due to the natural gas used in Switzerland.

Furthermore, a comparisoon of the quality properties of natural gas with the Austrian guidelines shows that the methane content of natural gas in Switzerland is subject to significant fluctuations of 88 – 98%, whereas in Austria a CH_4-percentage between 96,2 and 98,6 % is measured in control area East. The reasons for this can be found in the different natural gas qualities from the Netherlands that is delivered to Switzerland and those from Russia that are supplied to Austria. The fuel value of natural gas in Switzerland ranges from 11,10 – 11,6 kWh/m³ and is within the deviation range of the fuel value in Austria and the percentage of total sulphur from 8 – 11 mg/m³ is about in the same long term level of 10 mg/m³ in Austria.

3.4 Comparison of raw biogas with the quality requirements for feed-in into the grid

A comparison of the quality requirements of the individual countries shows two significant differences to the current situation in Austra:

1. For cost efficient biogas feed-in the differentiation between exchange gas and admixture gas with different quality requirements is a significant criterion. In the scandinavian countries, as in Switzerland, biogas content with natural methane content can fed into the gas grid as an admixture gas taking into consideration mixture effects with volume percentage of up to 5%, without undermining the quality requirements of the gas grid.
2. In Sweden and Denmark the quality requirements must be fulfilled „in the grid“ and not at the feed-in point. These countries reasonably take into account the mixture effect within the gas grid without undershooting the technical minimum criteria or ignoring the safety requirements.

The following table summarises the most important requirements for the feed-in of biogas into the gas grid in the individual countries. The figures stem from the regulations of the national gas and water associations of the respective countries. Only the most important figures from the regulations are given.

		Austria	**Germany**	**Sweden**	**Denmark**	**Switzerland exchange-gas**	**Switzerland admixture gas**
	Reference point	Feed-in	Feed-in	Grid	Grid	Feed-in	Feed-in
1.	Oxygen (O_2)	≤ 0,5 Vol.-%	< 0,5 Vol.-%	< 1 Vol.-%	n.s.	≤ 0,5 Vol.-%	≤ 0,5 Vol.-%
2.	Hydrogen (H_2)	≤ 4 Vol.-%	< 5 mg/Nm^3	n.s.	n.s.	n.s.	n.s.
3.	Carbon-dioxide (CO_2)	≤ 2Vol.-%	No upper limit	≤ 3 Vol.-%	1,4 Vol.-%	n.s.	Natural CO_2-Content of waste gas
4.	Nitrogen (N_2)	≤ 5 Vol.-%	No upper limit	n.s.	0,3 Vol.-%	n.s.	n.s.
5.	Total sulphur	< 10 mg S/m^3	≤ 30 mg/m^3	< 23 mg S/m^3	n.s.	n.s.	n.s.
6.	Methane-content	n.s.	n.s.	> 96 Vol.-%	87-91 Vol.-%	≥ 96 Vol.-%	natural CH_4-Content of Waste gas
7.	Water vapour dewpoint	Maximum -8° C at a pressure of 40 bar	t_s > ground-temperature	n.s.	< -5 °C	n.s.	n.s.
8.	Relative density	0,55 to 0,65	n.s.	n.s.	0,625	n.s.	n.s.
10.	Wobbe-Index (kWh/m^3)	13,3 to 15,7	n.s.	n.s.	14,42 to 15,25	n.s.	n.s.
11.	Fuel value (kWh/m^3)	10,7 to 12,8	8,4 to 13,1	n.s.	11,1 to 12,3	n.s.	n.s.

Table 11: Comparison of quality requirements for biogas feed-in into the grid in Austria, Germany, Sweden, Denmark (measured quality criteria) and Switzerland
Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

Of primary importance to the economic efficiency of the biogas feed-in is the question as to what extent the raw biogas must be cleaned and its methane content raised (enriched). The requirements defined in the national and internation guidelines therefore represent the standard for the quality of biogas at feed-in (and as mixture gas in the grid). In order to show the resulting needs for the cleaning and enrichment of the feed-in of biogas, the most important components of typical raw biogas and their effects are illustrated.

Components	Content	Effect
CH_4	50 – 75 Vol.-%	Combustible biogas components
CO_2	25 – 50 Vol.-%	Reduces fuel value; increases methane content and thereby the anti-knocking properties of motors; promotes corrosion (weak carbonic acid); if the gas is also damp, damaging for alkaline fuel cells
H_2S	0,005 – 0,5 mg S/m³	Corrosive in aggregates and pipelines (stress corrosion cracking); SO_2-emissions after burning and H_2S-emissions if combustion incomplete; catalytic poisons
NH_3	0 – 1 Vol.-%	Nitrous oxide emissions after combustion; damaging to fuel cells; raises the anti-knocking properties of motors
Water vapour	1 – 5 Vol.%	Contributes to corrosion in aggregates and pipelines; condensate damages instruments and aggregate; at frost temperatures, danger of icing of pipelines and jets
Staub	> 5 µm	Clogs jets and damages fuel cells
N_2	0 – 5 Vol.-%	Reduces fuel value; raises anti-knocking peformance of motors
Siloxane	0 – 50 mg/m³	Only with waste and landfill gas from cosmetics, washing substances; printing ink etc.; forms quartz grinding substances that damage motors

Table 12: Components of raw biogas
Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

For the utilisation of biogas, methane is the component with the highest value for the user. CH_4 represents carbon in its most reduced form. If it is oxidised in the presence of oxygen it provides energy until it is converted to carbon dioxide. CO_2 is the oxidised carbon compound. No more energy can be derived from it. Correspondingly more valuable is biogas with 75% methane content in comparison to only 50% CH_4 by volume. Manufacturers, as well as operators of biogas plants not only strive to produce as much biogas as possible from the substrate used, but also as high a percentage of CH_4 as possible.

It should be noted here that in the production of cleaned, but not completely conditioned biogas in agricultural plants, methane contents of between 50 and 60% and in larger commercial plants up to 75% can be achieved. Just as CO_2 , water vapour is also a component that does not provide any extra energy through oxidation. Additionally, there is the danger that the water vapour can condense when the gas is cooled and then in its liquid form, cause damage to measurement and regulation equipment, as well as to compressors. To avoid this, the biogas is dried before it is utilised. Ammonium (NH_3) ad Hydrogen sulphide (H_2S) are also among the undesirable components. Above all, hydrogen sulphide is present in any biogas in measurable quantities. It is formed from the decomposition of protein-rich compounds in the substrate. NH_3 as well as H_2S are aggressive compounds that can lead to corrosion of plant components that come into contact with them.

Most manufacturers of block type thermal plants and boilers therefore set strict limits for hydrogen sulphide, which should not be exceeded in order to avoid corrosion damage. Furthermore, during the burning of the hydrogen sulphide together with the biogas, undesirable SO_2 is formed. This SO_2 represents an air pollutant that can lead to acid rain in combination with water or form sulphuric acid in the exhaust line of the BTTP that can cause corrosion.

The following is a summary of the composition of raw biogas as compared to the criteria guidlines in Austria for natural gas.

	Raw biogas	Aust. RL	Unit
Methane	50 – 75	97	Vol.-%
Carbon dioxide	25 – 50	2	Vol.-%
Water vapour	1 – 5	0	Vol.-%
Nitrogen	5	5	Vol.-%
Oxygen	0 – 5	0,5	Vol.-%
Hydrogen	< 1	4	Vol.-%
Ammonium	< 1	frei	Vol.-%
Hydrogen sulphide	< 1	0,0003	Vol.-%
Fuel value	5,52 – 8,27	10,7 – 12,8	kWh/m³
Wobbe-Index	5,9 – 8,15	13,3 – 15,7	kWh/m3

**Table 13: Comparison of raw biogas with the limits set by the quality requirements according to Austrian guidelines; value calculated for methane from the fuel value.
Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)**

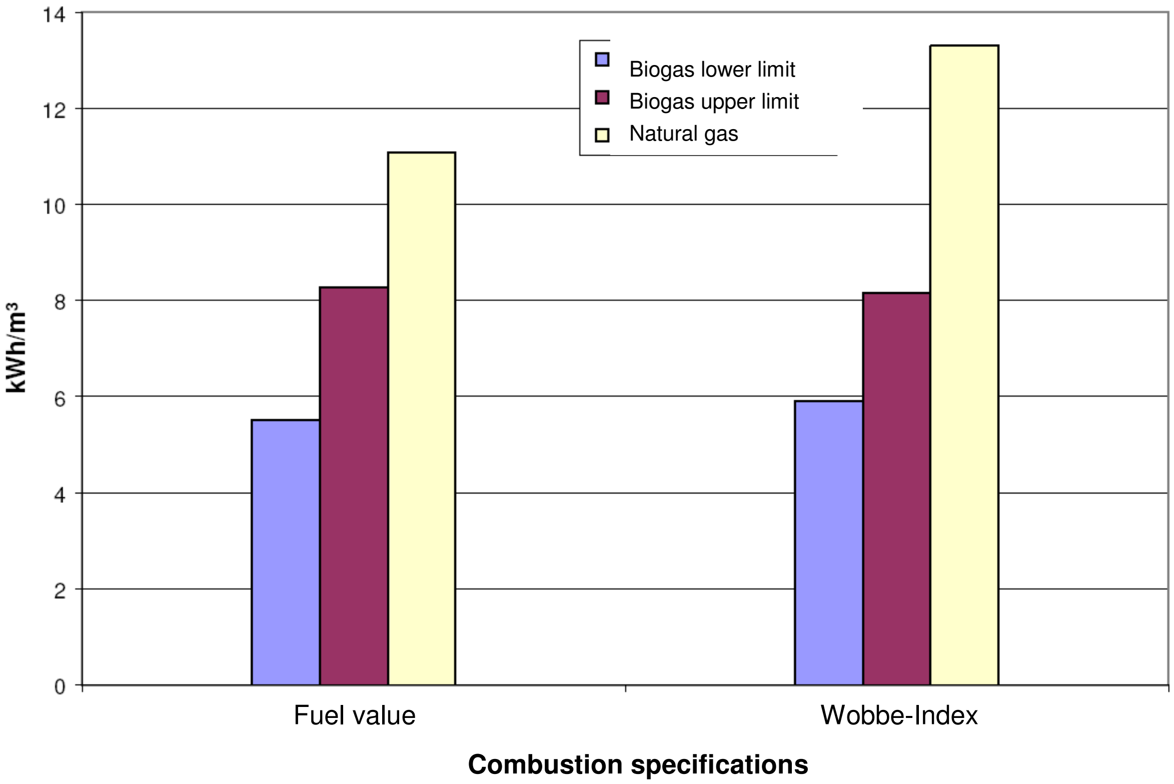


**Illustration 1: Comparison of combustion specifications of raw biogas with the current quality of natural gas
Source: Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)**

For the comparison of the combustion specifications, the currently valid fuel value of natural gas in control zone East of 11,07 kWh/m³, and the associated Wobbe-Index of 13,3 kWh/m³ were used for better comparability. The fuel value and Wobbe-Inex of raw biogas are of course clearly lower due to the lower natural methane content of raw biogas compared to natural gas.

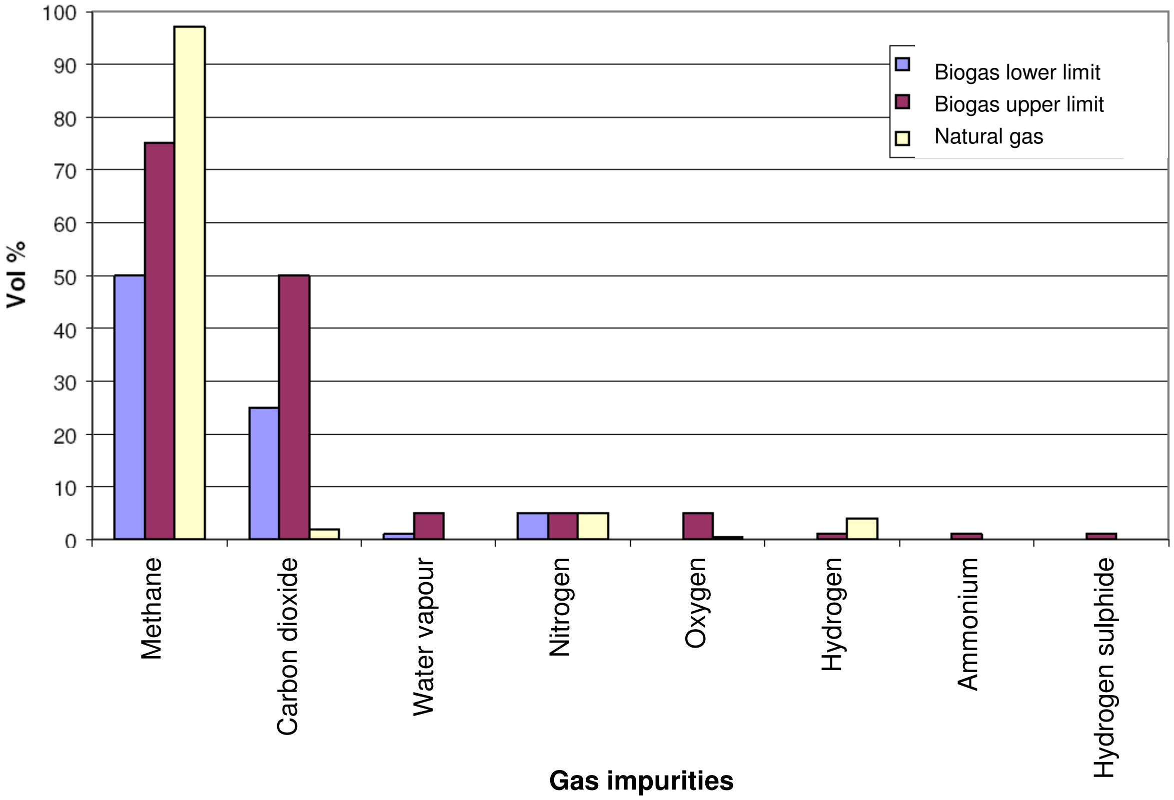


Illustration 2: Comparison of gas impurities of raw biogas with those of natural gas
Source: Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

Critical here are primarily the gas impurities: Particularly the high percentage of carbon dioxide in the raw gas deviates substantially from the highest allowable limit of 2% and, in combination with a high percentage of water vapour, presents a danger of corrosion in the gas pipelines. This high percentage of water vapour in the raw gas, is in contrast to the dry natural gas. Water vapour promotes gas hydrate formation, as well as corrosion in the pipelines and should therefore be avoided completely.

Raw biogas also has up to 2% oxygen and therefore also presents the danger of corrosion compared to the oxygen content of natural gas at 0.5%. Furthermore, raw biogas contains up to 1% ammonium, which is another corrosive component.

The majority of the limits cannot be raised, or not at least not significantly, for technical reasons and to avoid damage to the gas grid. This does not mean however that biogas must fulfil the limits for gas impurities at the feed-in point. If the biogas is fed into the grid as admixture gas, it is mixed with the natural gas and the concentration of the gas impurities in the mixed gas is reduced in comparison to the concentration in the biogas. Depending on the mix ratio, the biogas fed in can have clearly higher concentrations of gas impurities without endangering the safe operation of the gas grid. This can also reduce the costs for the cleaning and methane enrichment (CO_2-separation) of the biogas.

4. Biogas cleaning and conditioning

For the conditioning of biogas to natural gas quality, there are a variety of proven processes and technologies available. The arrangement of the process steps and technologies depends on the available biogas quality. In principle, the same processes can be used for the conditioning of biogas as for the conditioning of other technical gases. An overview of the contents with the respective treatment methods is displayed in the appendix.
Biogas plants already possess equipment for biogas conditioning (crude cleaning). A pre-treatment of the biogas before its use in a BTTP generally includes dehumidisation and desulphurisation. The biogas then has the average composition and specifications listed below (table 14). The operation of the fermenter (feeding, stirrers) can result in significant, time limited fluctuations of up to 100%. To achieve the required gas quality however, there are other conditioning steps (e.g. CO_2-, H_2S-separation) that are necessary for fine cleaning.

	Fluctuation range of biogas composition	**Average**
Methane	45 – 70 %	60 %
Carbon dioxide	25 – 55 %	35 %
Nitrogen	0,01 – 5 %	1 %
Oxygen	0,01 – 2 %	0,3 %
Hydrogen sulphide	10 – 30.000 mg/m^3	500 mg/m^3
organic sulphur compounds	< 0,1 – 30 mg/m^3	< 0,1 mg/m^3
Ammonium	0,01 – 2,5 mg/m^3	0,7 mg/m^3
BTX	< 0,1 – 5 mg/m^3	< 0,1 mg/m^3
Siloxane	< 0,1 – 5 mg/m^3	< 0,1 mg/m^3
Water vapour (at 25° C und 1.013 mbar)	100 % r. F. 3,1 %	100 % r. F. 3,1 %

Table 14: Biogas composition, fluctuation range
Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Studie: Einspeisung von Biogas in das Erdgasnetz (Leipzig, 2006)

To differentiate between the various quality levels of biogas before and after conditioning, a difference is made between **raw biogas** as a biogas quality after biogas production with basic cleaning and **conditioned biogas** or **pure biogas** after methane enrichment.

Conditioning takes place in several stages:

- Removal of solid and liquid components and drying of the gas (filtering of dust, separation of condensates and drying)
- Desulphurisation
- Methane enrichment and separation of carbon dioxide
- Removal of other gas impurities such as, for example, halogenated hydrocarbons, silicon and ammonium.

The respective gas conditioning stages are dependent on technical and economic conditions and can be combined and interlinked.

4.1 Biogas desulphurisation process

Various processes can be used for the desulphurisation of biogases. The processes can be differentiated according to the process principle – bilogical or absorptive, chemical and adsorptive or sorption-catalytic processes – and application – basic or fine desulphurisation.

Biological processes are based on the principle of hydrogen sulphide consuming (oxidising) microorganisms and are used exclusively for the basic desulphurisation of biogases. For the use of biogas in motors, the degree of purity or separation is generally completely sufficient. The biological desulphurisation process can be integrated into the fermenter or designed as a post process. Generally in this process, first the hydrogen sulphide is separated from the biogas, converted into elemental sulphur through microbes, oxidised and discharged from the process.

Chemical processes, such as sulphide precipitation with iron salts, reaction with iron chelates or the addition of iron oxides are based on the addition of sulphur binding reagents in the fermentation process or – after the fermentation process and generally as an adsorptive process – on the flow through of solid-state adsorbers with chemi-sorptive sorbents.

Sorption-catalytic processes are those that take place in parallel to the adsorbent and the chemical reactions of the adsorpt with the adsorbent. The contanimants to be removed are no longer bound to the surface by phsical force (Van der Waals), but rather are bound chemically. Furthermore, the catylisation of some materials (for example impregnation of active charcoal with potassium iodide) can accelerate the chemical reaction of the adsorpt to be separated.

The general advantage of sorption catalysis over simple adsorption is the clearly higher load capacity, whereby the higher adsorption enthalpies (binding forces) have a negative impact on the regeneration of adsorbent. In the area of biogas conditioning – but also in the conditioning of waste or landfill gas – these process are maily used for the fine desulphurisation of the biogas. Depending on the biogas composition (oxygen content) and the sulphur contamination and the requirements placed on the product gas, different sorbents are used. Impregnated active charcoal and zinc oxide are primarily used in the fine cleaning of biogenous gases with minimal sulphur contamination and higher purity requirements. With zinc oxide, for example, final purity of up to 5 ppb of hydrogen sulphide can be achieved.

4.1.1 Biological desulphurisation

The biological elimination of H_2S is based on the adsorption of hydrogen sulphide in water and the subsequent biological oxidation of the hydrogen sulphide dissolved in water by suspended and immobilised thio-bacteria (depending on the design of the process) with air-oxygen to sulphur.

Sulphur bacteria (Thiobacillus und Sulfolobus), that are contained in the fermentation mass, convert the H_2S formed in the fermentation process to elemental sulphur and further to sulphate. The direct oxidation of hydrogen sulphide to sulphate is thereby possible.
Dependent on the temperature, reaction time, the specific surface, as well as the place and quantity of the injected aire, desulphurisation rates of up to 99% can be achieved with this process. Final puritie smaller than 50 ppm in biogas after biological desulphurisation are achievable in percolating filter equipment and bio-washers. Temperatures above 20° C and humid conditions have a positive effect on this process. Biological desulphurisation can be designed as an external process (after the fermenter) as biofilters, bio-washers or as percolating filter equipment or integrated into the fermenter.

Desulphurisation in the fermenter
Biological desulphurisation integrated into the fermenter is achieved through the injection of air (8 to 12 Vol.-% of the biogas flow volume) into the gas space of the fermenter. This process is technically easy to execute and the state of technology particularly in small biogas plants. A disadvantage of this process is the very crude dosing of air that especially with fluctuating H_2S-content in the biogas only allows for a partial and unreliable desulphurisation (particularly in cofermentation) and due to the imprecise control of the air blower can lead to a very high level of inert gas (air) in the biogas. The H_2S decomposition capacity is furthermore very dependent on the available contact surface in the fermenter. Several biogas plants with internal biological desulphurisation only achieve for example decomposition rates of 50% max. of the hydrogen sulphide contained in the raw biogas. The significant entry of inert gas or oxygen also negatively impacts the biogas quality and harms the prerequisites for further conditioning processes since the post cleaning and removal of oxygen and nitrogen are required. An increase of corrosion in the fermenter and the formation of explosive mixtures with the addition of air should also be paid attention to.

In order to achieve higher performance of the biological desulphurisation, the process is frequently carried out in specially dedicated external reactors, generally for economic reasons in plants above 200 kW_{el}.
Percolation reactors made of plastic, that contain special fillers on which the H_2S oxidising microorganisms can settle.

Percolation filter equipment
In percolation filter plants the adsorption of hydrogen sulphide and the regeneration of the contaminated wash medium with air-oxygen are integrated into a container. The air necessary for the regeneration of the column is injected into the biogas before the introduction of the column of filling material. The thio bacteria that are necessary for the decomposition of hydrogen sulphide are suspended in the circulating

nutrient solution, as well as immobilised on the percolating filters (generally plastic PP) found in the reactor. Due to the size of the reactor and the percolating filters, very large surface areas are present that enable very long contact times. For these reasons, even contaminants that are very difficult to dissolve can be removed from the gas and very high decomposition rates of 99% can be achieved. Through the injection of air (2 to 6% vol.), the circulating wash solution is permanently regenerated. The oxidation products, sulphur and sulphate are expelled with the nutrient solution, so the nutrient solution must be at least partially exchanges. The optimal temperature of the wash solution should be between 28° und 32° C so that the microorganisms can function optimally. In winter therefore the circulating wash and nutrient solution should be heated and in summer cooled. Furthermore, the column could ideally be insulated and enclosed.

Using this process, desulphurisation rates of up to 99% can be achieved. In pure gas, depending on the sulphur contamination of the raw gas, remnant concentrations of less than 50 ppm can be achieved. Generally an output side maximum H_2S- concentration of 500 mg/m^3 Biogas is guaranteed. The dosage of air can be well controlled in this design whereby the entry of inert gas can be limited to approx. 1,5 to 2 Vol.-%.
Biological desulphurisation (internally or as percolating filter equipment) cannot be used in damp grids due to the entry of air of approx. 6% into the biogas stream during conditioning for natural gas-H-quality.

Bio-washers
Bio-washers consist primarily of a counter current absorber and a bio-reactor. In a counter current washer the biogase flows through a filling material column in which the H_2S is absorbed. Mildly alkaline water is used as the absorption medium. The advantages of adding a thinned caustic soda solution are that in comparison to water (pH level of 8 to 9) the water solubility of H_2S is clearly improved and consequently higher loads and separation rates can be achieved.

In the bioreator the H_2S containing wash solution is regenerated with air-oxygen. The microorganisms necessary for the decomposition are suspended in the solution. The precipitated elemental sulphur is continuously discharged from the bio-reactor in a sulphur separator. Due to the partial oxidation of the dissolved sulphur to sulphate and by the elimination of sulphur in the separator, a small amount of wash water must always be present and therefore the caustic soda must be resupplied. The regenerated wash solution is then fed back into the washer.

The air dosage must be precisely controlled in order to suppress undesirable formation of sulphates. Finally, the bio-reactor must be constantly supplied with nutrient solution to maintain optimal living and growth conditions for the microorganisms. The elemental sulphur formed in the bio-reactor is continuously withdrawn and deposited in a sulpher separator. After centrifuging of the sulphur sludge, it can be further processed or otherwise disposed of.

The advantage of this process is that no air is added to the biogas flow and the oxidation of the absorbed hydrogen sulphide in a separte bioreactor means that the clogging of the washer can be eliminated whereas it is possible in conventional biological desulphurisation processes (percolating filter equipment) with too little addition of air.

Furthermore, the process is very suitable for the removal of very high sulphur loads of up to 30.000 mg/m^3 from the gas. A two stage counter current absorption is in principle capable of crude and fine desulphurisation to less than 5 mg H_2S/Nm^3 . Actually, too little sulphur in the biogas to be cleaned is more of a problem for this process. Final purity of 100 ppm and less, depending on the hydrogen sulphide load of the input gas can generally be guaranteed.

A disadvantage however is the somewhat higher equipment expense in comparison to percolating filter equipment. Biowashers have been used primarily in waste water treatment, but are increasingly to be seen in the area of biogas conditioning. The bio-wash process with separate biological regeneration is very well suited for the cruded desulphurisation of medium to large volumes of biogas and particularly well suited for biogas conditioning to the level of natural gas quality. For further biogas conditioning to synthetic natural gas quality, an additional sulphur separation (fine cleaning) is necessary. This applies in particular with CO_2-separation using alternating pressure adsorption (PSA). Biological desusulphurisation can contribute significantly to the efficiency of the entire gas preparation process.

4.1.2 Chemical / physical desulphurisation

For chemical / physical desulphurisation there are many different systems and chemicals available. These are used intensively in the natural gas industry for gas conditioning on a large scale. The processes are principally divided into precipitation, adsorption and absorption systems.

4.1.2.1 Sulphide precipitation

In this method Fe^{2+}-ions are added directly to the during the fermentation process, either as iron salts or as a salt solution. Suitable iron salts are iron chloride ($FeCl_2$) or iron-(II)-sulphate. Due to handling considerations it is generally added to the fermenter as pre-mixed salt solution. It can also be added to the substrate before the actual process. Fe^{2+}- ions bind the S^{2-} ions to themselves and form a non-soluble iron (II) sulphide that collects as a salt in the fermentation mass. An adjustment of the process parameters (pH value or temperature) within the fermenter is not necessary in this process.

With regard to investment costs, this process is very economical, since, other than a storage tank for the salt solution and a dosage device, no ther equipment is required. The operating costs on the other hand can be quite high depending on the sulphur content because of the high consumption of iron salts. Another disadvantage is the minimal load change dynamic with respect to the fluctuating sulphur contents in the input substrates. An advantage of this process is that no air is injected into the biogas.

This means that the formation of hydrogen sulphide is largely prevented, but can still be possible. This process is preferred in waste water treatment to reduce high sulphur contents. Through the addition of 3 to 5 g $FeCl_2$ per m^3 waste water, H_2S-values of < 100 ppm are possible. For the desulphurisation of biogases, much higher added doses of iron chloride are necessary. Typical residual concentrations in the gas flow amount to approx. 100 to 150 ppm H_2S.

4.1.2.2 Desulphurisation with iron chelate

Desulphurisation with iron chelate is a chemical process that converts hydrogen sulphide using an iron-redox-reaction to elemental sulphur. Iron (III) ions (Fe^{3+}) are stored in a water solution in an external container, whereby organic ligands or chelate binders prevent the Fe^{3+}- ions from binding to iron sulphide or iron hydroxide. The Fe^{3+}-ions act as desulphurisers by being reduced to Fe^{2+}-ions through the action of hydrogen sulphide and the formation of elemental sulphur. Parallel to this reduction the Fe^{2+}- ions are regenerated to Fe^{3+} ions with the aid of oxygen and water that are again stored in complexes via the chelate binders. A renewed adsorption can then take place.

The sulphur that is formed collects in the solution and at a sulphur content of approx 10 to 15% by weight, are separated through filtering or decanting. With high concentrations of oxygen in the biogas being desulphurised, the formation of thiosulphates can occur. Thiosulphates stabilise the chelation and reduce the consumption of chemicals, but can impact the pH value negatively. If the entry of air is too high, the formed salts must be neutralised with lye, which entails more costs. Depending on the pH value in the absorber and the CO_2-partial pressure in the raw gas, carbonic acid can form leading to carbonate formation. In several cases caustic potash has had to be added to the washers.

In practice, desulphurisation with iron chelate is also referred to as the LOCAT-Process. This process is designed to remove sulphur quantities in a range of 200 kg to 20 t per day, whereby desulphurisation rates of over 99.9% can be achieved. At volume flows of approx. 1.000 m^3/h gases with an H_2S concentrations of approx. 0.01 to 0.05% by weight can be cleaned. The concentrations of iron(III) ions in the solution range from 0.01 to 0.05% by weight. Generally the LOCAT-Process is offered in two different variation: aerobic and anaerobic.

The **aerobic opereation** is used in order to clean exhaust flows containing H_2S and air (to reduce foul odours). The H_2S contaminated gas is directed into the absorber and the H_2S is converted to elemental sulphur through contact with the iron chelate solution. The sulphur sludge is filtered out. At the same time in the reactor the regeneration of the solution takes place through the oxygen contained in the gas. The H_2S concentration in the gas in this variation can amount to 50 to several thousand ppm.

In the **anaerobic operation**, the oxygen-fee gases can be freed of hydrogen sulphide. The individual steps of reduction and oxidation are physically separate from each other. The gas to be cleaned flows through a reactor filled with iron chelate solution where the sulphur binding (reduction) takes place. The reduced solutions is then fed into a second container and then oxidised by the injection of air to regenerate it and it is then pumped back to the absorber to complete the cycle.

4.1.2.3 Hydrogen sulphide removal with impregnated active charcoal

The separation of hydrogen sulphide with impregnated active charcoal takes place through catalytic oxidation of the adsorbed hydrogen sulphide on the active charcoal surface. The impregnation of the active charcoal with chemical substances acts as a catalyst and causes an increase in the speed of the reaction and the possible load capacities. Different impregation materials can be used for the removal of H_2S.

Potassium iodide impregnated active charcoal

Potassium iodide (1 to 5% by weight of the active charcoal), can only be used when oxygen and water are present. After the H_2S and O_2 has been dissolved on the film of water on the surface of the active charcoal, O_2 reacts even at low temperatures (50° to 70° C) and an operating temperature of 7 to 8 bar to form elemental sulphur and water. Potassium iodide acts as the catalyst to accelerate the reaction and the presence of potassium iodide also minimises the undesirable formation of sulphuric acid (side reaction). The sulphur that is formed is adsorbed on the inner surfaces of the active charcoal and the water is desorbed from the catalyst surface. Loads of up to 150% by weight of sulphur and pure gas concentrations of < 5 mg H_2S/m^3 are possible. In the absence of oxygen, the oxidation of the H_2S can take place with KI_3 impregnated charcoal, whereby in this case only a stoichiometrich ratio of sulphur will be bound.

The spent active charcoal is exchanged and disposed of. Hot gas or hot steam regeneration (at temperatures over 450° C) is possible. In spite of active charcoal regeneration a certain residue remains on the active charcoal that can only be removed at high cost (hot steam regeration at 800° to 850° C).

Advantages of active charcoal impregation with potassium iodide are: high load capacities, high achievable purities and low operating temperatures. A disadvantage is that air-oxygen, as well as water are required to remove the hydrogen sulphide, so that a potassium iodide sorben cannot be used for oxygen free biogas. Due to the high operating costs – impregnated active charcoal is much more expensive than conventional active charcoal – this process should only be used for fine desulphurisation.

Potassium carbonate impregnated active charcoal (K_2CO_3)

At temperatures above 50° C and with the prerequisite that water vapour and oxygen are present, active charcoal impregated with potassium carbonate can be used to remove H_2S, whereby K_2CO_3 makes up 10 to 20% by weight of the active charcoal. Through the reaction of hydrogen sulphide with K_2CO_3 and O_2 , in addition to carbon dioxide and water, potassium sulphate is formed that is adsorbed on the active charcoal surface. The consumed active charcoal can be regenerated with a water wash and re-impregnated. Here as well, the active charcoal with potassium iodide can not be used for the fine desulphurisation of oxygen-free biogases and not for the crude desulphurisation of biogases.

4.1.2.4 Hydrogen sulphide removal with zinc oxide (ZnO)

The removal of hydrogen sulphide with zinc oxide as the adorbent, which is generally in pellet form, is a preferred method for fine and post-desulphurisation of gases. In addition to the removal of H_2S, carbonyl sulphide (COS) and mercaptane are separable with ZnO, if they have previously been hydrolised to H_2S. This is possible through the mixture of CuO or also Al2O3 to the ZnO-sorbent that the hydrolysis catalyses. At temperatures of 200° to 400° C, hydrogen sulphide and zinc oxide react to form water and insoluble zinc sulphide.

With zinc oxide, depending on the application, load capacities of 17 to 40% weight by gas in relation to a kg of zinc oxide can be achieved, whereby the load capacity decreases with decreasing temperature. The loaded adsorbent cannot be regenerated and is therefore exchanged and disposed of. Typical areas for the application of zinc oxide are in petrochemicals – in particular in sulphur sensitive processes such as stream reforming- fine and finest desulphurisation (H_2S, but also for the separation of COS, CS_2 or Methanethiol) of natural and synthetic gases. An important advantage of zinc oxide sorbents is the very high purities that can be achieved of less than 1 ppm to just a few ppb. A disadvantage is the high sorbent costs and high process temperatures that only make sense for the fine desulphurisation of gases in combination with other hot process stages.

4.1.2.5 Hydrogen sulphide removal with ferrous cleaning compounds

The desulphurisation of biogas with ferrous cleaning compounds is carried out with iron (III)-hydroxide ($Fe(OH)_3$) or with iron(III)-oxide (Fe_2O_3). The process flows are similar. The differences are in the specific reaction conditions and the final purities that are achieved. Both processes belong to the group of adsorptive (dry) desulphurisation processes.

Iron(III)-hydroxide

$Fe(OH)_3$, also referred to as bog iron ore or luxmasse has become itself particularly in waste and biogas conditioning. In the first step the H_2S reacts with iron(III)-hydroxide to form iron(III)-sulphide and water. In parallel the iron(III) sulphide that is formed is re-oxidised using oxygen and water (partial regeneration). Iron (III) hydroxide is once again formed, as well as elemental sulphur. The sulphur that is formed is adsorbed by the cleaning compound ($Fe(OH)_3$) and is deposited on its surface so that the reactive surface is reduced for a further cleaning cycle. Each cycle reduces the conversion of hydrogen sulphide and the adsorption capacity for the sulphur formed, so that, at a certain point in time, no further desulphurisation is possible. The load iron (III)-hydroxide is then disposed of and replace by „fresh“ cleaning compound.

In practice, good cleaning results of sulphur loads of up to 25% by weight can be achieved. At input concentrations of < 1.000 ppm H_2S and < 5.000 ppm, depending on the design and control of the process, pure gas concentrations of < 1 ppm and < 100 ppm can be reached. The desulphurisation with iron (III)-hydroxide takes place at the ambient temperature in tower desulphurisers. Smaller plants work with single tower desulphurisers and the addition of oxygen (air) for regeneration takes place simultaneously with the loading process. Larger plants (flow volume > 250 m^3/h), two towers are used that are loaded and regenerated alternatively. The regeneration reaction is very exothermic. Therefore the temperature should be monitored during the regeneration in order to prevent self-ignition of the bog iron ore.

Iron(III)-oxide

In the first step, desulphurisation with Fe_2O_3 , analogue to desulphurisation with $Fe(OH)_3$, insoluble iron(III) sulphide and water are formed. In the second step (regeneration), iron (III) oxide and elemental sulphide result again from the oxidation of iron(III) sulphide with oxgen. Here as well, the sulphur formed covers the active suface of the adsorbent iron (III) oxide, which according to the load must be exchanged. Since regeneration is very exothermic, the temperatures should be monitored for safety reasions, because the cleaning compound can ignite. The optimal temperatures for this process are between 25° to 50° C, whereby a minimum temperature of 12° C must be maintained. Furthermore, the biogas must contain a certain dampness since water is required for the flow of the reaction. Iron (III) oxide is used in the form of steel wool, impregnated wood chips (load of 20 g H_2S per 100 g of wood chips) or pellets ((load of 50 g H_2S per 100 g pellets). In principle, in addition to hydrogen sulphide, mercaptane can also be removed with impregnated wood chips.

A disadvantage may be seen in the fact that iron(III) oxide impregnated wood chips lose approx. one third of their load capacity after each regeneration and therefore can be regenerated a maximum of two times. Due to the high consumption of chemical, the high disposal costs and the characteristic of the loaded wood chips that are not without danger – the regeneration with air is very exothermic and can lead to fire – the use of this process has been declining rapidly.

With the desulphurisation processes with ferrous materials being used currently, final purities of a few ppm with regard to hydrogen sulphide can be achieved, depending on the sulphur content of the gas flow. A negative aspect is that since regeneration is not possible there are high operating costs due to the high consumption of cleaning compounds (iron (III)-hydroxide and iron (III)-oxide). The disposal of the loaded chemicals can, in practice, also be difficult and expensive.

4.1.2.6 Summary of desulphurisation processes

Process	Invest-ment costs	Operat-ing costs	Air-entry required	Application for crude-/fine-desulphurisa-tion	Miscellaneous
Sulphide precipitation	+ +	– –	No	Crude	Minimal Load alternation dynamic
Internal biological desulphurisation	+ +	+	Yes	Crude	Minimal load alternation dynamic, unreliable, danger of corrosion in the fermenter, negative impact on biogas yield
(Percolation filter equipment)	–	–	Yes	Crude	Air entry, danger of clogging if not enough air entry, slow decomposition of H_2S
Biowasher	– –	–	No	Crude	Suitable for highest H_2S-loads, high technology costs
Iron chelate – MINI-CAT, anaerobic mode of operation	–	–	No	Crude	Suitable for highest H_2S-loads, high technology costs
Iron chelate – sulphured	– –	–	No [a]	Crude	Suitable for highest H_2S-loads, high technology costs
Active charcoal – KI	+ +	– –	Yes	Fine	High load capacities, disposal costs, air necessary
Active charcoal – K_2CO_3	+ +	– –	Yes	Fine	Disposal costs , Air notwendig
Active charcoal – $KMnO_4$	+ +	– –	No	Fine	High load capacities, disposal costs , no air entry
Zinc oxide	+	– –	No	Fine	Highes final purities, disposal costs, no air entry necessary, high temperatures (200° to 400° C)
Bog iron ore – $Fe(OH)_3$	+	– –	No [a]	Crude	Fire danger[b], limited regeneration capability, disposal costs
Fe_2O_3-Wood chips Sulfa-Treat-Process Sulfa-Rite-Process Sulfa-Bind-Process	+	– –	No [a]	Crude	Fire danger only with wood chips, limited regeneration capability, disposal costs , high consumption of chemicals

+ + Very high investment-/operating costs
– – Very low investment-/operating costs
a When designed as two-stage process with external regeneration
b Regeneration reaction very exothermic, temperature exothermic, temperature monitoring necessary

Table 15: Evaluation matrix for different desulphurisation processes
Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Studie: Einspeisung von Biogas in das Erdgasnetz (Leipzig, 2006)

4.2 Biogas drying

Drying of the biogas is absolutely necessary in order to prevent corrosion (due to the gas components CO_2, H_2S and O_2) and negative effects on the gas cleaning process. Pre-drying is achieved first through the biogas compression. This causes condensate to form so that a partial separation of the water is possible after the compression. Suitable drying processes for biogas include adsorption with the aid of silica gel and active charcoal, condensation drying and glycol wash as adsorptive processes.

As with desulphurisation of the biogas, there is also the possibility to use processes for the removal of the water vapour that can be carried out independent of the cleaning of other materials to be removed and those that can be used in combination to remove the water. The goal of the dehumidisation is to lower the water vapour dewpoint through the various treatment processes. Dehumidisation is necessary for biogas to be used in fuel cells and also to extend the life and maintenance intervals of biogas BTTPs. Every attempt has therefore been made to use numerious large scale solutions from the natural gas industry in order to derive processes that can be adapted to the scale of biogas plants.

4.2.1 Condensation

Eingesetzte Methoden sind das Auskondensieren an langen kühlen Gasleitungen, die statische Abscheidung im Gasspeicher, die Kondensattrocknung und Process mittels Wasserkühlung. All diese Methoden sind für die Verstromung in einem BHWK ausreichend.
For condensation, the physical effect of the transition from the gaseous state (water vapour) to the liquid aggregate state through cooling, pressure, or both is used. In conventional biogas facilities, the biogas saturated to 100% with water vapour is usually dehumidified using simple equipment to enable the stable operation of the BTTP. Methods used include condensation over long, cool gas lines, the static separation in gas tands, condensation drying and processes that use water cooling. All of these methods are sufficient for power generation in a BTTP. For the feed-in of biogas into the gas grid however, more effective methods must be implemented, since the normal processes only yield minimal rates of dehumidisation. For feed-in into the gas grid, the water content must be significantly reduced in order to prevent corrosion in the distribution systems. This can be done through condensation on a heat exchanger. For more thorough dehumidisation, it is necessary to compress the gas. The following expansion allows for temperature below the freezing point. Attention must be paid to icing problems.

Dehumidisation through cooling
For dehumidisation through cooling, a refigerating machine is required. The main components of a refrigerator are the evaporator, compressor and the liquefier that are connected in circuit in which the refrigerant circulates. As the coolant evaporates in the evaporator it draws off evaporation heat from the environment. If the gas then flows past the evaporator, the water is condensed and collected. The nessary plant investment includes the refrigeration unit, the heat exchanger, a transport pump and the water tank. The majority of the operating costs are for the energy necessary to operate primarily the refrigeration unti. Other operating costs are for maintenance and repair.

Due to the unpressurized cooling, a dewpoint of 4° to 10° C can be achieved. So far, this process has rarely been used for biogas plants, since in comparison to conventional dehumidifying methods, there are higher investment costs. However, when the total costs is taken into consideration over a longer period of time, the operating costs are lowered due an increased lifetime and increased efficiency of the BTTP. It is expected that dehumidisation through cooling will make significant progress in its application in the area of BTTP.

4.2.2 Membrane technology

Thin membranes can be used to remove certain components from biogase due to their different permeability. The application of a higher pressure level can accelerate the separation process.

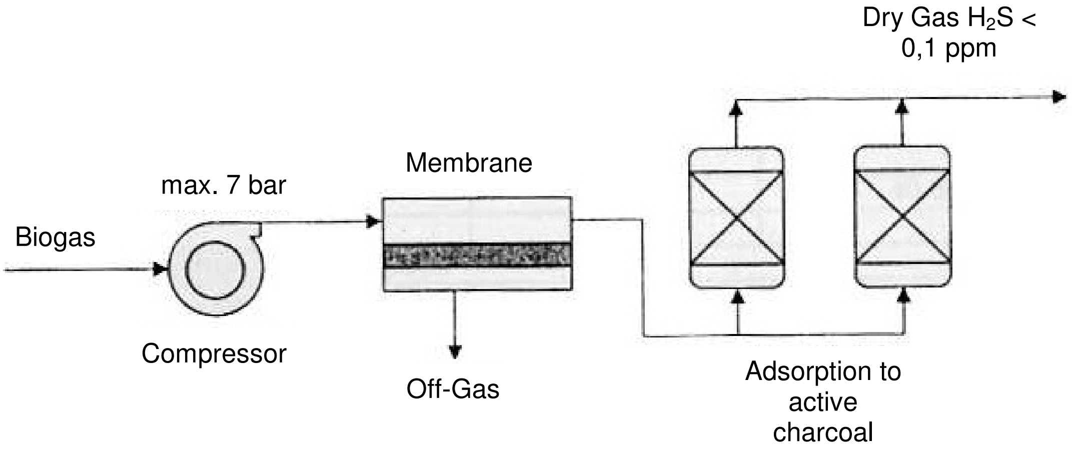


Illustration 3: Process schematic for the cleaning of biogas with membrance technology
Source: Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

This technology can also be implemented for the separation of H_2S und CO_2. Membrane technology with regard to biogas technology is still in the development phase. The significant cost factors in this application are the investment for the membranse and the operation due to the pressure level. This technology, in addition to the removal of H_2S and H_2O, will be revisted with regard to methane enrichment.

4.2.3 Freezing technology

The possibility of employing freezing technology for gas cleaning is the focus of a project in the field of waste gas. In order to eliminate the damaging influences of various biogas components, the following cleaning process has been proposed.

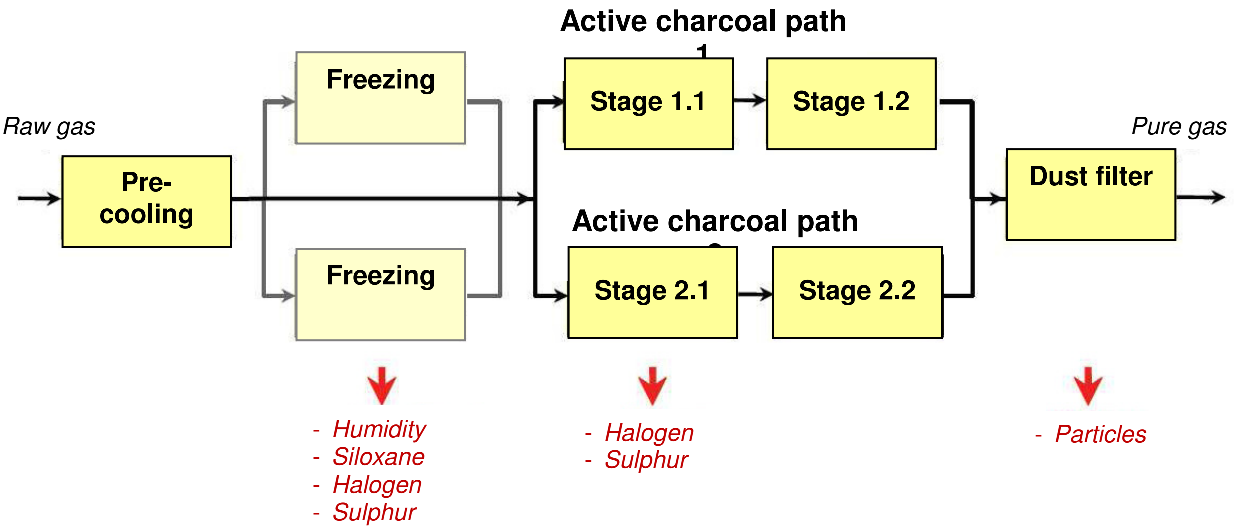


Illustration 4: Process schematic for the cleaning of biogas using freezing technology
Source: Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

The original concept for gas cleaning using freezing technology achieved a complete dehumidification with pre-cooling (2° to 3° C) and a subsequent freezing (to -25° C). The condensation of complex compounds (siloxane) was also realised. The downstream use of active charcoal suppressed halogen and sulphur compounds. Particles > 0,5 were able to be eliminated with a downstream fine filter. Plant availability was approx. 90% was to a large extent due to redesigning the waste gas cleaning equipment with a subsequent test operation over several weeks.

The fact that the condensation of the humid gas also led to ice formation and thereby had the desirable effect of also eliminating siloxane together with the ice and water; it also had the negative impact that the plant could not be used without interruption. The periodic thawing phases that were necessary for the ejection of the ice periodically caused pressure loss in the entire system due to iced valves. The cooling increased the capacity of the active charcoal, which achieved use life of above 6 months based on initial experience. The electrical power consumption of the cleaning unit at 3,5 kW was minimal due to the heat recovery unit.

Due to the icing problems the plant design was adapted. The simplified version of the gas cleaning does without the freezing, but a refrigeration unit is still employed as a dryer. The gas temperature is now only +3° C and after subsequent warming to approx. 10° C the relative humidity at the active charcoal filters is under 50%. The pressure level in the gas cleaning is remains unchanged at approx. 140 mbar.

4.2.4 Dehumidification with triethyleneglycol

Another possibility for drying biogas is treatment with triethyleneglycol. In this case the biogas is dehumidified by contact with the clear, colourless, odourless and hygroscopic liquid. The system is sealed and therefore low maintenance. Attention must be paid to the possibility of foaming which is why an anti-foaming material is frequently used as a supplement. A heat source is necessary for the regeneration of the wash solution (the waste heat could be useful in the operation of a BTTP). According to manufacturer data, other glycoles are also capable of separating SO_2, H_2S, CS_2 and COS.

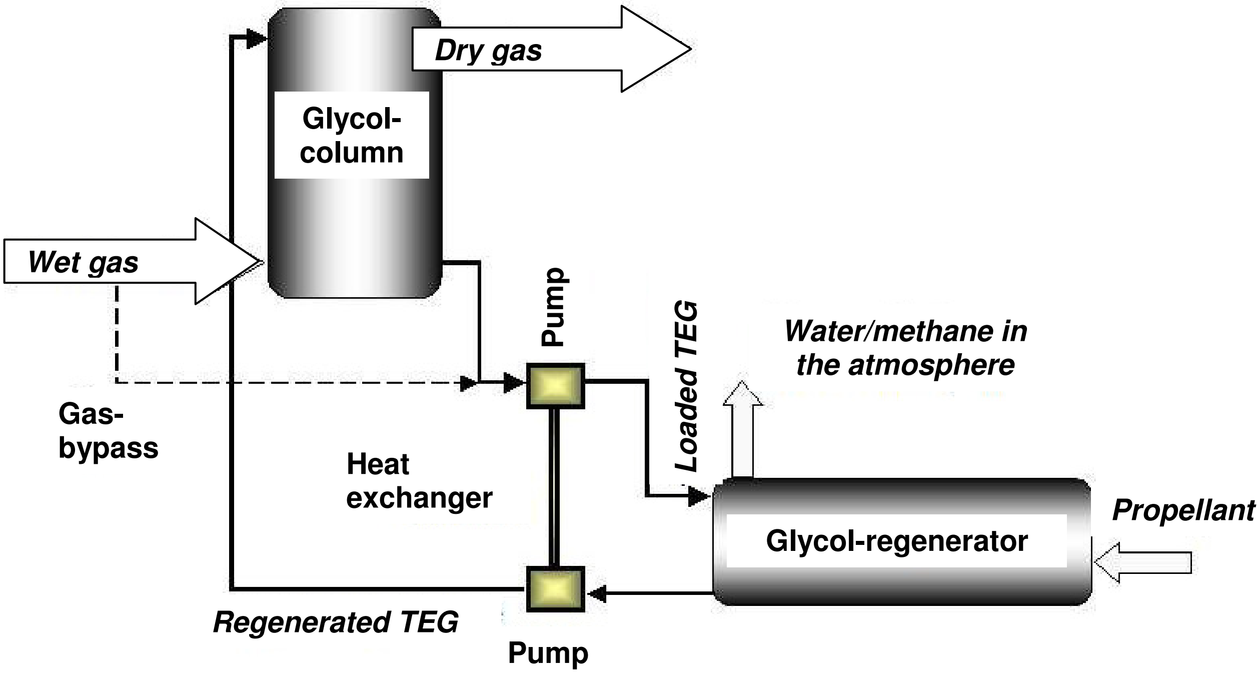


Illustration 5: **Principle of a dehumidification plant using triethyleneglycol (TEG)**
Source: Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

Plants such as this are used for the dehumidification of gas on a large scale in the natural gas industry.
The wet gas is dehumidified in the glycole column, the TEG loaded with water is then reformed in the regenerator and then returns to the circuit. A heat source is required for the regeneration. In a single stage operation, the dewpoint can reduced to under 10° C. This represents sufficient drying for the operation with active charcoal.
Bei einer Anlagenauslegung von 150 m³/h betragen die spezifischen Kosten ca. 1,9 cent/m³ und bei 500 m³/h ca. 0,86 cent/m³. Mit einer einstufigen Glykoldehydratisierung wird eine Entfeuchtung auf einen Taupunkt zwischen 5° und 10° C erreicht, die Entfeuchtungsrate einer zweistufigen Ausführung müsste erst im Detail geprüft werden.

4.2.5 Dehumidification with potassium chloride

Another dehumidification method, which uses less energy, is dehydration with potassium chloride. With this method a dewpoint of 10° to 12 ° C can be achieved. However, associated corrosion and clogging have led to reduced significance. Nevertheless, at a pressure level of 7bar (up to 140 bar) and a temperature range between 10° und 50° C, the operating costs are kept within limits. Other operating costs are the purchase of potassium chloride and the disposal of the brine and the regeneration of the potassium chloride, which can also be implemented in the form of tabs and pellets. The most significant investements are for the boiler, the necessary valves and the pipelines. This method is appropriate for smaller flow volumes.

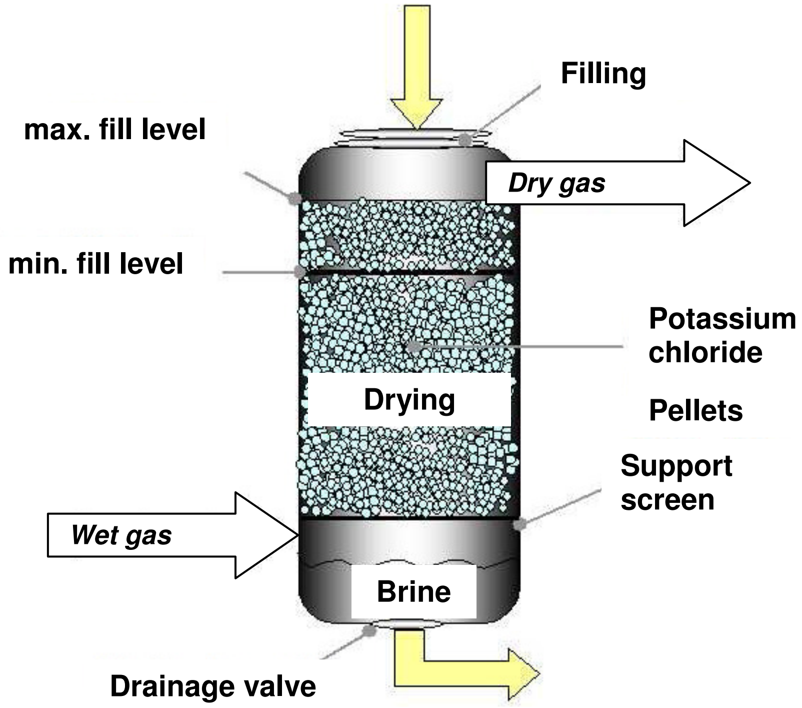


Illustration 6: Schematic for dehumidification with potassium chloride
Source: Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

Operating expenses are limited to the filling of the column with potassium chloride pellets. Operation is possible using two columns or with a periodic system. The damp pellets liquify and drain as brine to the floor of the column. Due to its disadvantages, this system is now rarely used. The application of this technology for biogas with the known contents must be investigated in more detail.

4.3 Removal of siloxanes

Siloxane is the term for oxygen compound of silicon with the general formula $H_3Si–[O–SiH_2]_n–O–SiH_3$. The polymerisation products of this organosilicon compound are the so-called silicones. Siloxane is used as a precursor for silicones which can be classified according to their application into oils, resins and rubber. Siloxane and silicon are used in this way as foam insulation, hydraulic oil, mold release agents, glas water repellent (e.g. in pharmaceutics), ceramics, textiles, leather, as lubricants for plastics processing and in plastic transmissions, polish for car paint, leather and furniture, as print ink additive to prevent the bleeding of pigments in pigmented paints, as manometer fluid, component of metal cleaners or as collectors in flotation processes. Silicon oils also play an important role as dielectrics (e.g. in transformers), as diffusion pump oils, heating fluids and insulation. In medicine and cosmetics, silicon oils are a component of skin care products, salves base, for hair stiffeners, as fixators for perfumes and as ingredients in tooth paste.

This range of applications demonstrates that siloxanes can often be found in landfill or waste gas. This is very often criticized by the manufacturers of gas engines that are used by BTTPs that use landfill and waste gas (due to damage). In agricultural plants, their entry into the biosphere (through the cycle of waste water and the spreading of sludge – absorption by plants – entry into the biogas plant) is possible, but not yet proven. The concentration should be significantly less than in waste or landill gas. Contrary to speculations that higher siloxane values could develop through the entry of grease separator contents, this has not been proven at size parameters of 0.1 ppm.

Siloxane has proven to be problematic when used in engines since it can cause the glazing of cylinder heads if high it is present in sufficiently high quantity. There is also a possible potential for harm to human beings and the environment. No toxic effect has been established for the non-volatile silicons. Mildly volatile silicons under the collective term siloxane are said to have an estrogenous effect or cause suppression of androgens. The removal of siloxanes is best achieved using the cooling or adsorption (active charcoal) methods. The possibility of adsorption to (heating) oil has not proven to be effective in practical trials. In addition to the minimal cleaning performance, the trials showed that the transmission of the heating oil in the gas line and the combustion chamber can cause problems, since it changes the combustion temperature. This method would not be appropriate for feed-in into the gas grid.

4.4 Other gas contaminants

In agricultural biogas plants, the following impurities may be present:

- Ammonium
- Aromatic compounds such as benzene, toluene, ethylbenze, xylene, cumenel
- Polycyclic aromatic hydrocarbons (PAC)
- Halogens such as chlorine, fluorine, mercaptans

According to measurements at biogas plants, these impurities are predominantly below the limit of detection. The concentration of ammonia in these measurements was mainly under 0.1 mg/m³, the aromatic compounds were under the limit of detection of 1 mg/m³, the PAC values were under the limit of detection of 0,01 µm/m³ and halogens were under the limit of detection of 0,1 mg/m³.

Landfill gas in contrast can contain a wide variety of trace and scents (gas impurities). A general toxicological evaluation is very difficult due the nature of a landfill. Each individual case must be checked to see if the respective gas composition meets legal regulations so that it has no damaging impact on the gas grid or consumers.

4.5 Biogas conditioning – Methane enrichment process for biogas

In biogas plants generally, methane enrichment is not carried out. Average CH_4 content of 50 to 70% is completely adequate for the use of biogas in BTTPs. However, if higher methane content is required, for example for biogas grid feed-in, there are several enrichment processes available. Several processes are already standard for industrial gas cleaning (e.g. PSA, pressurized water wash), while others are still in the research and development state (e.g. cryogenics). The processes for methane enrichment differ from those in the cleaning process, not only in the quality of the conditioned gas, but also with regard to the more complex process execution, which is reflected in higher costs (investments and operation).

In order to enrich the raw gas with methane it is necessary to separate the carbon dioxide. As a result of the methane enrichment the necessary gas properties (fuel value, Wobbe-index) for gas feed-in are achieved. The conditioning of biogas to natural gas quality is already practiced in Sweden, Holland and Switzerland. There are already 60 plants with an output of approx 125 MW raw gas – fuel heat output capacity in Europe. The predominant amount of biogas is used as motor vehicle fuel and only a part of it is fed into the natural gas grid. Biogas conditioning can therefore be considered to be state of the art. There are about 8 manufacturers throughout Europe that have accumulated nearly 15 years of operational experience in the field of biogas conditioning.

4.5.1 Pressure swing adsorption with a carbon molecular sieve

This is a dry enrichment process that makes use of the different adsorption of CH_4 and CO_2 at increased pressure on a carbon molecular sieve. The carbon dioxide binds faster and more strongly to the solid than to methane, which is why these types of plants are often referred to as PSA (pressure swing adsorption) plants.

PSA plants generally consist of four adsorption units. During a period with high pressure biogas flows through an adsorption unit. The CO_2 (as well as a small amount of CH_4) is adorbed until the carbon molecular sieve is nearly saturated. Then the biogas stream is directed to another adsoption unit in order to be able to regenerate the saturated carbon molecular sieve. Then the pressure is reduced and the desorbed CO_2 is extracted. A further reduction in pressure desorbs even the minimal remaining quantities of CH_4 . This is why this gas flow is recycled to the raw gas (untreated biogas). For complete regeneration a vacuum is used to generate negative pressure.

The pressures during the adsorption and depending on the plant are usually between 6 and 10 bar. There are however plants that use higher pressures. In addition to CO_2 , oxygen and nitrogen are also adsorbed and separated from the methane as an added advantage. Humidity and H_2S must have been removed from the biogas before entry into the adsorption equipment, because H_2S binds permanently to the molecular sieve.

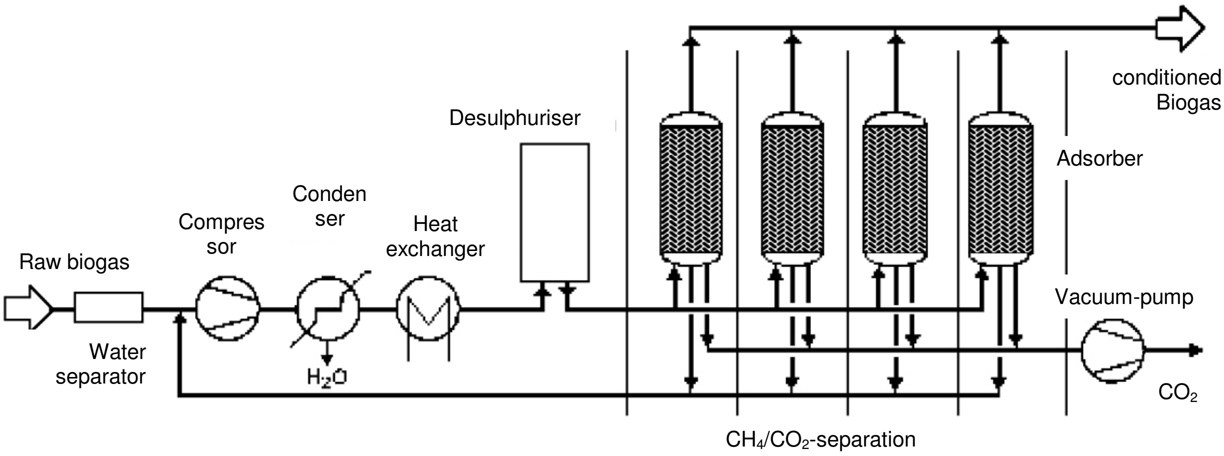


Illustration 7: Schematic of a PSA-plant
Source: Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

The main components for the gas conditioning consist of water separation, compression and desulphurisation, as well as the conditioning and the actual methane enrichment. It can generally be assumed that using PSA technology the following parameters can be achieved.

CH_4-content in raw gas 60 % in product gas > 96 %
CO_2-content in raw gas 38,94 % in product gas 1,9 %
H_2S-content in raw gas 300 mg/Nm³ in product gas < 5mg/Nm³
Dewpoint at ambient pressure is -65 ° C
Condensation point is -8 ° C and a pressure of 40 bar

The requirement to produce biogas with natural gas quality presupposes the metered addition of liquid gas. If this process stage were not implemented, the investment costs, depending on the size of the plant, could be reduced by 10 to 15%. The operating costs would also be lower. The energy expenditures for the conditioning are only rational due to the energy needs, as well as the loss of chemically bound energy (due to the conditioning).

For the PSA process in comparison to other processes there is a relatively large amount of data available on the technology as well the economic efficiency. This indicates the comparatively high state of development of this technology. The number of plants built in Europe shows that this technology is frequently used (25.9% of all recorded plants in Europe).

4.5.2 Gas wash

The components CO_2 and H_2S can also be washed out of the biogas stream. For this purpose either a pressurised water wash is used or a wash with certain wash fluids (e.g. Monoethanolamin MEA). This technology is used particularly in connection with large scale industrial applications for the conditioning of natural gas with flow volumes of > 20.000 m³/d. This method is most frequently used to condition biogas to natural gas quality.

Pressurised water washes
This process is based on the physical effect of the dissolution of gases in liquids. The solubility increases with rising pressure which is why compressed biogas is used. In order to separate the biogas from the components CO_2 and H_2S, it is compressed to a pressure of 6 to 8 bar and fed in through the floor of the absorption column. Water is sprayed from the top of the column so that it trickles down to the gas in an opposing stream. The adsorption column is equipped with filler material to assure a larger surface area for the gas-fluid-contact.

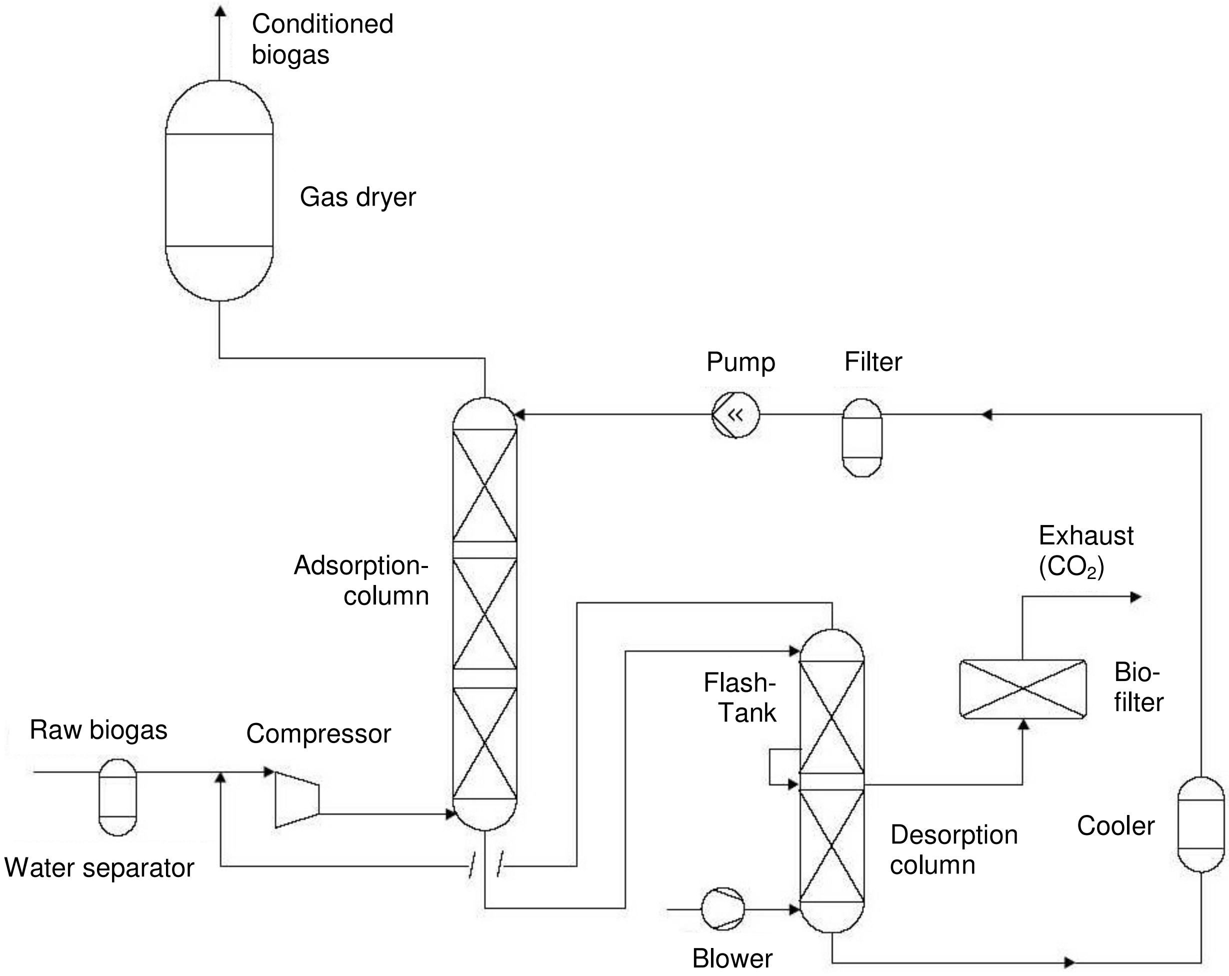


Illustration 8: **Schematic of a pressurised water wash plant with circulatory layout of the wash water Source: Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)**

In addition to the undesirable components CO_2 and H_2S a small amount of CH_4 is also dissolved. To keep the loss of methane to a minimum, the wash solution is fed into a flash-tank. Here, gas with a high CH_4-is desorbed. It is then fed back into the absorption column. The wash solution, after it has been expanded, flows back into the desorption column. In order to drive out the dissolved gases, the pressure is reduced or heat is added (or both). Additionally, air is injected in a counter stream through the liquid. The desorption column is also equipped with filler material. After the regeneration the wash water is cooled and then sprayed again into the absorption column.

The exhaust gas can also possibly contain odorous materials, which is why a biofilter is usually installed. The biogas saturated with water vapour after the conditioning and must be dried before it can be used. A big problem in this process is the fact that the solubility of H_2S in water is very high. It is not possible to extract all of the H_2S in the desorption column. Furthermore, part of the H_2S in the column is oxidised to elemental sulphur. This accumulates in the system and can cause clogging. It is therefore absolutely necessary that the wash water is exchanged periodically or that the biogas is desulphurised before the wash process. There are also process variations without the circulation of water that are used. These processes can however cause high costs during operation if the resource water cannot be obtained at a reasonable price.

Monoethanolamine-wash

This process is comparable to the pressurised water wash. However in this case the undesirable gas impurities are not physically dissolved but rather removed by chemical binding to a wash liquid. In order to accelerate the process the pressure and temperature are raised. The wash fluid loaded with CO_2 und H_2S is regenerated in a reversible reaction stage. The single use of of monoethanolamine (MEA) without circuit layout is not possible due to the toxicity of the substance. Furthermore there are high costs for the acquisition and disposal of the MEA. In addition to water, monoethanolamine is the most frequently used wash solution. There are also other mediums that can be used for the gas wash, which include diethanolamine (DEA), hydroxiaminoethylester and potassium carbonate.

Wash solution	Advantages	Disadvantages
Monoethanolamine (MEA)	Very efficient , low acquisition costs	High equipment costs, toxicity, corrosion protection and foam preventer are necessary
Diethanolamine (DEA)	Very efficient , non-corrosive and non-foaming	High costs for the equipment and the wash solution
Hydroxiaminoethylester	Low equipment and operating costs	Corrosiion protection necessary
Potassium carbonate	Very efficient , low acquisition costs	High equipment costs, corrosion protection and foam preventer are necessary

Table 16: Comparison of advantages and disadvantages of different wash solutions for gas washes Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

The significant components of the gas wash are the absorption and desorption column, compressor and blower, the cooler, as well as the downstream gas drying. Desulphurisation is not compulsory if the raw gas concentrations are kept within a certain range, since the sulphur can also be removed by the gas wash. At higher concentrations however a desulphurisation system must be installed. At H_2S concentrations in raw biogas < 300 ppm active charcoal is not required.

A big difference in the operating costs results from the resource water. The acquisition costs (relatively inexpensive well water vs. expensive tap water) must be calculated together with the costs for the disposal of the waste water. Detailled research in this regard must be carried out concerning the prevailing conditions (water, sewage fees) at the location.

Just as for the PSA process, there are relatively comprehensive data available concerning the pressurised water wash technology and its economic efficiency. This demonstrates the higher stage of development of this technology. The number of such plants built in Europe also indicates the intensive use of this technology (55.2% of all recorded plants in Europe).

As mentioned previously, the costs for resource water (water, sewage fees) can be a significant factor. The cost situation for one's own well water must be taken into considertation for each individual plant. A variation of the pressurised water wash is the use of treated waste water to save operating costs. This method is used by several Swedish waste water treatment plants. It is however to be expected that this can lead to deposits in the wash column, which in turn can raise operation effort and expense.

Also, as with the PSA technology, doing without the admixture of propane gas can also bring a reduction in costs. The investment costs can thereby be reduced by 10 to 15% depending on the size of the plant and also reduce operating costs.

4.5.3 Low pressure – membrane absorption

In principle this variation is not a classic membrane separation but rather a combination of absorbtion and membrane technology. In this case a special absorbent is directed through a microporous, hydrophopic membrane or membrane module. The gas molecules in the biogas that flow past the membrane exterior surface are captured by the enlarged contact surfaces. While the low pressure membrane absorbtion is the most expensive variation with regard to investment costs, the operating costs are more reasonable than those for PSA technology and the pressurised water wash, so that the process costs are about the same. This is due to the minimal energy expense and also because of the very minimal loss of methane. The significant components are the pre-cleaning, the blower, the CO_2 separation, the stripper (for the regeneration of the solvent) including the waste heat recovery and gas drying. The removal of H_2S- must be planned if the sulphur content is greater than 500 ppm.

Up to now in Europe only one such plant has been built. This may be due to the fact the membranes necessary for this process are patented. Field reports indicate that this technology has not achieved the results expected based on theoretical knowledge. This perhaps explains the delayed implementation of low pressure membrane absorption. The savings due to the elimination of the liquid gas would also be between 10 and 15% of investment costs depending on the size of the plant. The operating costs would also be accordingly reduced.

4.5.4 Gas permeation using membranes

Thin membranes from cellulose acetate, polysulphones, silicones or poly carbonates serve to separate different components from the biogas. Due to the varying permeabilities of the gas components, CO_2- and H_2S molecules can pass through the membrance faster than CH_4- molecules. In the case of cellulose acetate membranes the permeability of CO_2 amounts to approx. twenty times the permeability of CH_4. H_2S exhibits approx. 60 times higher permeability. To accelerate the separation process, pressures of 25 to 40 bar are used. On the high pressure side of the membrane the methane accumulates while most of the CO_2- and H_2S-Molecules (and small amounts of CH_4) pass through. Since the methane rich gas is withdrawn on the high pressure side, further compression is unnecessary for the feed-in. A disadvantage of this separation process is the loss of methane due to the escaping CH_4 molecules. This is countered by the serial connection of several membranes and the recapturing of the methane rich parts of the stream. This method can also be sued for desulphurisation and dehumidification. With the appropriate selection of membranes and a corresponding plant concept, the simultaneous separation of CO_2 is also possible.

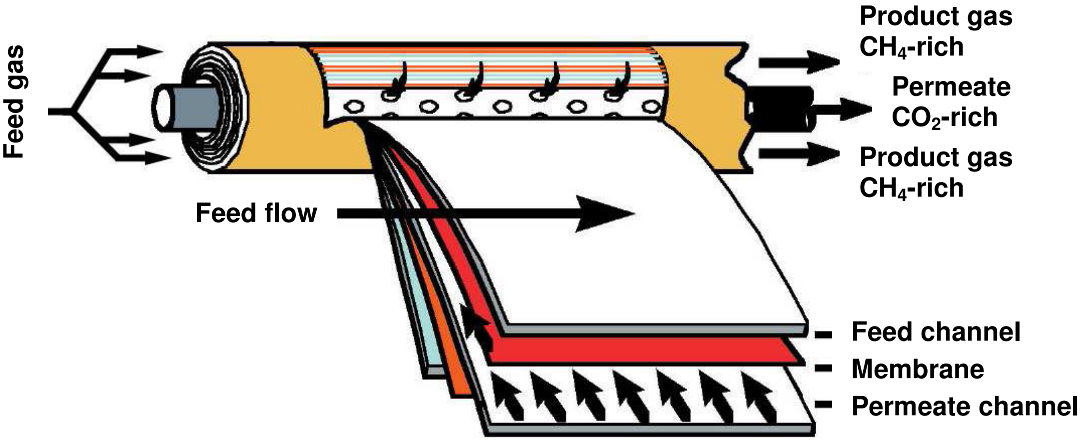


**Illustration 9: Spiral winding module for gas separation using gas permeation
Source: Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)**

From the illustration of the separation principle, it can be see that a construction design is possible in a very narrow space in spite of the necessary surface requirements for the permeation, due to the winding. Compact modules for the processing of 1.180 m^3/h have measurements of 2,5m width, 1,8m long and 1,8m high. As the output parameter the CH_4- content is fixed. The plant is controlled using the variable parameters such as gas quantity, pressure and temperature. Varying methane contents can be produced in this way through the regulation of the volume flow. The problem of high CH_4 loss have been able to be kept within limits in pilot projects and in a two stage arrangement of the membranes has amounted to about 1.5 to 3%.

In comparision to normal conditioning plants (see the previous chapter), investment costs are higher by a factor of 3 to 16 times. The conditioning of the gas to within the final percentual range of methane content is associated with relatively high costs. However, a reduction in the demands on the product gas can result in significantly lower investment and operating costs. The costs and therefore the economical implementation of biogas conditioning using gas permeation is very dependent on the required gas quality. One possibility to feed-in the gas as admixture gas is provided by this technology due to the controllable gas quantity, pressure and temperature and because of the significantly more economical framework conditions it offers. In Europe, there are alread five plants in operation that enrich biogas using gas permeation. In the plants built so far, there is still a very high loss of methane during the conditioning, which makes this technology less competitive to other methods. A series of several membranes can increase the yield, but also entails higher investment and operation costs. Using a two-stage arrangement of the membranes, the CH_4 losses are approx. 1.5 to 3%.

4.5.5 Cryogenic gas separation

The individual components of biogas have different condensation temperatures. Cryogenic gas separation makes use of this fact. The first step is the compression of the biogas to 65 to 85 bar. With the aid of condensation separators the water and part of the hydrogen sulphide can be removed. A subsequent molecular sieve reduces the water and H_2S content further. Using this method a water dewpoint of -100° C and an H_2S of less than 5 ppm is achieved. There are two molecular sieves per plant. While one is in operation, the other is regenerated. The biogas now consists only of methane and carbon dioxide (mit minimal traces of impurities). A significant advantage of cryogenic gas separation is therefore the purity of the methane (approx. 99.95% at -151 °C and 2 bar) and of the carbon dioxide (ca. 98 % at 46 bar and 12 °C). With conventional distillation technology the gas mixture from methane and carbon dioxide can only be rectified due to physical reasons to a methane content of approx. 92%.

The remaining CO_2 content then transforms into its solid state and leads to the icing of the equipment. To separate both components, a cryogenic separation stage is used. External cooling (e.g. from a stirling engine) and expansion cooling is used to cool the gas mixture to a temperature necessary for the separation. The actual separation of CH_4 and CO_2 takes place with the aid of classic rectification technology and the used of micro-heat-exchangers. At the head of the separation column the CH_4 can be drawn off with a purity of 99,95 % at -151 °C and 2 bar. At the sump, the carbon dioxide has a purity of approx. 98% at 46 bar and 12 °C. At these process temperatures, approximately half of the separated methane is in fluid form and the other in a gaseous state. Therefore, there is a subsequent division of these two phases at the connection to the separation column. The fluid part is stored temporarily in a LNG tank (**L**iquified **N**atural **G**as).

Due to the volume ratio of fluid to gaseous CH_4 of 1:580, a substantial amount of CH_4 can be stored in an LNG tank. The energy density ratio of biogas (65 % CH_4, 35 % CO_2) to liquid methane is even 1:850. Due to an evaporation rate of approx. 1% per day, the temperature-pressure-balance maintained, since the LNG is cooled by the evaporation of the methane. Due to the high energy density it is worth considering the transport of the LNG in road tankers. The produced gas then no longer has to be utilised on site, but rather can be sued where there is a true need for a gaseous energy source. This alternative is particularly interesting for biogas producers who do not have the possibility of connecting their plant to the gas grid.

The gaseous part of the methane is available for direct use in the BTTP or in fuels cells, as well as for fee-in into the gas grid. The CO_2 at the sump of separation column with a purity of 98% is stored in a pressure tank at approx. 12 °C and 46 bar in liquid from in a pressurised tank. It is also available for commercial use and thereby represents an additional source of income for the plant operator.

Up to now, one cryogenic biogas conditioning plant has been built in Germany as a pilot plant (Kremmen). The need to compress the biogas to 65 to 80 shows the higher energy requirements of this type of treatment. The decisive question is what advantage can be achieved with it with regard to the total process. This concerns the system integration i.e. how can the energy requirements be optimised in connection with other users and how can the CO_2 (that is available at a high level of purity) be utilised. In this regard, there is another project in Germany (Anklam), which plans the construction of such a plant for the utilisation of methane in the field of transportation. With an initial capacity of 100 m^3/h, the investment costs should be approximately the same as in other porcesses. The operating costs are calculated to be 0,75 kWh_{el}/m^3 of input-gas under automatic operation. A further, purely experimental CO_2/CH_4 separation plant using micro-system technical components for a throughput of 8 m^3 has already been planned and operated.

4.5.6 Comparison of processes for methane enrichment

For the purpose of comparing processes for methane enrichment, the pressure swing adsorption, pressurised water wash and the low pressure membrane adsorption methods will be used. The comparison of cryogenic gas separation and gas permeation using membranes is left out here because these types of plants are still in the pilot phase. A comparison of the specific process costs of the three technologies for methane enrichment which can be used to produce biogas with natural gas quality shows that the enrichment costs only differ slightly from each other. The specification of the product gas refers to the exchange gas (incl. liquid gas mixture).

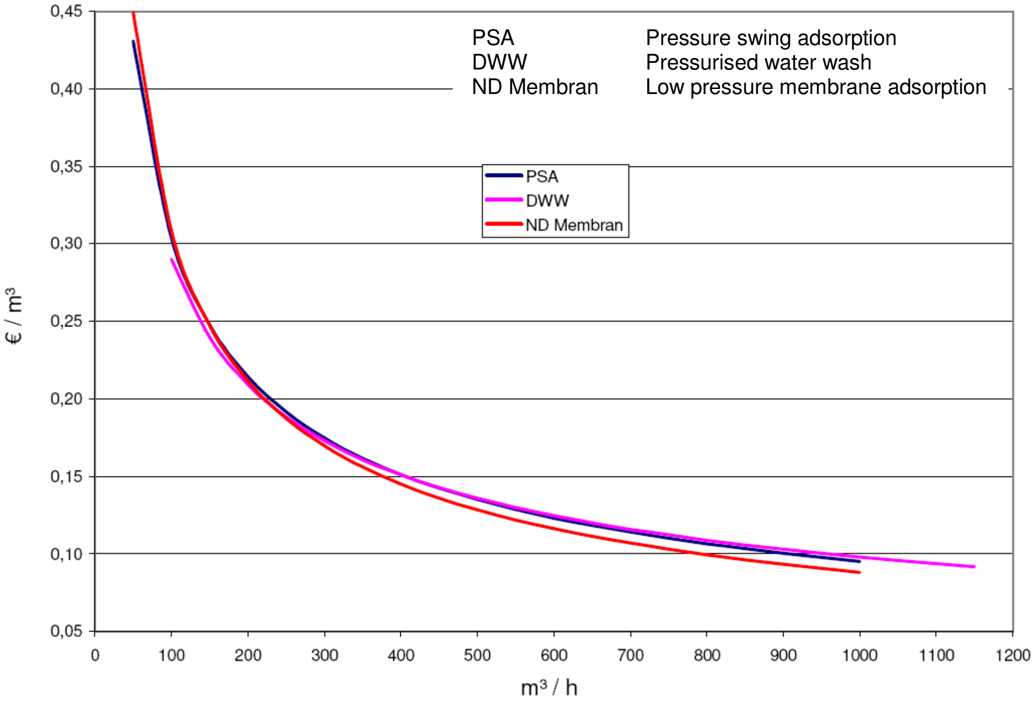


Illustration 10: **Specific process costs of methane enrichment in €/m³ based on the product gas and depending on the plant size m³/h**
Source: Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

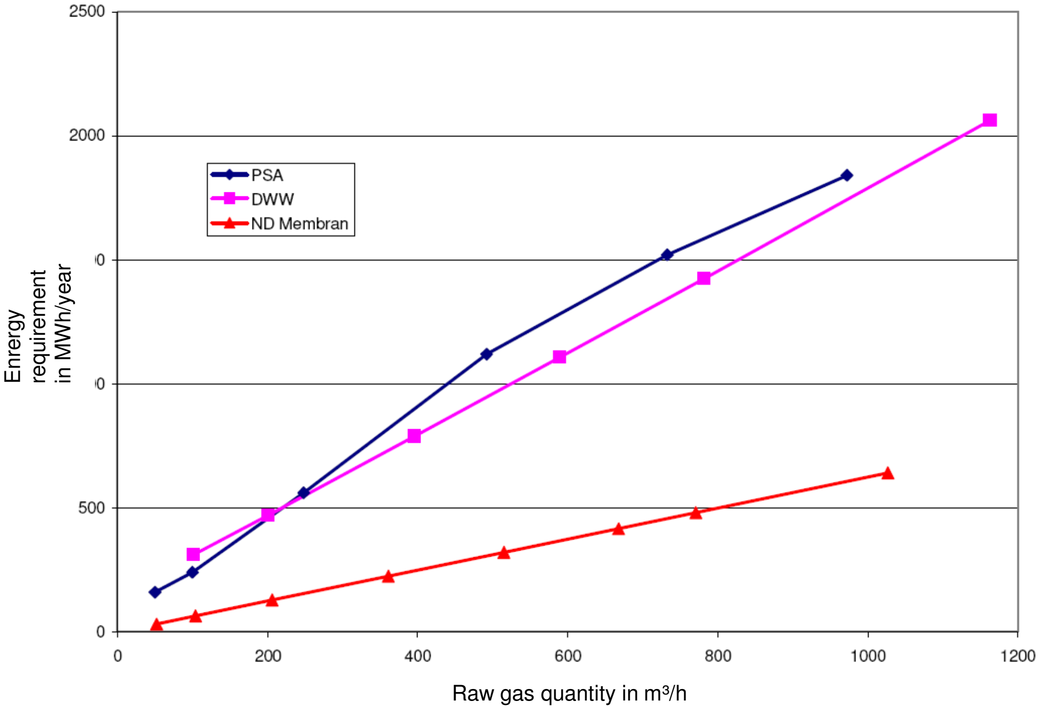


Illustration 11: **Energy requirements of gas conditioning plants in kWh/year based on raw gas throughput**
Source: Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

In operation the processes show clearly different energy consumption. The PSA and PWW have similarly high energy consumption due to the respective pressure level (5 to 10 bar with PSA and 8 bar after dehumidisation with PWW). For the low pressure membrane adsorption, energy requirements are approx. a third of the two other technologies, since this process only requires a blower.

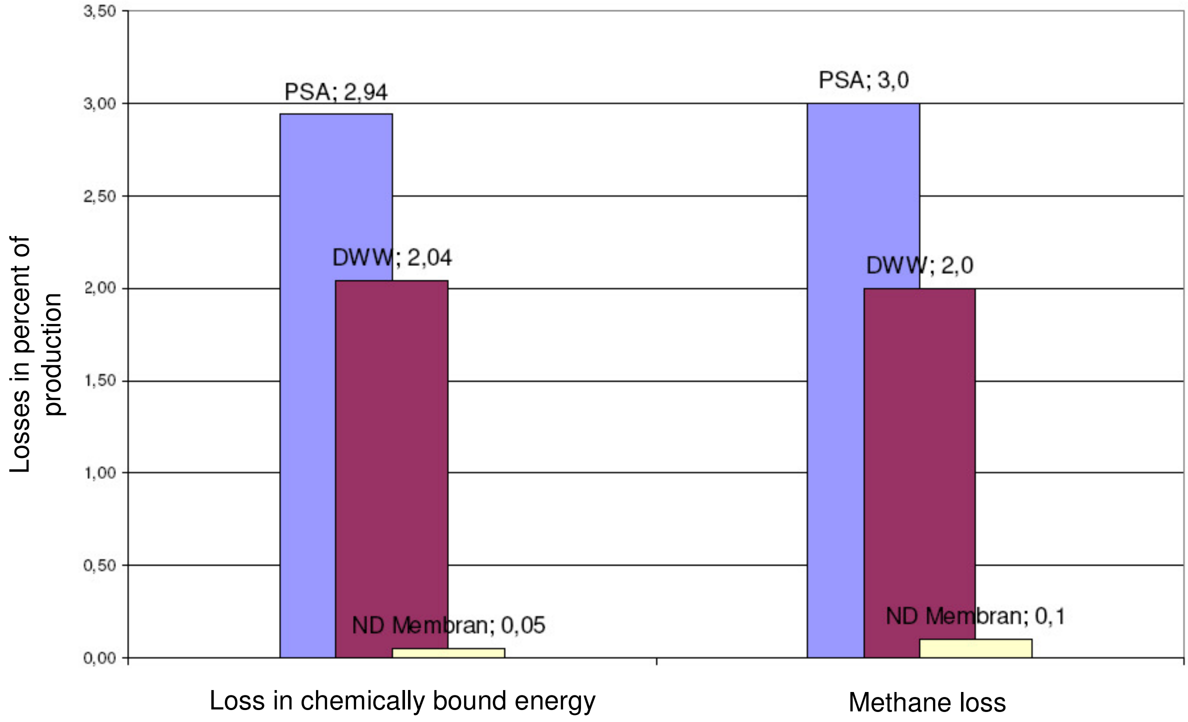


Illustration 12: Losses in gas conditioning plants in percent, based on prodution
Source: Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)

The loss to chemically bound energy is based on the energy balance of the conditioning plant. The values are the losses related to the production. The methane losses are process dependent, since the individual technologies cannot separate 100% of the CH_4 from the CO_2. In the PWW, for example, during the reforming of the wash water a part of the CH_4 is also washed away. It has been demonstrated that the losses in the PWW and PSA methods are higher than those in the low pressure membrane method.

On the basis of the methane enrichment plants in operation, it can be concluded that the pressurised water wash is very suitable for biogas conditioning. This technology has already been implemented 32 times in Europe. In any case, the location must be taken into consideration when employing this technology. For example, what are the costs for the required process water (drainage from a waste water treatment plant or expensive drinking water).

The second most frequently seen type of plant uses the PSA technology, with 15 such plants constructed in Europe. Important here is that the possibly high concentration of H_2S in the raw biogas must be reduced in the adsorber before the actual methane enrichment takes place, in order to avoid clogging the molecular sieve.

Experience gathered from the plant operation of the only low pressure membrane adsorption plant in Europe will show whether this technology is practical for biogas conditioning.
The process of gas permeation using membranes is being researched intensively. In Europe there are already 5 plants working according to this principle. If the plant costs can be reduced, particularly with regard to new membrane technology, this process could be iimplemented more frequently.
Cryogenic gas separation is currently still in the research and development stage. It cannot yet be said if this process will be used more intensively in future.

5. Technical requirements for the feed-in of biogas into the natural gas grid

The transport of natural gas after production generally takes place through high pressure gas conduits with operating pressures of 67.5 to 80 bar and in older pipelines between 20 to 40 bar. In certain exceptions, the high-pressure conduits are laid offshore (e.g. North Sea). Due to the pressure decline of 0.1 bar/km, compressor stations are necessary after 80 to 130 km. The high-pressure main pipelines are usually operated as supra-regional integrated grids of natural gas distributors and transport companies. Feed-in takes place at transfer points to industrial customers and at those on the high-pressure grid operated by the regional gas supply companies. The local grids are intermeshed supply grids that flow from high-pressure pipelines to medium-pressure to low-pressure pipelines. These grids are often operated by local gas supply companies who supply industrial end customers (e.g. high-pressure at 4 bar) or private end customers at the house connection (low pressure to 0.25 mbar) using connection lines with natural gas of the contractually agreed quality and quantity. Gas pressurisation system reduces the supply gas pressure to the required pressure of the gas consuming equipment. Internal building lines are operated under low pressure. At the transfer points to the next grid level, gas pressure regulators and measurement equipment are necessary. At the transfer points of overlaid pressure levels (high-pressure, medium-pressure) to underlaid pressure levels (medium-pressure, low pressure), gas pressure regulating equipment is mainly used.

The pipelines are constructed with various fittings. One type of fitting is the cut-off device. These can be slide valves, stop cocks and balanced disc stop valves. The main function is the separation of the following pipeline from the gas supply. Condensation separators are another type of fitting necessary in the natural gas grid for the collection and expulsion of condensed water from the gas grid.
The feed-in of the conditioned and normalised gas takes place through compressor and/or pressure regulation and measurement equipment. For the feed-in it must be assured that the gas is available at a pressure higher than that of the pipeline pressure at the feed-in station. According to the state-of-the-art technology, the conditioned biogas process already necessitates higher pressure, which, depending on the conditioning process, is generally sufficient for feed-in into the local gas grid.

Equipment required for the feed-in include gas measurement and control equipment. For time and heat equivalent transfer, there must be proof of the transferred energy quantity (quantity and fuel value), and, as necessary, odorisation and the Wobbe-index must be carried out. Furthermore, there must be regular monitoring of gas impurities.

If the gas is being transferred as admixture gas instead of exchange gas, a mixer must be installed. Mixing equipment regulate the heat value or Wobbe-index, whereby the pressure and flow volume serve as variables. Problems can appear here if the volume flow is too low or there are interruptions which can make regulation complicated. Furthermore, the size of the grid is to be taken into consideration since it acts as an attenuator.

5.1 Connection lines

The natural gas pipeline grid is a pipe grid. The materials used in the pipelines are grey cast iron, steel or plastic. The connection is made in older lines (cast iron) with lead joint sockets or screw bushings. The sealing is done with rubber gaskets. Steel pipes and plastic pipes are welded or connected with rubber sealed joints. In contrast to steel pipes, plastic is not as mechanically durable and if laid in the open it ages. The advantages of plastic pipes are the low costs and it anti-corrosive and insulating properties.

The connection lines are considered to be an extenstion of the pipe grid, which means the properties of the local grid must be observed with regard to material, nominal diameter and pressure level. The connection line is always at least one step smaller as the line that is being fed into. Since the specific pressure loss has less importance as in the pure gas transport pipeline the connection lines can be set up for higher flow speeds (30 to 40 m/s at PN > 16, 20 m/s at PN 16, 5 m/s at PN 0,1). The labels DN and PN indicate the pipe diameter (DN) and nominal pressure (PN). During the gas transport through the pipelines, the loss of pressure leads to a cooling of the gas at 0,4 to 0,6 K/bar (Joule-Thompson effect).

A pre-warming of the gas is necessary to avoid the transported gas cooling below the dewpoint of the water contained in the gas. The pre-warming is preferably carried out in the upstream measurement and control equipment. To avoid exterior corrosion the pipes and weld seams are covered during production and after being laid out at the construction site with suitable passive protection layers (bituminous materials with support insets from fiberglass with thicknesses of 4 to 6.5 mm, increasingly with PE sleeves with a high electrical insulation resistance and high resistance to aggressive substances).

The combination of the PE coverings with a fiber cement lamination protects the outer cover from destruction and enables the cost saving use of the excavated ditch material for refilling. To avoid or limit stray current corrosion, in addition to these passive corrosion protective measures, active protective measures are taken through the application of parasitic current. The maintenance of a minimum gas temperature avoids undershooting the water vapour dewpoint temperature and thereby prevents interior corrosion. In the transport pipelines coating with epoxy resin is an effective anti-corrosion measure. Gas losses in the transport and distribution system can be traced back to a significant extent to older joint connections in the distribution grid and have been or are minimised through continual refurbishment of the grid.

5.2 Gas compression

Compressor stations are required to overcome friction pressure loss during long distance transport (transport compression) and to create a relatively high pressure for underground gas storage (storage compression).
In the natural gas distribution grid there are substantially three different pressure levels: High (HP), medium (MP) and low (LP). In the main transport pipelines that are operated by the initial suppliers (regional and long distance), the natural gas is transported under high pressure to the actual gas suppliers. It then proceeds to the regional and local gas supply companies through medium to low pressure lines who then deliver it to the end consumers.

5.2.1 Compressor stations and pressurisation systems

In the transport pipelines there are high flow quanitities with a relatively low pressure that have to be compressed. Turbo compressors are used with industial gas turbines as the drive train. In large plants, to improve the efficiency of the gas turbine, a steam turbine process is installed downstream. With gas tanks minimal flow quantities are stored with a relatively high compression ratio for which reciprocating piston compressors are used with a gas engine drivetrain (mostly two-stroke otto engine). To assure sufficient reliability and variability of the flow volume and the pressure ratio, in addition to the rotational speed, bypass and throttle control, several compressors are installed in parallel and/or in series. An additional reserve unit with the output of the largest installed operating unit is recommended. It assures the minimum flow volume in case of planned or unplanned downtime of the compressor.

For the safe and economical operation of the compressor stations, in addition to emergency backup power supply, the following components are required:

- Cooler for the exhaust of motor dissipation heat and to maintain a maximum gas temperature of approx. 50° C.
- Equipment for dust removal using baffles, angle plates, or cyclone separators and for the filtration with fine porous materials, e.g. ceramic, fibre mats and impregnated paper
- Addition of combustion gas for the drivetrain engine with a fluid separator, pressure control and excess pressure valve that turns off the compressor when it reaches a certain value limit
- Expansion system with central exhaust blower that is place approx. 10 m above the station
- Pump prevention line with automatically controlled bypass fittings betweenthe pressure and intake ports of the turbo-compressor that should prevent the appearance of dangerous vibrations if the minimum flow volume is not reached by the opening of this fitting.
- Measurement and analysis devices for the flow volume and the gas properties
- Drying equipment with hygroscopic liquids or renewable adsorption material (silica gel, active charcoal) for the reduction of the water vapour content and maintenance of a dewpoint temperature of 5° C, which should prevent hydrate formation to a great extent.
- Safety technology: automatic gas and fire warning devices, as well as fire extinguishing equipment

5.2.2 Biogas compression

The compression of the biogas is dependent on the local characteristics for the feed-in into the public natural gas grid (pressure level of the adjacent pipeline) and on the concrete biogas conditioning process. Some gas conditioning processes, such as, for example, presssure swing adsorption, biogas conditioning with active charcoal or a gas wash require a certain minimum pressure for technically and economically optimal operation. Presssure swing adsorption plants work with an operation pressure of 4 to 10 bar, the operation pressures in adsorptive gas cleaning equipment (washers) fluctuates, depending on the adsorption process, between 6 bar and very high pressures of up to 70 bar. Gas cleaning with active charcoal is primarily used with equipment pressures between 0.1 and 1 bar overpressure.

The pressure level of low-pressure lines is generally below 0.1 bar and is limited to a maximum or 0.12 bar (depending on the regional gas supply companies). Medium-pressure lines are operated in the area of 0.1 bar and high-pressure lines with pressures from 1 bar. The high-pressure area is often subdivided into ranges of 1 to 4 bar and 4 to 16 bar. Furthermore, a fourth pressure level (highest-pressure) can be present that includes pressures abover 16 bar. It must be considered that a biogas feed-in into a high pressure grid may no longer be sensible with regard to energy and economic aspects, since the required compression work increases quadratically with the pressure ratio and possible synergies in the gas conditioning process can no longer be utilised.

When biogas that is saturated with water is compressed, condensation forms that has to separated. Biogas compression can therefore be used for the pre-dry of the gas, but the compressor has to be suitable for operation with wet gas. Possible impurities in the biogas, as well as certain gas components such as e.g. hydrogen sulphide which can limit the functionality of the compressor, must be taken into consideration in the selection of the compressor. Many types of compressor designs are oil lubricated.
It must therefore be calculated that there will be oil residues of approx. 1 to 3 mg/m^3 in the gas that can lead to technical problems in certain subsequent gas cleaning processes, such as, for example, biogas cleaning with active charcoal or pressure swing adsorption.

Dry running compressors, which work without oil lubrication, have the disadvantage that the amount of gas leakage is clearly above that in oil lubricated compressors and material wear debris can contaminate the compressed gas. The efficiency of this design is also worse. With regard to the flow volume quantity and the final pressure of the biogas the reciprocating piston compressor, rotary piston compressor (multiple cell compressor, liquid ring compressor, oil-free worm compressor) appear to be principally suitable and for larger flow volumes, in certain cases, turbo-compressors (radial and axial compressors). In the natural gas grids (and often in process technology), turbo and reciprocating piston compressors are used primarily for pipeline transport.

Reciprocating piston compressor	Small to medium througput; final pressures above 10 bar; reasonable specific energy consumption; shorter life than turbo compressors; higher efficiency than worm compressors
Rotary piston compressor	Small to medium througput; in general small final pressures; possible two-stage design with two units in series
Multiple-cell compressor:	High reliability und operational safety; compression of impure or dusty media possible; 1 stage medium throughput up to 5.400 m^3/h and final pressures up to 5,2 bar; 2-stage medium throughput up to 1.800 m^3/h and final pressures up to 11 bar
Liquid ring compressor	Oil-free compression; high reliability; insensitive to liquids and dust; medium throughput of 1.400 to 3.000 m^3/h; 1-stage final pressure up to 2,5 bar, 2-stage final pressure up to 6 bar
Worm compressor:	Oil-free; minimal wear; high running smoothness and life (20.000 to 50.000 operating hours); high operational safety; insensitive to aggressive media; medium throughput of 540 to 21.600 m^3/h; 1-stage final pressure up to 6 bar; 2-stage final pressure up to 14 bar
Turbo-compressor	High running smoothness; minimal wear (operating life up to 6 years)
Radial compressor:	Medium to large throughput of up to 2.000 to 100.000 m^3/h; larger throughput possible; pressures up to 300 bar
Axial compressor:	Small to medium throughput of 50 to 70.000 m^3/h; larger throughput of 1.000.000 m^3/h possible; pressures seldom above 10 bar; higher pressures possible; higher efficiency and smaller dimensions than radial compressors

Construction type	Flow range [m^3/h]	Over pressure [bar]	Properties
Rotary piston compressor	100 to 5.000	1 to 2,5	Oil lubricated, residue oil content 1 to 5 mg/m^3
(Multiple-cell compressor)	150 to 3.000	3 to 10	Oil lubricated, residue oil content 1 to 5 mg/m^3
Side channel blower	4 to 1.100 250 to 1.900	0,2 to 0,58 0,1 to 1	Pulsation-free, oil-free, quieter than rotary piston blower
Rotary piston compressor	20 to 10.000	0,1 to 1,4	Oil-free, not , not pressure surge protected

Table 17: Overview of gas compressors – Application areas and properties of compressors for biogas, marsh gas or natural gas
Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Studie: Einspeisung von Biogas in das Erdgasnetz (Leipzig, 2006)

Membrane compressors, although technically suitable for the compression of biogenous gases, are not economically competitive with reciprocating piston compressors due to their technically sophisticated construction. These compressors are used for very special and therefore cost-intensive applications, such as for the high pressure area (final pressures up to 4,000 bar) and for the compression of inert gas.
In practice a careful selection must be made together with the compressor manufacturer, since in addition to the listed properties and a series of other criteria (e.g. gas composition, humidity content of the gas, pulsation of the gas flow, location of the compressor, etc.) can influence the compression.

5.3 Gas storage

Since biogas production is not always continuous and is subject to constant fluctuations, the possibility of biogas storage should be created in order to assure the continuous utilisation of the biogas. Reasons for the irregular formation of biogas can be the different quantities to be fermented or also different substrates with unequal dry residue content, which can result in varying decomposition times. The main reason however rests in the mode of operation of the fermenter and the activity of the microorgansims. Since the BTTP, as well as the gas conditioning require a flow volume which is as constant as possible, corresponding storage (buffering) must take place. Principally, continuous gas production should be strived for so that the supply and demand for the biogas is in equilibrium, which also results in smaller and therefore more reasonably priced storage capacities. There are 3 cases that can make gas storage necessary:

- Storage before the conditioning
- Storage for liquid gas / air mixture
- Buffer storage for feed-in.

Gas from fermented production is stored in dry and wet gas tanks in biogas plants before conditioning at the following pressure levels:

- Unpressurised 0 to 5 mbar
- Low pressure 10 to 50 mbar
- Medium pressure 10 to 20 bar
- High pressure > 20 bar.

The storage container size is generally dependent on the average gas production per day, the usage of the biogas and the mode of operation of the production plant. Reasonable sizes are storage volumes of 30 to 50% of the daily gas production, whereby other various safety allowances are to be made; the upper limit is the storage of one day's production of biogas. These guideline sizes appear to be understandable in view of the fact that, viewed from an energy standpoint, 1,000 l biogas corresponds to only 0,6 l of heating oil, so that the storage of biogas requires more space for storage. Long term storage of biogas is therefore not practical or economical.

The storage process of biogas is generally categorised into three pressure levels, whereby the high pressure area can be considered a fourth category. Particularly in the use of biogas as a fuel, this last variation is used. Non-pressurised and low-pressure processes are appropriate from a cost specific viewpoint for small and medium sized plants. Due to the high investment costs and the increased energy need for the gas compression and extraction, medium and high pressure processes are mainly used in large plants. The advantage is that proportional to the pressure, the amount of biogas that can be stored increases.

Pressure range	**Operational pressure [bar]**	**Normal storage-sizes [m^3]**	**Storage construction**
Non-pressurised	0 to 0,005	10 to 2.000	Fermenter, Balloon-/ Foil storage
Low pressure	0,01 to 0,05	100 to 2.000	Gasometer, double-membrane storage
Medium pressure	5 to 20	1 to 100	Steel pressure tank
High pressure	200 to 300	0,1 to 0,5	Gas bottles

Table 18: Pressure ranges of biogas storage
Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Studie: Einspeisung von Biogas in das Erdgasnetz (Leipzig, 2006)

Part of the non-pressurised storage process includes firstly the fermenter itself in which the biogas produced can collect in small quantities to then be transported into correspondingly larger storage. The storeable quantities here are minimal. For larger quantities, special high silo ceilings are offered for fermenters. With these it is possible to adjust the ceiling angle depending on the biogas production so that larger quantities of biogas can be stored. Due to the construction and the materials employed, long life, prevention of odorous emissions by approx. 95%, high weather resistance and high structural integrity are ensured. There are no maintenance costs, but an inspection every two years is recommended. Biogas extraction takes place via a special shaft. The second possibility for non-pressurised biogas storage are gas sacks, which are available in different shapes and sizes. Storage here results from the change in the volume, i.e. from the filling of the gas sacks with the gas using the same principle as filling an air balloon. Correspondingly referred to as balloon or (foil) pillow storage, this temporary storage consists of a foil (primarily from PVC) and is used when the gas pressure i.e. the fill quantity of the interior space does not fluctuate substantially. For protection from weather effects, the gas sacks are hanged in protective containers or in unused facility buildings. The emptying of the storage takes place with the aid of special devices that act as a load on the balloons, putting pressure on them. Typical sizes range from 100 to 1,500 m^3 and other sizes can be supplied on demand. Due to the simplicity of the gas sacks, they are viewed as a reasonably priced solution for the storage of biogas.

The process for low pressure gas storage are categorised into wet and dry gas storage. In wet gas storage gasometers are used that either consist of a bell or disk. Coated at the edge with a sealing liquid (generally water or liquid manure), the bell/disk moves up and down through the buoyant force of the gas according to the fill level. The pressure created by the weight of the bell/disk on the stored gas amounts to 5 to 10 mbar. Applications of this technology for biogas storage are seen very seldom. More frequently, dry gas storage is used in the form of membrane/double memebrane storage that stores the gas in high quality, corrosion resistant plastic/rubber membranes.

These are characterised by fast production and assembly, high quality, safety, long life, as well as a reasonable price/performance ratio, since they are standard products. The double membrane storage consists generally of three membranes. The floor membrane provides the sealing of the foundation, the inner membrane stores the biogas and the exterior membrane serves to stabilise the entire construction and protects against the weather. Normal sizes for double membrance storage are in the range of 100 to 2,000 m^3. If more storage capacity is required, the individual storage containers can be easily coupled with each other. Further advantages are that they are maintenance-free, and the possibility of installing them on existing high containers, whereby the floor membrane is no longer required. The gas extraction takes place through a pressurisation blower that creates pressure on the inner membrane.

Other possibilities for gas storage are processes that are used for the storage of natural gas. This includes the liquification and the subsequent storage in tanks, which however is out of the question for biogas due to the high costs. The second option is underground storage in the form of pore-space or cavern storage. Pore-space storage is former natural gas storage that can be found at depths of up to 2,700 m. The gas is stored in the hollow spaces i.e. pores and cracks in the stone. In cavern storage these hollow spaces are created artificially. They are often salt caverns whereby the hollow spaces are leeched out of the salt stone. Underground storage is a technically complex process with which very large quantities of gas can be stored at pressures from 100 to 200 bar. The necessary compression and the associated high costs lead to the conclusion that this process is not suitable for biogas storage.

5.4 Gas pressure measurement and regulation equipment

The term gas pressure measurement and regualtion equipment refers to combination of gas measurement and gas pressurisation systems.

Gas measurement systems are equipment in the natural gas pipeline systems which are used to measure the gas flow volume. Measurement is carried out using gas counters that work according to different physical principles. They are categorised into simple operational measurements that serve to regulate the grid and highly precise calculation measurement systems.

Gas pressure regulation equipment is found at the interfaces of different lines, grid parts or grids. Its task is to regulate and limit the flow volume. The gas is expanded from the input pressure to a lower output pressure. Generally, the input pressure fluctuates, while the output pressure of the flow volume is to be kept constant. Gas pressure control equipment is frequently combined with gas measurement equipment into gas pressure measurement and control equipment so that the gas flow volume can be directly converted into a „rate of flow“. If control is carried out according to a predetermined quantity of gas per time unit (e.g. as hourly or daily rate for the acquisition optimisation of transfer capacity), this is referred to as flow rate control. In addition to the pressure regualtion and quantity measurement, the downstream grid is protected by safety devices against the permissible pressure capacity being exceeded. Furthermore, other components are required for pressure regulation, quantity measurement and safety: isolation cut-off points, shut-off valves, filters and separators, pre-heaters and heating, thermometers, temperature sensors, manometers, pressure sensors, power supplies, data recording, data transmission, quantity transformers, tarif devices and the building. The applicable rules and regulations must be observed for the planning, building, outfitting and operation of a gas pressure measurement and regulation plant.

For two-track gas pressure measurement and regulation equipment, generally only one is in operation while the other is ready in reserve. The gas enters the actual plant through an isolation station followed by filtering, separation and pre-heating. The latter is required when, after expansion to the lower pressure level there is a danger of undershooting the dewpoint. After the two safety shut-off valves per section, there follows the gas pressure regulation and the silencing and then the quantity measurement. The gas finally enters the downstream grid through the second cut-off point. In the public gas supply grid for supra-regional transport there are operating pressures of up to 80 bar. For transport to the next successive grid the pressure in the gas is reduced in gas expansion equipment, usually without using the released energy, to the locally prevailing grid pressure. In so-called expansion machines, this throttling process can be used to drive a generator.

5.5 Gas properties measurement equipment

A differentiation is made between the gas measurement and gas pressure regulation equipment and the equipment for measuring the gas properties. The term „gas properties“ includes the fuel value, heat value, density, Wobbe-Index (for billing) as **combustion specifications**, CO_2, gas impurities, O_2, sulphur components as **main components**, the water dewpoint and the condensation point (water condensate).
Depending on the requirements, the magnitudes are measured for all of the variables or just individual ones. Process gas chromatography devices are used to determine the main components, calorimeters for the heat value, density measurement devices for the density, individual measurement devices (e.g. CO_2, S, H_2, O_2), dewpoint level for the determinatio of the dewpoint and capacitive humidity sensors for determining the condensation point.

The measurement devices are placed in a diverted gas flow which is ejected after analysis. If a meaurement cannot be made on site, automatic samplers are used to take a representative sample of the average gas composition over certain period of time. This method is appropriate primarily for gases with a minimal range of fluctuation, where it can be assumed that there are no gas impurities which are not allowed to enter the downstream grid. The monitoring of gas properties is requried on account of legal considerations with regard to product liability (H_2S, dewpoint, absence of gas impurities). This is necessary from a technical standpoint for the control of the conditioning equipment. It is only with gas properties measurement in real-time, particularly for the feed-in of admixture gas that compatible gas properties can assured with regard to heat value, fuel value and the Wobbe-Index. For the time and heat equivalent transfer, the gas properties measurement serves as the control factor.

5.6 Odorisation equipment

Generally odorisation is not carried out during feed-in into the transport pipelines since this is not distributed directly to the end customers, but transferred to the downstream grid where it si odorised. Odorisation may not be necessary if only small amounts are being fed into the grid compared to the available quantitiy. In this case an agreement between the biogas producers and the grid operator is necessary.

Normally, for the odorisation, quantity dependent regulated dosing using an injecton valve is used through which the odorant is injected into the gas flow. A difference here is made between those pressurised plants with natural gas or nitrogen or the non-pressurised ones. The latter stand directly over an active charcoal filter in direct connection to the ambient atmosphere. The adjustment of the odorant quantity to the gas throughput takes place through a regulation device. This automatically adjusts the dosage according to the quantity. The impulse provided by the gas quantity measurement is processed by the regulation device and the required value is sent to the dosage pump. Odorisation equipment must be monitored weekly or using remote monitoring in order to assure zero error functionality.

5.7 Conditioning and gas mixing equipment

The term „conditioning“ does not mean here primarily the adjustment of combustion specification of the base gas (e.g. production L from H gas), but rather purpose oriented regulation of exchange or admixture gas as the feed-in.

Mixing equipment is controled by heat or Wobbe values and should be abel to be operated contnuously, which means that a uniform acceptance of gas should be assured. Large fluctuations in gas properties cause a great need for regulation and require a grid which serves as „attenuation“.

A differentiation is made between three cases:

1. Feed-in as exchange gas (L-gas): No additional equipment is necessary. The gas can be fed-in without a mixer with sufficient pressure.
2. Feed-in with liquid gas/air mixture: Additional equipment for the mixing of liquid gas/air mixture is necessary.
3. Feed-in as admixture gas: Mixture equipment is necessary for the feed-in equipment.

Mixing equipment consist of injectors in which the highly pressurised propellant gas (natural gas), sucks in the transport gas (air) and compresses it.
In individual cases, corresponding to contractual arrangements between the grid operator and the feed-in operator, various equipment can be dispensed with or feed-in equipment can be supplemented with additional devices.

6. Examples of Biogas Feed-in

Currently in Europe, plants for the conditioning of biogas to natural gas quality are being operated in several countries (Sweden, Switzerland, Germany, Austria, The Netherlands and France). Of these, at least in Switzerland, Germany, Austria and The Netherlands, a part of the conditioned biogas is fed into the natural gas grid.
In The Netherlands there are a total of 4 locations where the conditioning of landfill gas to approx. 90% methane content is taking place and partially being fed into the public grid. The conditioning processes being used include the pressurised wash and pressure swing adsorption process. Biogas from agricultural plants is not conditioned.
Since the conditioning of biogas from agricultural plants is only being carried out in Sweden, Germany, Austria and Switzerland, the following examples are based on the situations in these countries.

6.1 Germany

Motivated by the innovation bonus in the renewable-energy law, there are currently several projects for biogas conditioning and feed-in being realised that will shortly begin commercial operation. One biogas plant already in operation that is conditioning biogas to natural gas quality on a large scale can be found in Pliening.

Bio-methane plant Pliening
The bio-methane plant in Pliening is the first plant in Germany for the feed-in of bio-methane into the natural gas grid. This makes the plant the most modern biogas production facility in Europe. The project that is very closely tied to the areas of energy plant cultivation, materials logistics, biogas technology, the gas industry and energy suppliers is unique in Germany.

Biogas technology:	Three main fermenters each 1.000 m³, three post-fermenters 2.700 m³
Operating temperature:	mesophil, to 42° C
Bio-raw gas processing:	920 standard cubic meters per hour (Nm³/h)
Bio-methane production	485 Nm³/h
Annual conditioning capacity:	approx. 3,9 M. Nm³ Bio-methane in natural gas quality
Annual feed-in capacity:	approx. 43 M kWh – this corresponds to the heating needs of approx. 1.300 single family homes
Feed-in:	Natural gas grid of the City of Munich
Delivery:	Energy supply contracts with E.ON Bayern AG, Power & Air Solutions GmbH, Munich City Utilities, etc.
Energy efficiency:	approx. 85 % through all-year power and heating use
Input:	approx. 35.000 t corn silage, Corn-Crop-Mix (CCM), whole plant silage and grains
Gas conditioning:	The enrichment of the biogas to bio-methane takes place using the pressure swing process. The gas is compressed to a pressure of 6 bar and pressed into so-called adsorption containers. There the CO_2 contents are deposited on carbon molecular sieves, while the methane passed through. Through pressure expansion the bound CO_2 is released to the atmosphere. This multi-stage process increases the methane content to natural gas quality of over 96%. The feed-in into the natural gas grid of the Munich City Utilities takes place directly at the plant.

The goal of the gas conditioning is to bring the biogas to natural gas quality (96% methane content) in accordance with the requirements of the DVGW guidelines of the gas industry. At the bio-methane plant Pliening the pressure swing adsorption process (PSA) is used. The technology for the gas cleaning and conditioning comes from the CarboTech Engineering Company from Essen. The pressure swing adsorption process is an „adsorptive“ or so-called „dry process“ for carbon dioxide separation, which means there is no process or waste water involved.

The physical separation effect is based on the strong adsorption of CO_2 under high pressure, as well as on the differing molecule sizes of CO_2 and CH_4. The PSA in Pliening consists of four adsorption tanks which are filled with carbon molecular sieves. The biogas is pressed into the tanks through a compressor (approx. 6 bar). There the carbon dioxide is adsorbed by active charcoal, while the methane passes through freely. To remove the CO_2 the containers are de-pressurised (desorption). The active charcoal in the molecular sieves is regenerated. The gas cleaning is followed by the gas measurement, pressurisation to the grid pressure, odorisation as well as the feed-in of the biogas methane into the natural gas grid of the Munich City Utilities.

As a result of the feed-in into the gas grid, utilisation takes place separate from production. The energy contained in the bio-methane is transportable and can be directed through the gas grid to the consumer for the production of electricity, heating or as fuel. The marketing of bio-methane is carried out through the trade platform of the RES Bio-methane Coompany, which is active throughout Germany and is a joint subsidiary of the Aufwind Schmack Group and RES Renewable Energy Systems,. Other projects for biogas feed-in of the Schmack Biogas Company are being realised in Kerpen and Straelen.

6.2 Austria

Austria’s first demonstration facility for the conditioning and feed-in of biogas was constructed in Pucking, Upper Austria (UA). Natural Gas UA, together with UA Ferngas and the UA Agricultural Chamber of Commerce constructed a plant on the farm of Elisabeth and Franz Linsbod with trendsetting technology and a high level of future potential. The goal was the conditioning of raw biogas to natural gas quality and subsequent feed-in into the natural gas grid. 10 m^3/h of raw biogas corresponding to ÖVGW guidelines (ÖVGW G 31) are being conditioned and fed into the natural gas grid.

The conditioning of the biogas comprises the following steps:

- Desulphurisation
- Compression
- Particle separation
- Drying
- Carbon dioxide separation
- Quality monitoring
- Odorisation
- Feed-in into the natural gas grid

In order to enable the efficient separation of the carbon dioxide, the first step is the desulphurisation of the biogas. The desulphurisation used in the plant is based on a bio-technological process in which microorganisms (thiobacillus) oxidise the hydrogen sulphide to sulphate in the presence of oxygen. The addition of oxygen generally takes place in the form of air being added directly to the gas space of the fermenter. The nitrogen (78%) contained in the air remains in the biogas as an impurity, which leads to its being emitted as nitric oxide when converted into energy. At the plant in Pucking, to keep additional nitrogen from entering the gas during the desulphurisation, this takes place in a separate bio-percolating-fitler with an adjacent bubble column. The biogas flows through a container (bio-percolating-filter) filled with filler material. The bacteria form a biofilm on the filler material, which desulphurises the biogas flowing past. A nutrient solution sprayed into the bubble column serves as the nutrient medium for the bacteria. The enrichment of the nutrient solution with oxygen takes place in the bubble column through the inject of air. The oxygen in the air remains in the nutrient solution which flows into the bio-percolating-filter. The nitrogen contained in the air escapes from the bubble column without forming a bond with the nutrient solution. This assures that no additional air-nitrogen enters into the desulphurisation flow (bio-percolating-filter), so that there is no enrichment of the biogas with air-nitrogen.

Since the ÖVGW guidelines G31 prescribe very low limits for nitrogen in the natural gas grid, this process is very suitable for the conditioning. The maximum hydrogen sulphide content amounts to 200 ppm upon exit. The partially desulphurised biogas is then compressed. The sulphur enriched nutrient solution is continuously expelled and used as fertiliser.

After the desulphurisation using the bio-percolation-filter, the separation of the condensate and the required compression of the gas to approx. 8 bar (absolute) is carried out with reciprocating piston compressor. Due to the compression the gas is cooled to approx. 70° C and then passed through an active charcoal filter. This provideds further desulphurisation and particle separation. The hydrogen sulphide is then deposited on the inner surfaces and decomposed to elemental sulphur and water. The sulphur and particles remain on the surface of the active charcoal, which must be exchanged at certain intervals. Since the biogas is still saturated with water vapour, it is then cooled to the ambient temperature and the condensate that is formed is separated. The gas is then expaned to a pressure of 6 bar, thereby reducing the relative humidity of the gas. The additional drying of the biogas is carried out using the integrated drying material filler.

The methane enrichment through the separation of the carbon dioxide from the biogas takes place using pressure swing adsorption. The separation is based on the favoured adsorption of carbon dioxide (in comparison to methane) by the carbon molecular sieve. This separation effect is based on the improved physical adsorption of CO_2 , as well as on the different molecular sizers of both molecules (CH_4, CO_2).
In addition to the CO_2 separation, other gas impurities are removed at the same time, including traces of H_2S, ammonium, higher hydrocarbons, siloxane and above all water. The dewpoint is approx. -50° C to -60° C and the gas does not require any further drying.
The adsorption process at the carbon molecular sieve is a regenerative process and can be broken down as follows:

- Adsorption of CO_2 at high pressure
  As a result of the passage of the biogas through the carbon molecular sieve, primarily carbon dioxide, due to the high partial pressure and the molecular size, is adsorbed by the inner surfaces of the carbon molecular sieve. The methane flows through largely unhindered and is then present as conditioned biogas with a very high methane content.
- Desorption (reversal of adsorption) and thereby the regeneration of the carbon molecular sieve at low pressure
  For the regeneration of the carbon molecular sieve, the pressure in the tank is reduced to the level of a vacuum. The adsorbed molecules (CO_2) are then released from the carbon molecular sieve and can be expelled from the process. The carbon molecular sieve is thereby completely regenerated and then resumesthe adsorption of biogas.

The pressure swing adsorption plant in Pucking consists of four adsorption tanks, which are each filled with carbon molecular sieves. Each adsorption tank undergoes alternately an adsorption and desorption process. Due to the parallel arrangement of the tanks, continuous operation is assured.
Corresponding to the regulation of the ÖVGW guidelines G 31, the quality of the conditioned biogas is continuously monitored, the pressure is expanded to that in the gas grid and the gas is odorised and fed into the grid.

6.3 Sweden

In Sweden a lot of experience has been gathered in the conditioning of biogas for motor vehicle fuel and natural gas quality. Currently there are 20 conditioning plants in operation. The feed-in of conditioned biogas into the natural gas grid takes place at two locations. In addition to several pressure swing adsorption plants, primarily pressurised water wash plants are used for Swedish production.

Nearly 50 % of the biogas that is conditioned comes from waste water treatment plants and at the other locations industrial waste (e.g. slaughterhouse waste, waste from the sugar and potato industries) and communal, separated bio-waste are converted into biogas. The gas conditioning is done according to Swedish gas standards (for natural gas pipelines and vehicle gas), so that 96 to 98 % methane content is assured and in the case of gas grid feed-in the heat value of natural gas must be reached. The latter case means that propane must be added to the conditioned biogas at the feed-in plants, since the natural gas lines are operated with H-gas from the North Sea.

In general, the conditioning plants are directly connected with the biogas filling stations, or they are connected through biogas lines up to 7 km in length. Due to the lack of clear financial impulses for the use of biogas for energy needs, there exist a wide variety of forms of biogas utilisation, whereby the production of electrical energy is the exception. Usually a mix of different types of biogas utilisation exists at the plant site. Primarily, however, biogas is used as vehicle fuel. It is used in several cities as part of the ecologicall friendly communal bus system and to reduce emissions. Altogether there are 50 natural gas filling stations in Sweden and 50 % of the gas sold consists of biogas. Approximately 4,700 gas operated vehicles are supplied in this way. To promote the use of gas as motor fuel, the filling station grid is being expanded and the additional costs for the acquisition of gas operated vehicles is subsidised by most of the communities.

The Stockholm Henriksdal plant

The largest Swedish plant is located in Stockholm Henriksdal and is operated by the community waster supplier. Here, the largest waste water treatment plant in Stockholm cleans the waste water underground. Biogas is produced by the anaerobic decomposition of the waste sludge that is used partially for operational heat and for the electricity needs of the 4 BTTPs, each producing 700 kW_{el} and three boilers (max. 6,9 MW_{th}). Currently and in parallel, approx. 600 Nm^3/h of raw gas is conditioned to natural gas quality (> 98 % methane) with a Swedish pressurised water wash and odorised. Furthermore, an extension of the plant (800 Nm^3/h) is under construction. The conditioned biogas is used for the operation of a biogas filling station on the plant grounds, a biogas filling station at a bus station 3 km away and for heating and cooking gas for a community 1.5 km from the plant.

The production costs for the conditioned biogas, including all fixed and operating costs are given as 0,65 €/Nm^3 by the operator. An investigation concluded that methane loss during conditioning to be 2 %. The plant has been operated very satisfactorily and mostly without interruption since 2003 according to the operator.

Conditioning plant in Norrköping

The conditioning plant in Norrköping is operated by the energy supplier Sydkraft. After the expansion of the natural gas grid, it should support the gas requirements. The biogas here is produced from the decomposition of waste water sludge from the waste water treatment plant for the 105,000 inhabitants. It was used in BTTP before the installation of the gas conditioning plant in 2004. The heating of the fermenter is realised with district heating. Approximately 250 m^3/h raw gas is conditioned with a pressurised water wash. According to the manufacturer, the wash is carried out using waste water from the waste water treatment plant and consumes approx. 0,5 kWh per cubic meter of conditioned biogas ((Rune Simonsson, Malmbergs Water AB). A special feature of this plant is that it was most pre-assembled as a complete compact module (except for the wash column), transported to the operation site and in operation 3 weeks after delivery. The gas produced with about 97 % methane content is used for a filling station on site and for a filling station at a bus depot approximately 4 km away.

Biogas plant Kristianstadt-Karpalund

The biogas plant in Kristianstadt-Karpalund has been producing biogas since 1998 from industrial organic waste (slaughterhouse waste, community biowaste, vegetable processing waste, fat separation waste, potato industry waste etc.). This produces a very high raw gas quality of up to 80 % methane. This raw gas is mostly used in a district heating production plant about 4 km away. Surplus gas, together with waste gas from the community waste water treatment plant has been used since 1999 as vehicle fuel in a plant for the conditioning of up to175 m^3/h raw gas using pressurised water wash. The purified gas is sold at a filling station on the plant site and at filling station of the community bus company.

Biogas plant Helsingborg-Filborna

Since 1996 a pressure swing adsorption plant for gas conditioning has been operated at the biogas plant in Helsingborg-Filborna; first as a pilot plant 5 Nm^3/h and since 2003 on a large scale. The biogas is produced exclusively from industrial wastes (potato industry, slaughter waste, fats etc.). The resultant biogas has a methane content of nearly 80 %. The biogas is partially conditioned (350 Nm^3/h raw gas) in a pressure swing adsorption plant to about 98 % methane content. An even greater part of the raw gas is used together with the available landfill gas in a combined biogas and steam turbine (0,8 MW_{el}, 1,5 MW_{th}), two BTTPs (1,2 MW_{el}, 1,6 MW_{th}) and a boiler (4 MW_{th}) to produce power and district heating. The conditioned gas is offered at a biogas filling station next to the waste recycling plant for 20 collection vehicles, 4 trucks and about 70 cars. The surplus amount of the conditioned gas, after odorisation and the addition of approx. 6 % liquid gas is then fed into the medium pressure natural gas grid, primarily at night. If the biogas is not sufficient for the filling of the vehicles, there is the possibility of directing the natural gas to the pressurisation and then to the tanking station. The gas feed-in is operated by the energy supplier Sydkraft which is responsible for gas supply in the region.

In summary, the Swedish plants for the conditioning and feed-in of biogas have been evaluated by the operators as very reliable. The operation of the plants is generally fully automatic, so that personnel is only required for monitoring procedures. The quality of the conditioned gas does not generally fluctuate. There have been no reports by the operators of any forced shutdowns due to insufficient gas quality. The only sources of problems have been components in older plants that were not made of high quality stainless steel that did not have appropriate corrosion resistant coatings. Furthermore, the admixture of liquid gas during the feed-in of the conditioned biogas into the natural gas grid in Helsingborg-Filborna, shows a slight increase or decrease in the heat and Wobbe value for approximately 5 minutes during the switch-on, turn-off procedure. An improvement of this situation is being worked on. Finally, it has been shown that the modular production of conditioning plants in small series in Sweden for the conditioning of biogas to natural gas quality is state of the art technology.

6.4 Switzerland

In Switzerland, experience with the conditioning of biogas has been gathered over approx. 10 year. Biogas plants are used primarily for the utilisation of separately collected house biowaste, greenery and food waste. The advantage of these plants, in comparison to liquid manure plants rests in the minimal hydrogen sulphide content in the biogas. Other advantages of the Swiss concept are the complete utilisation of end products of the utilisation plants. The substrate passes through the reactor after about 15 days and the liquid part is separated from the solids. The result is compost and liquid fertiliser. The biogas formed is either used for power generation or conditioned to natural gas quality. In the case of power generation, acceptance by the BTTP must be assured.

There are 6 plants that condition biogas (four biogas plants that use biomass and two waste water treatment plants). Two of the biogas plants feed the conditioned gas into the public gas grid. There are 14 „natural gas filling stations“ that use biogas as motor vehicle fuel, out of a total number of 57 natural gas filling stations. Billing is based on an input-output balance sheet. Here the input is the fed-in gas volume and the output is what is delivered by the filling stations over a certain period of time.
The success of the concept can be traced to the good cooperation between the plant operators, plant manufacturers and gas suppliers. Clear conditions are negotiated for contractual agreements that make the feed-in of biogas financially viable for all parties.

Biogas plants Otelfingen
At the biogas plant in Otelfingen, 10,000 t of greenery (similar to the bio-waste containers), as well as food waste is recycled. A horizontal fermenter with a retention time of approx. 15 days is used to produce approx 5,000 to 6.000 m^3 of biogas daily. A pressure swing adsorption plant with a capacity of 50 m^3/h, conditions part of the biogas for the operation of a gas filling station. Since this location cannot sell the entire biogas production as fuel, part of the biogas production is used for power generation in two BTTP plants with an electrical output of 190 kW$_{el}$ bzw. 90 kW$_{el}$ without gas conditioning.

7. Summary

Biogas as a renewable energy source is current used primarily for decentralised energy production. In order to make use of this energy for heat production on a larger scale, the feed-in of the biogas into the public grid of the gas suppliers is necessary.

Biogas has a different chemical composition and differs from natural gas in its lower methane content (approx. 60 %) and lower fuel value (approx. 6,6 kWh/m3). Furthermore, biogas contains so-called „gas impurities“ that can cause damage to the gas grid and the consumer. Biogas conditioning therefore also includes the cleaning and methane enrichment of the biogas. The impure raw biogas with a low fuel value is converted into a purified product gas with, if its methane-enriched, a higher fuel value.

Depending on whether the biogas is to be used as admixture gas (mixing with natural gas) or as exchange gas (substitution of natural gas) fed into the gas grid, the biogas must either be cleaned (admixture gas) or also enriched (exchange gas). Mixed types, partially methane-enriched, are also possible. This is then referred to as enriched admixture gas.

Currently, the most frequently encountered conditioning plants in Europe are those using pressurised water wash, followed by PSA technology and membrane technology. One plant is in operation that conditions biogas with low pressure membrane technology. Up to now 5 enrichment plants using gas permeation technology have been constructed in Europe. This technology, due to its residue-free operation (there are no consumables necessary, such as active charcoal in PSA or water in pressurised water wash) is certainly of interest in it application in the biogas field. Gas separation using cryogenics is promising with regard to purity of individual gas components. Due to the complex plant technology and operating costs, however, no such plants have been constructed for practical operation.
The illustrated process and its costs are to be viewed as guidelines.

Process specific characteristics such as the cleaning output with regard to raw biogas and product gas must be investigated individually for each case. A general recommendation as to which cleaning and enrichment process is the most economical and which yields the best technical results cannot be given. The selection of the technology and cost optimisation can only take place in the course of detailled plant project planning.

Natural gas is transported and distributed in the pipeline grid. These grids are categorised according to their nominal pressure into high pressure grids (> 1 bar), medium pressure grids (100 mbar to 1 bar) and low pressure grids (23 mbar).

The feed-in of conditioned biogas into low pressure grids is mostly impractical. The decisive factor is the different volumes of gas consumption between summer and winter. The feed-in of small amounts of 30 m3/h can be possible if an appropriate grid and customer structure exists (special contract customers). These are however individual case decisions and cannot be appraised generally. For these cases, there must generally be proof of feed-in possibilities through a grid calculation with the gas supply company. In any case, the feed-in into a low pressure grid must correspond to the grid gas quality. In particular the feed-in into a heavily intermeshed grid is not assured due to the various mixtures and a constant gas quality cannot be guaranteed due to the greatly deviating quality of the biogas.

Significantly better is the situation for feed-in into medium pressure and high pressure grids. With this type of feed-in there are no pressure problems; the feed-in quantity is distributed and then delivered to the customers. These grids, in particular those of the gas transport companies, also have the advantage that the biogas conditioning plants do not have to be in the immediate vicinity of the consumer. This allows biogas conditioning plants in rural areas with the appropriate grid connection to produce and feed in large quantities of gas.

Direct feed-in depends on the feed-in point and the actual grid and consumer structure. Due to the pipeline density, feed-in points into the medium pressure system are to be preferred.

8. Biogas feed-in options in the target countries

8.1 Bulgaria

8.1.1 Natural gas grids in Bulgaria

Bulgartransgaz is the only gas transmission operator for the territory of Bulgaria. Bulgartransgaz is member of Gas Infrastructure Europe (GIE).

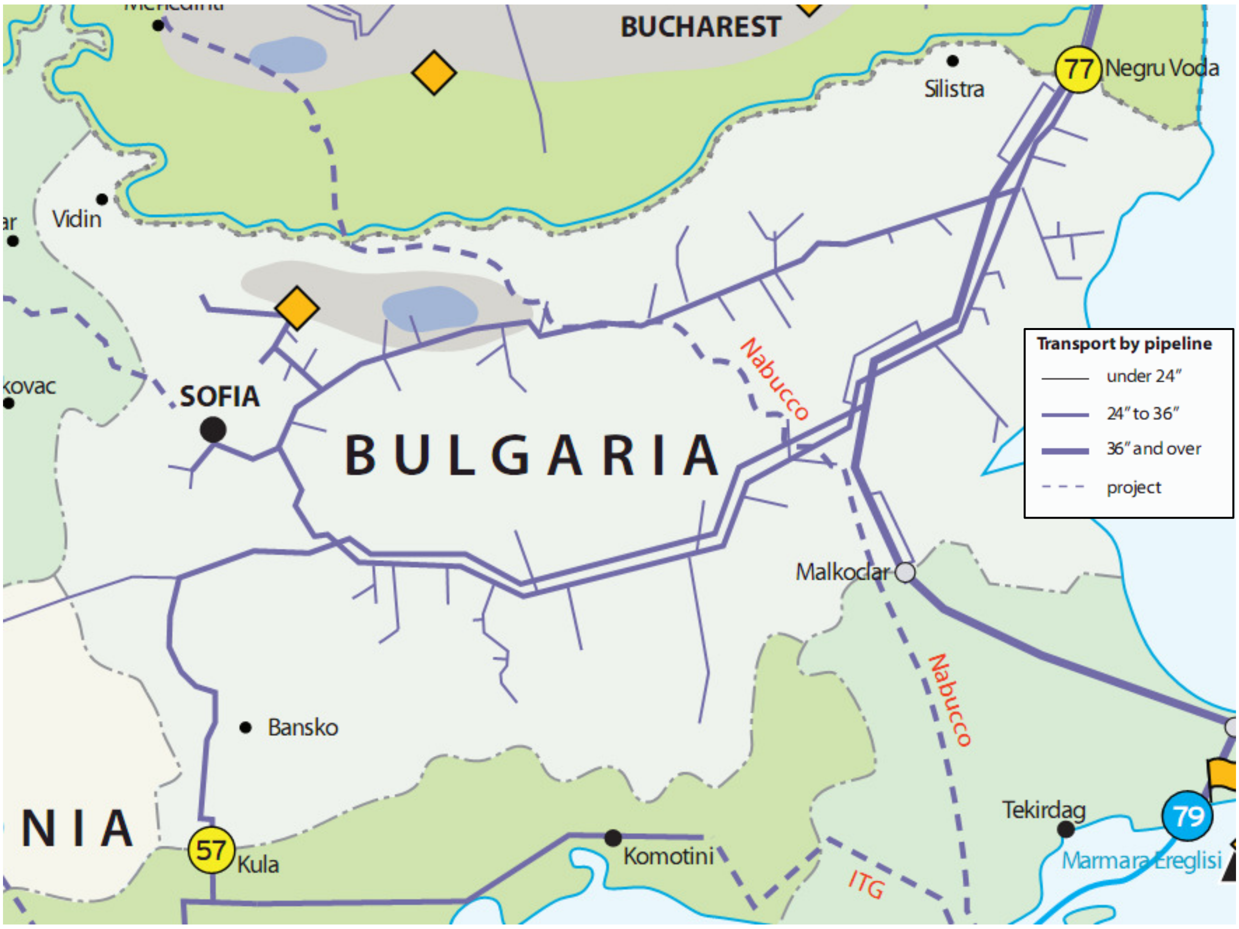


Illustration 13: Bulgarian gas network; Source: ENPRO

The biggest privetly owned gas company in Bulgatia is Overgas Inc. The company provides construction and operation of gas distribution networks and sale of natural gas to end customers. Overgas has major part in 28 companies. From 96 licenses for distribution and delivery of natural gas for the country, subsidiary companies of Overgas have 56 licenses in 50 municipalities. The total lenght of the gas distribution network is over 1.600 km

8.1.2 Characteristics of natural gas grids

The indexes for quality of natural gas in Bulgaria, according to Bulgarian State Standard, are harmonized with ISO 6976.

Index	Technical requirement
1. Composition of natural gas: - methane - ethane - propane, butane and others heavy hydrocarbons - nitrogen - carbon dioxide - oxygen - hydrogen sulphide - mercaptan sulphur - total sulphur - water and other dissolved solids	 min 92 mol % max 4 mol % max 2 mol % max 2 mol % max 1 mol % max 0,02 mol % max 2,0 mg/m^3 max 5,6 mg/m^3 max 20 mg/m^3 not allowed
2. Temperature of the gas in the outlet of the gas regulation station	> - 5˚ C (268˚ K)
3. Down limit of the calorific value (*when temperature is 20˚ C and pressure is min 0,101325 MPa*)	not less than 8000 +/- 100kcal/m^3 (33,5 ± 0,418) MJ/m^3
4. Pressure	4.1 *for the natural gas transmission grid* – up to 5,5 MPa; 4.2 *for the natural gas distribution grid* – up to 1,6 MPa, in this number for: - steel pipes – up to 1,6 MPa; - PE HD pipes – to 1,0 MPa - at the inlet of industrial consumer grid – according to the contract circumstances; - for private premises – 0,01-0,013 MPa
5. Odor of the natural gas (odor detection threshold)	Odor detection threshold – the natural gas assure perception, when its quantity in the air is ≤ 20 % from the down limit of flash point

Table 19: Indexes for quality of natural gas in Bulgaria (harmonized with ISO 6976)
Source: ENPRO

8.1.3 Technical requirements for biomethane injection into the natural gas grid

Technical requirements to the natural gas grid and equipment are given in the following regulations:

- Regulation No 6 of 25 November 2005 about technical rules and standards for design, construction and usage of objects and equipment for transmission, storage, distribution and supply of natural gas
- Regulation for structure and operation of transmission and distribution gas pipelines and of natural gas equipment, installations and appliances (ordinance No 171, 16 July 2004)

Specific requirements for biomethane injection into the grid are not given.

8.1.4 Opportunities for biomethane injection

The law of energy governs the public relationships related to the activities of generation, import and export, transmission, transit transmission, distribution of electric and heat energy and natural gas, trade with electric and heat energy and natural gas, and use of renewable energy resources, as well as the authorities of state bodies in defining of the energy policy, regulation and control functions. According to Article 197 (1) “The transmission company shall be obliged to connect to its network at an interconnection point of its choice, the distribution companies, extraction companies, companies for gas storage.”

The ***conditions and procedure*** for gas production enterprises access to the natural gas transmission/distribution networks are regulated by “Rules for conditions for access to the natural gas transmission and/or gas distribution" networks”, promulgated SG No 67 of 2 August 2004. According to article 5 (1) “gas transmission and gas distribution company could not refuse access to the gas transmission/ distribution networks”.

Currently, biogas injection in Bulgaria is not discussed.

8.2 Croatia

8.2.1 Natural gas grids in Croatia

There are 2 grid levels recognised in Croatia: transportation (high pressure 50 to 70 bar) and distribution (middle pressure 1 to 4 bar and low pressure < 1 bar). The transportation gas system (existing and planned) are shown in the figure below.

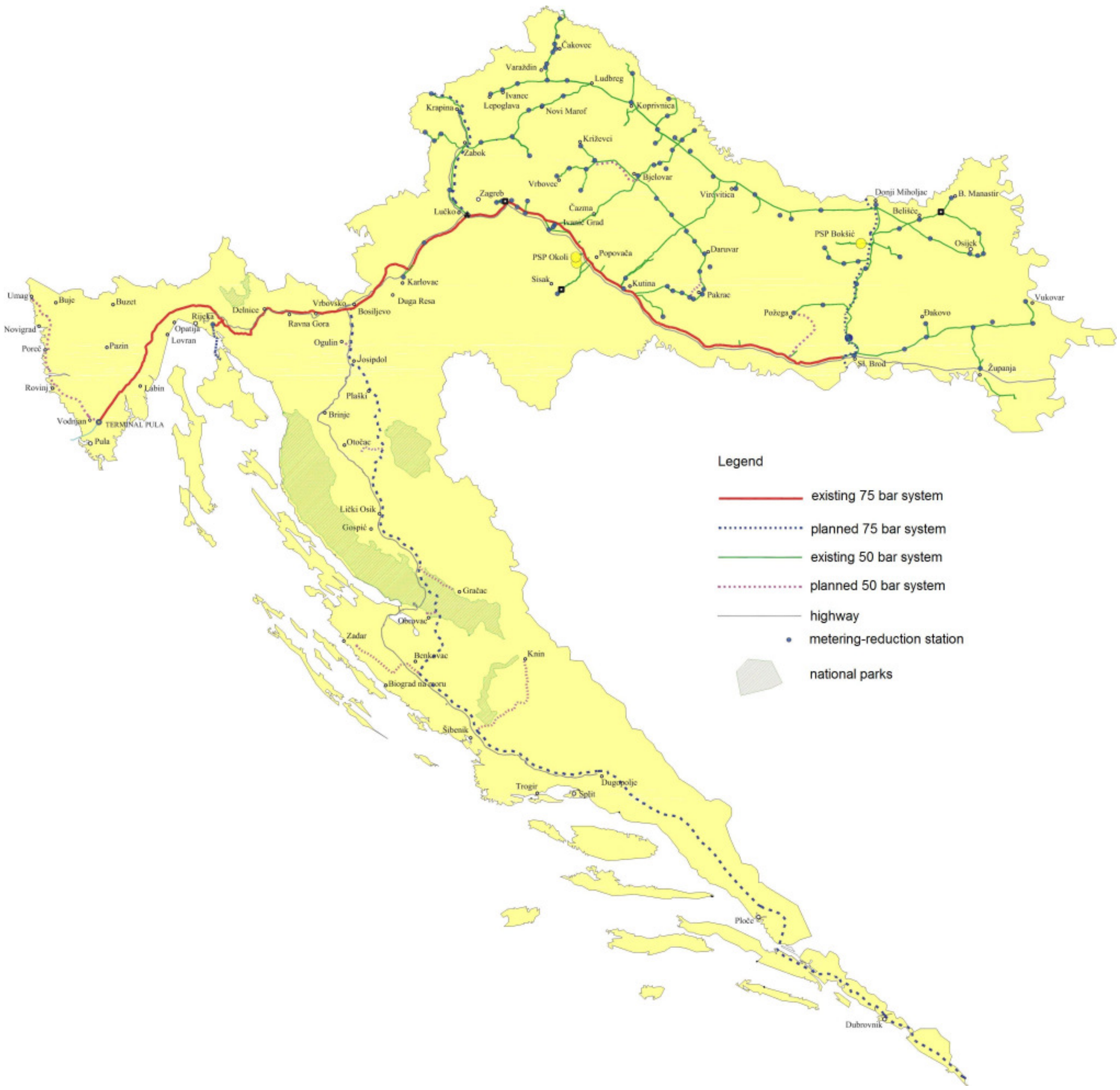


Illustration 14: Croatian gas transportation system; Source: EIHP

Natural gas transportation is the primary activity of the company PLINACRO Ltd., which is the owner and operator of the gas transmission system. PLINACRO is fully owned by the Republic of Croatia.
In 2006, 3.097 billion m^3 of natural gas have been transported, of which 2.680 billion m^3 from entry to exit measuring-reduction stations, and 417 million m^3 to underground storage Okoli. During peak demand approximately 530.000 m^3/h were transported, while the maximum quantities of 630.000 m^3/h have been delivered to customers.

The natural gas transmission system comprise 2,034 km of pipelines, 142 exit measuring-reduction stations with 210 measuring lines and 19 entry measuring stations. The whole system provides gas for 14 out of 21 counties including the City of Zagreb.

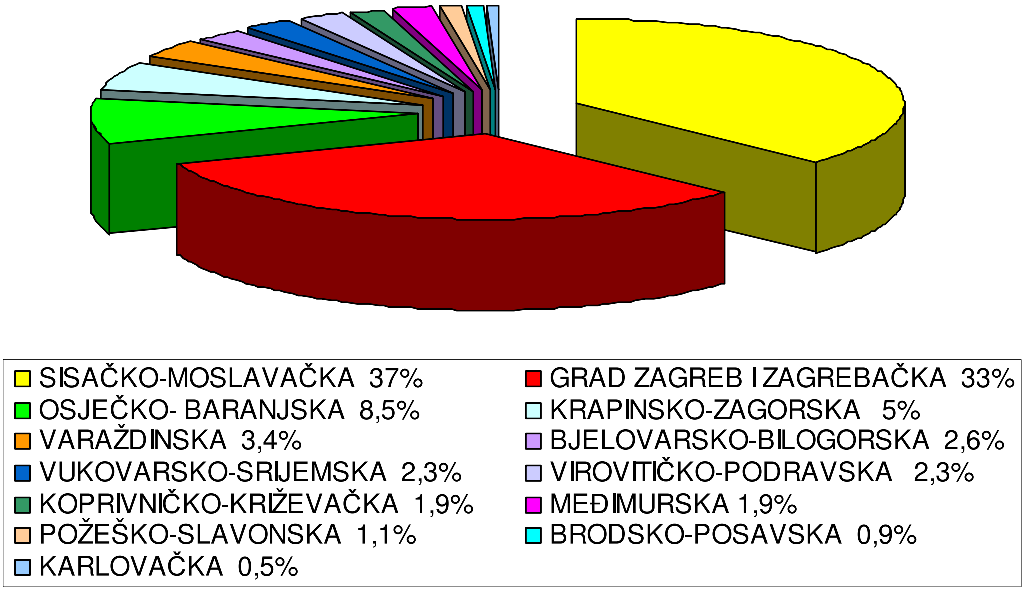


Illustration 15: Structure of transported natural gas quantities per Counties (NUTS2 level) in Croatia Source: EIHP

DN (mm)	L (km)
700	53
600	175
500	566
450	95
400	80
350	62
300	365
250	76
200	120
150	337
< 150	105
Total	**2.034**

Table 20: Profiles and lengths of transport gas pipelines in Croatia (2006), Source: EIHP

Transportation gas pipelines	length (km)
International	35
Main transmission lines	1.125
Regional	645
Local linking lines	229
Total	**2.034**

Table 21: Categorisation of transport gas pipelines in Croatia; Source: EIHP

Regarding distribution level, there are 36 natural gas distribution companies in the Republic of Croatia, and the total gas pipeline length amounts to 15.980 km. In addition, two companies distribute city gas and LPG/air mixture, with the total network length amounting to 239 kilometres. Thus, the total distribution network in Croatia is 16.219 km long.

8.2.2 Characteristics of natural gas grids

In Croatia there are three different levels of natural gas grids.

Low pressure grid:
Max. utilization pressure < 1 bar

Medium pressure grid:
Max. utilization pressure 4 bar
Min. utilization pressure 1 bar

High pressure grid:
Max. utilization pressure 70 bar
Min. utilization pressure 50 bar

8.2.3 Technical requirements for biomethane injection into the natural gas grid

In order to be distributed via natural gas grid, biogas has to have the same characteristics of natural gas. The Ordinance on Biofuels (OG 141/05) describes quality characteristic of biogas as well as the methods for determination of those characteristics as:

Characteristic	Method	Unit	Limit values	
			Min	Max
Relative density	HRN EN ISO 6976	-	0,55	0,70
Calorific value*	HRN EN ISO 6976	MJ/m^3	30,2	47,2
Wobb index	HRN EN ISO 6976	MJ/m^3	46,1	56,6
Particles	-	-	Technically clean	

* at temperature of 288,15 K and pressure of 101.325 kPa

Table 22: Biogas characteristics in Croatia, Source: EIHP

However, this Ordinance describes biogas in the sense of Biofuels Directive which refers to fuels for motor vehicles. There are no data for Croatia for the technical criteria to biomethane injection.

8.2.4 Opportunities for biomethane injection

Biogas is recognised in Law on Gas Market (OG 40/07) which refers to biogas in the Article 1, paragraph 2 as:
(2) The rules determined by this Law and corresponding regulations are applicable on biogas, gas from biomass and other types of gas if it is possible both technically and safe transport through the gas system of the gases in question.

Up to the time of writing this report (May 2008) there are no corresponding regulations that describe biogas implementation in gas market as gas transport, distribution, storage, supply, supply of tariff customers, LNG terminal management are regulated energy activities while gas production, supply and sales of natural gas from own production, supply of eligible customers, mediation on gas market, representation on gas market are market activities.

8.3 Greece

8.3.1 Natural gas grids in Greece

The introduction of natural gas into the Greek Energy System can by compared in magnitude with the electrification of the country. Natural gas is an effective and modern form of energy, environmental friendly and safe. The implementation of this major energy project was undertalen by the Public Gas Corporation of Greece (DEPA) S.A. The Greek gas sector is still in the early stages of development and the Greek State is the key player of the market through direct or indirect ownership of the key-palyers.

Today, there are three entry points for the natural gas transportation system, which transports natural gas to consumers in continental Greece:

1. the first is on the Greek-Bulgarian border (Promachonas) where the gas form Russia (through the Ukraine, Moldavia, Romania and Bulgaria) enters Greece via a high pressure pipeline. The natural gas from Russia gas covers 85 % of the import demand for the year 2006 [1].
2. the second is on the Greek-Turkish border (Kipoi) where the Greek System interconnects with the Turkish. This entry point is new, helps the diversity of import sources and is the expantion of the pipeline between Komotini, Alexandroupoli and Kipoi.
3. the third is on the islet of Revythoussa in the Gulf of Pachi near Megara, where is located the terminal for Liquefied Natural Gas (LNG). The LNG from Algeria is transported by special tankers and covers 15 % of the import demand fro the year 2006.

A pipeline connection to Italy, the Italy-Greece Interconnector (IGI), is expected to become operational by the end of 2010 [2]. The interconnector pipeline extends from Komotini to Stavrolimena to Otranto.

According to to Law 3428/2005 the National Natural Gas System (ESFA) comprises of:

- The National Natural Gas System within the Greek borders.
- The LNG receiving terminal on Revithoussa islet.
- Auxiliary installations and infrastructures for the transportation system.

The National Natural Transportation System is comprised of [3,4,5]:

- The central gas transportation pipeline (599 km) which extends from Promachonas to Attica and from Thessaloniki to Kipoi.
- Transoportation branches (566 km) linking the various regions of the country (Eastern Macedonia and Thrace, Thrssloniki, Platy in Imathia, Volos, Viotia, Inofyta, Attica). With the completion of the Korinthos project by the autumn of 2007 the transmission branches will extend 600 km. In 2007 branches towards Western Thessaly and Evia have begun (119 km).
- The natural Gas Metering and Regulating Stations.
- The Gas Control and Dispatching Center.
- The Operation and Maintenance Centers (in Attica, Thessaloniki, Thessaly and Xanthi).

The main Infrastructure works (apart form the city networks) began in July 1992 and were completed in August 2000, while the terminal on the islet of Revythoussa has been in operation since February 2000.The system has been supplied with Russian natural gas since September 1996 and with Algerian since the first quarter of 2000 [6].

The main gas company in Greece is DEPA which is currently the only importer of gas. The framework of the gas market liberalization (Law 3428/05) allows to other companies to have access to the high pressure pipeline in order to engage commercial activities or to have access to foreign suppliers. At the end of 2005 DEPA proceeded with a legal separation of its activities. A company under the name “National Natural Gas System Operator SA (DESFA S.A.)” was established and undertook the operation, management, exploitation and development of the National Natural Transportation System in Greece.

The Gas Supply Companies (EPAs) has undertaken the mission to distribute gas to concumers with unnual consumption up to 100 GWh Gross Calorific Value and operate, maintain and expand the “city networks”. According to DEPA’s estimation until 2010 the city networks (low pressure networks) will reach of 7.000 km [1].

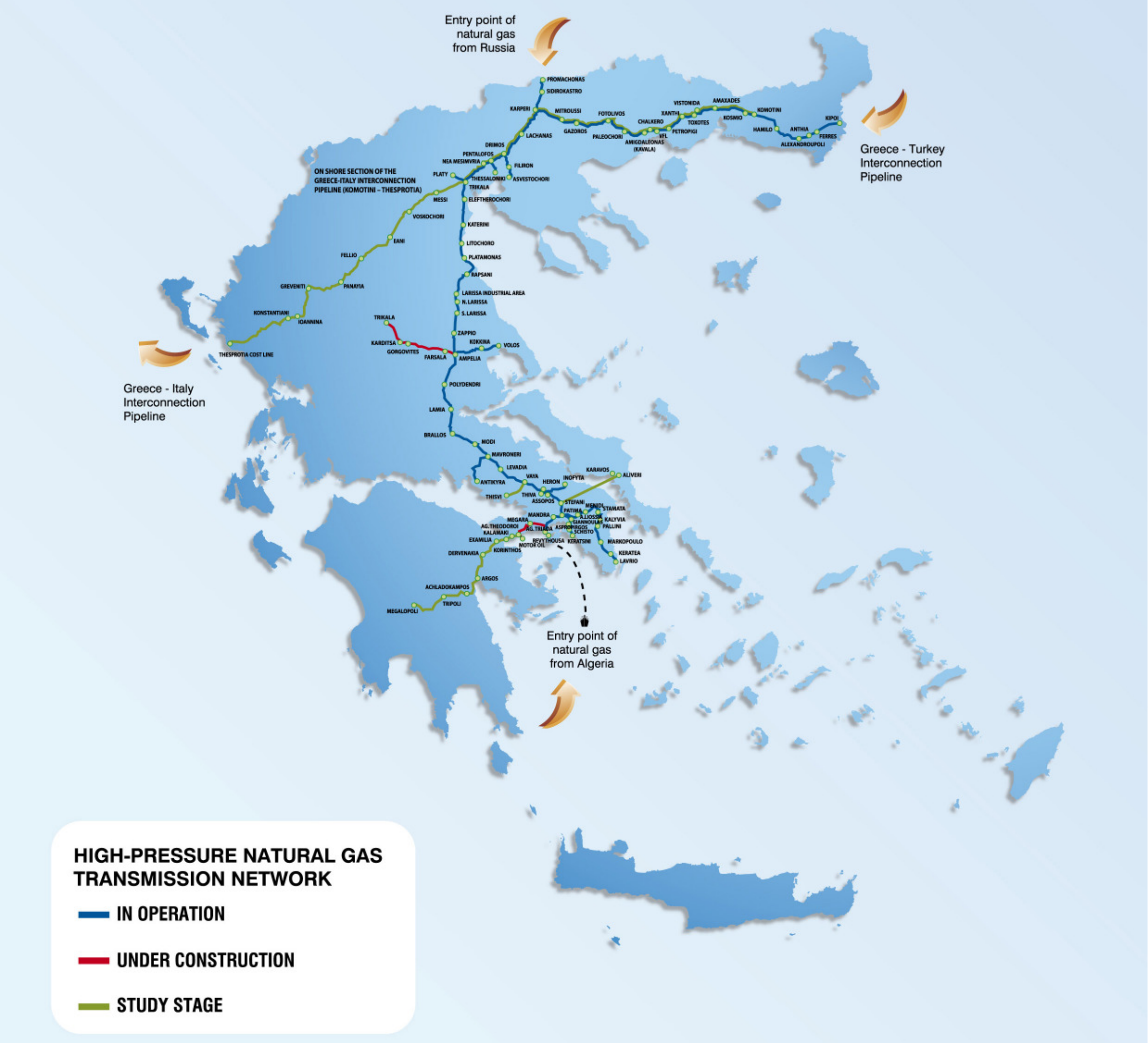


Illustration 16: The Greek Natural Gas System; Source: DESFA, 2008

8.3.2 Characteristics of natural gas grids

Natural Gas enters Greece via high pressure pipelines. Their cource continues through medium pressure networks (19 bar) that deliver gas to industrial consumers, but also through low pressure networks (4 bar) that provide door-to-door gas to domestic, commercial and industrial consumers.

The pipeline that crosses the Greek-Bulgarian border has a diameter of 28 inch and then connects to the Greek North-South central pipeline (Greek-Bulgarian border to Attica) which is a high-pressure pipeline (70 bar) with a diameter of 28 inch too [1]. The 87 km long between Komotini, Alexandroupoli and kipoi and the transoportation branches linking the various regions of the country consist of high pressure pipelines.

Medium pressure networks have been developed and are still being developed in Attica, Thessaloniki, Larissa, Volos, Inofyta, Thiva, the greater of Halkida, Lamia, Platy in Imathia, Kilkis, Serres, Drama, Xanthi, Kavala. Alexandroupoli and Komotini. Low pressure networks have been developed and are still being installed in Attica, Thessaloniki, Larissa, Volos, Inofyta, Kilkis, Xanthi and Komotini. Medium and low pressure networks are expanding in areas like Central Greece and Evia, Eastern Macedonia and Thrace and Central Macedonia by the EPAs [3].

8.3.3 Technical requirements for biomethane injection into the natural gas grid

Natural Gas is a mixture of hydrocarbons in a gaseous form. It mainly consists of methane (CH_4), belonging to the 2nd Cluster of gas fuels. Regarding natural gases, a reference state has been defined, named «normal» state and to that state their quantities are reduced. This state is 273,15 K (0°C) as to temperature and 1,01325 bar as to pressure.

The Ministerial Decision (Y.A.) Δ1/1227/2007 "On the determination of the procedure for the conclusion, content and terms of agreements for the exercise of the right to access and for the use of the National Natural Gas System" (Officail Gazette 135/B/5.02.2007)" determines the content, the terms, and the procedure for the conclusion of Agreements for the Transfer of Natural Gas concluded for the exercise of the right to access and use the National Natural Gas System (Ε.Σ.Φ.Α. in greek) and in particular the part of the National Natural Gas System that constitutes the National System for the Transfer of Natural Gas (Ε.Σ.Μ.Φ.Α. in greek).

Index	**Technical requirement**	
	Min.	**Max.**
1. Wobbe-Index	46,80 MJ/Nm^3	58,46 MJ/Nm^3
2. Gross Calorific Value (GCV)	36,45 MJ/Nm^3	48,97 MJ/Nm^3
3. Relative demsity	0,56	0,71
4. Composition of natural gas:		
a. Methane (CH_4) content	75 mol-%	-
b. Carbon dioxide (CO_2) content	-	3 mol-%
c. Nitrogen (N_2) content	-	6 mol-%
d. Oxygen (O_2) content	-	0,2 mo-l%
e. Hydrogen sulphide (H_2S)	-	5,4 mg/Nm^3
f. Total sulphur	-	80 mg/Nm^3
5. Water Dew point (H_2O DP) at 80 bar		+5°C
6. Hydrocarbon Dew Point (HC DP) at 80 bar		+3°C
7. Dust & liquids	free	
8. Odor of the natural gas	Free (entry points). It is added before gas supply according to ASAE code when it deemed neccessary	

Table 23: Quality of natural gas grid in Greece (Reference conditions: 0°C; 1,01325 bar)
Source: Ministerial Dicision Δ1/1227/2007 - ANNEX 5

8.3.4 Opportunities for biomethane injection

According to LAW No. 3428/27.12.2005 "Liberalization of Natural Gas Market" (Officail Gazette 313/A/2005) article 39:

"The use of Natural Gas Systems pursuant to the provisions of this law is also allowed for the transmission of biogas, gas produced from Biomass and other kinds of gases, provided that it is so possible from a technical point of view and the technical specifications are met, after taking into consideration the quality requirements and the chemical features thereof".

References

[1] Ministry of Development (2007). 1st report for the long term Energy Policy in Greece 2008-2020, part 1, Athens August.
[2] IEA (2006), Energy Policies of IEA Countries, Greece 2006 Review
[3] DEPA (2006), Annual Report
[4] DEPA's site, www.depa.gr
[5] DESFA's site, www.desfa.gr
[6] ICAP SA and DELOS Communications SA (2001), The Energy Market in Greece, Athens

8.4 Latvia

8.4.1 Natural gas grids in Latvia

Natural gas supply in Latvia is provided by JSC „Latvijas Gāze“. This company is the only gas transmission operator in Latvia. The shareholders structure of ”Latvijas Gāze” at the end of 2006:

- E. ON. Ruhrgas International AG – 47,23 %
- AAS Gazprom – 34 %
- SIA Itera-Latvija – 16 %
- Other shareholders – 2,77 %

JSC„Latvijas Gāze“ has received an exclusive licence (valid until 10.02.2017) to distribute natural gas in whole territory of Latvia using medium and low-pressure grid with projected pressure up to 1,6 MPa (16 bar). The gas transportation system (existing and planned) is shown in the Figure below.

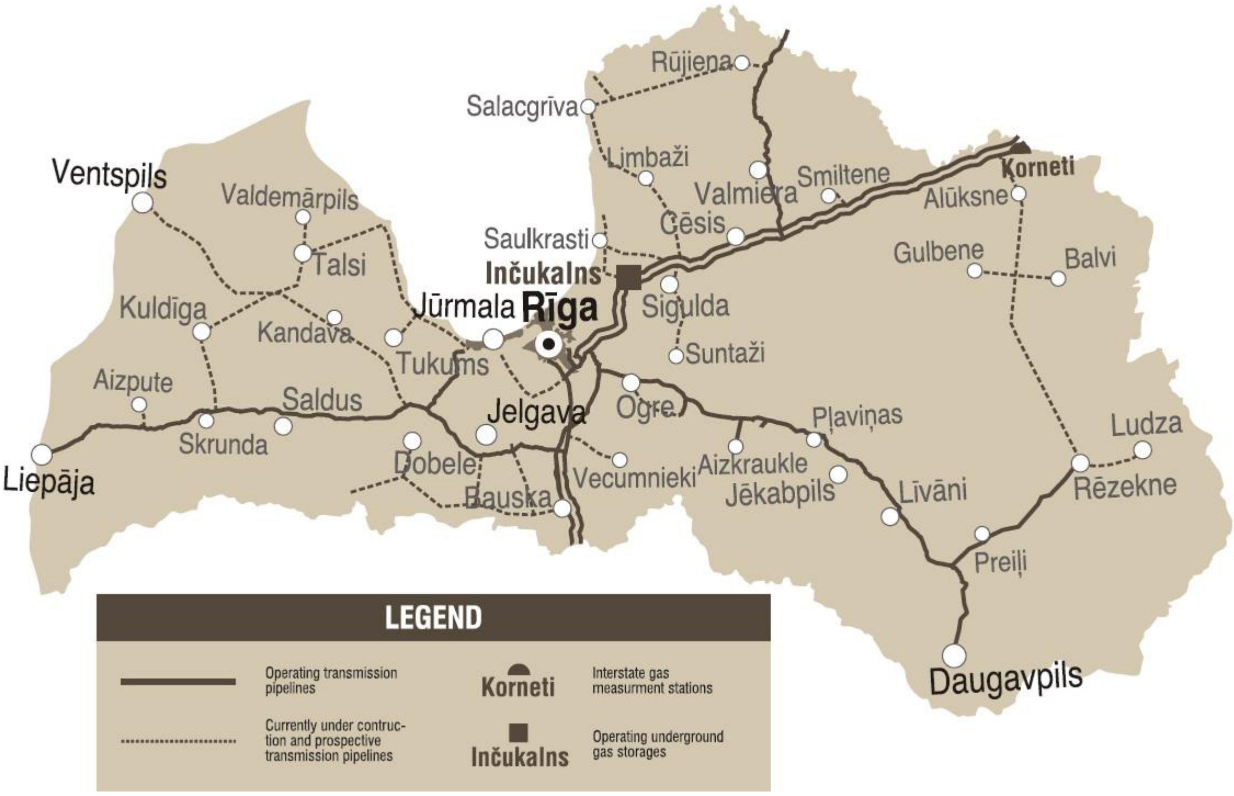


Illustration 17: Latvian gas transportation system; Source: JSC Latvijas Gāze Annual Report 2006

Latvian gas transportation system has connections with three countries – with Russia, Estonia and Lithuania. The whole Baltic gas transportation system is not connected to EU gas transmission network and Russia is the only gas supplier.

Existing Law on Energy of Latvia makes no provision for third party access to natural gas transmission, distribution and storage infrastructure. According to Law on Energy Law implementing provisions, Natural Gas Market in Latvia will be open in 1st January 2010.

8.4.2 Characteristics of natural gas grids

Latvian gas transportation system is specific because gas is supplied from large underground gas storage (UGS) with active volume of 2,2 billion m^3, ensuring 170 % of annual self-consumption, located in Inčukalns. In summer gas from Russia using two parallel gas transmission pipelines is delivered to UGS and in winter gas is taken from the storage avoiding gas import in a period with a highest consumption. In winter maximal gas output from Inčukalns UGS is 24 million m^3/day, where approximately half is provided to Latvia supply and the left – for foreign countries.

Latvian gas transportation system initially was constructed to ensure the gas consumption of 3 billion m^3/year. In 2006, natural gas consumption in Latvia was about 1,75 billion m^3. The total length of the natural gas pipelines on 1st January 2007 reached 5.872,3 km, including the gas transmission pipelines (1.281,06 km) and the gas distribution pipelines (4.591,25 km) – *Source: JSC Latvijas Gāze Annual Report 2006*.

According to the agreement, supplied gas should meet following criteria:

- Net calorific value should not be less than 7.900 kcal/m^3 (in reality it is higher)
- Methane content is between 97 – 98 %

Gas coming from Inčukalns UGS is with moisture content of 0,15 g/m^3 and with pressure of 50 – 55 bar.

8.4.3 Technical requirements for biomethane injection into the natural gas grid

There are no regulations on the technical criteria and experiencies for Latvia for biomethane injection. However, it is almost certain that in order to inject biomethane into the natural gas grid, biogas has to have the same characteristics as natural gas. Physical characteristics of natural gas (please see in the Table below) were prescribed in Cabinet of Ministers Regulation No.23 “Regulation on Gas Supply and Use” (not in force since 17.03.2005). The new Cabinet of Ministers Regulation No.99 “Regulation on Natural Gas Supply and Use” (in force since 16.02.2008) insinuates that natural gas parameters and quality is defined by contracts between gas supplier and gas user.

Characteristic	Unit	Limit value
Net calorific value*	MJ/m^3	31,8
Highest limit of Wobbe index	MJ/m^3	41,2 – 54,5
Hydrogen Sulphide	g/m^3	≤ 0,02
Mercaptan Sulphur	g/m^3	≤ 0,036
Oxygen	%	≤ 1,0
Particles	g/m^3	≤ 0,001

* At temperature of +20° C and pressure of $1{,}01325 \cdot 10^5$ Pa

Table 24: Biogas characteristics – Latvia
Source: Cabinet of Ministers Regulation No.23 “Regulation on Gas Supply and Use”

8.4.4 Opportunities for biomethane injection

According to the EC Gas Directive 2003/55/EC Member States should ensure that biogas are granted non-discriminatory access to the gas system, provided such access is permanently compatible with the relevant technical rules and safety standards. These rules and standards should ensure, that biogas can technically and safely be injected into, and transported through the natural gas system.

There is no legal base for biomethane injection in Latvia. In order to inject biomethane in natural gas grid, it is necessary to amend a Law on Energy in chapter 8 “Gas supply system” ensuring that natural gas transmission operator gives permission for appropriate quality biomethane injection.

With reference to information obtained from JSC “Latvijas Gāze” so far no offers for biomethane injection were received. However, JSC “Latvijas Gāze” is constantly following experiences of other countries on this subject.

8.5 Romania

8.5.1 Natural gas grids in Romania

The total gas consumption in Romania was about 17 billions cubic meters in 2006 and only 30 % have been imported the rest was based on internal production.

From the total consumption 20 % is utilized as raw material and 80 % as fuel. It has to be noted that the import of natural gas (especially from Russian Federation) started in 1979 with almost 2 % from the total consumption increasing up to 29 % in 1996 and more than 32 % in 2003. The prognosis for the 2025 is that 77 % will be imported.

Romania will be more and more dependent on the import of natural gas. One strategic objective for the sustainable development and a constant concern of the Ministry of Economy and Trade is the promotion of a more divers import sources of natural gas. This objective is also a pillar in the sustainable development strategy for Romania till 2025.

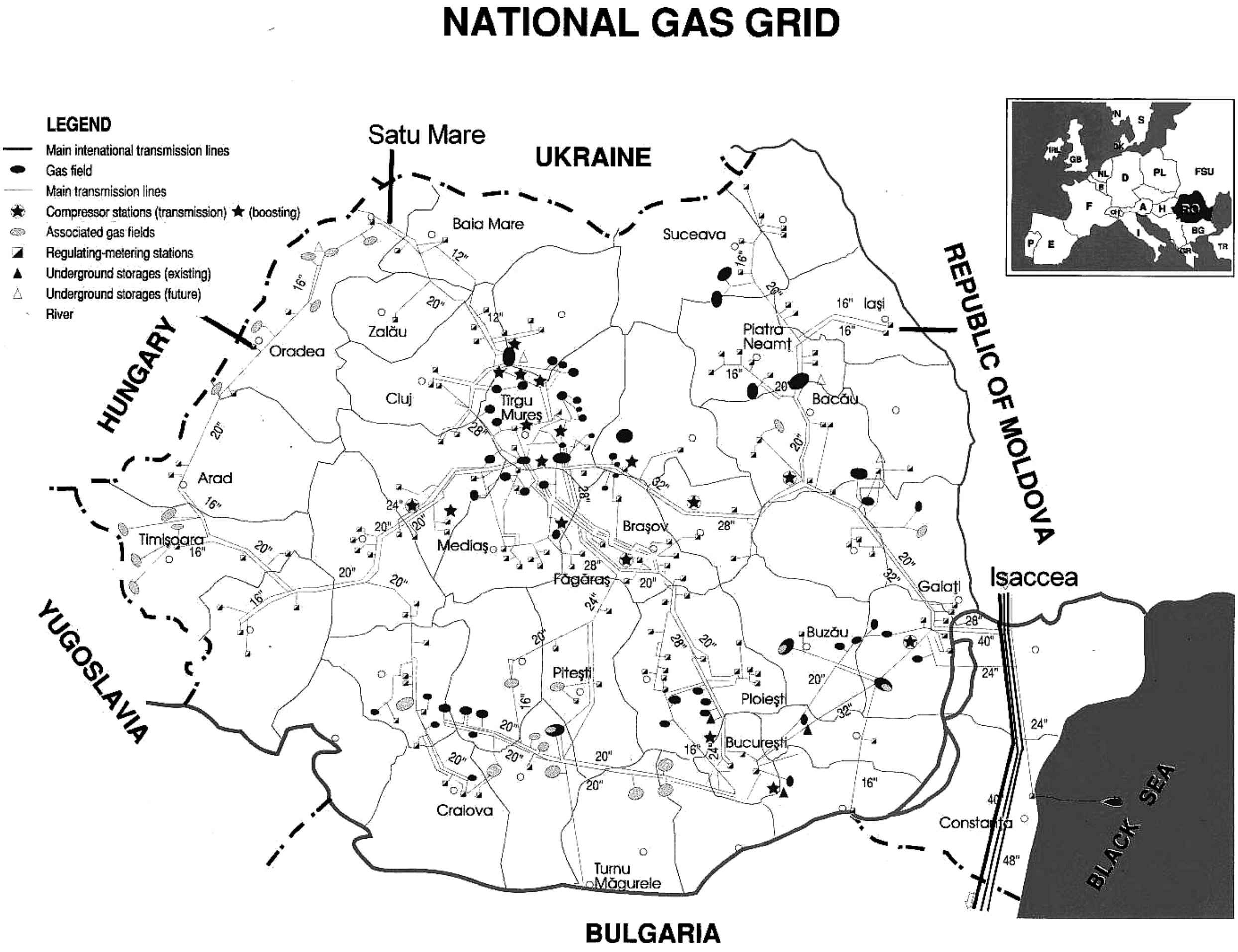


Illustration 18: National gas grid – Romania; Source: Mangus

In 2000 Romania reorganized the stat owed company Romgaz into several smaller companies: Exprogaz and Depogaz with activities in the extraction and respectively in the gas storage, Transgaz with activities in the transport of natural gas on the national territory and Distrigaz Nord and South with distribution to the industrial and household consumers. Later in 2001 Exprogaz and Depogaz merged into Romgaz. Starting with 2005 51 % of the Distrigaz Nord and South were sold for 300 millions Euro each.
In the production sector the Romgaz is dominating with almost 51,99 % followed by Petrom with 46,17 %, Amromco with 1,5 % and Wintershall Mediaş with 0,12 %. (ANRGN report, 2006).

On the distribution market a number of 34 operators works for 2,5 millions clients from 1.700 localities. Distrigaz Nord (47,53 %) and Sud (46,88 %) are the dominant players followed by other companies (Congaz 0,97 %, Petrom distributie 0,84 %).

Imports are mainly directed towards Distrigaz Sud (30,59 %) and Nord (26,76 %). All the imports in Romania are from the Gazprom – Russian Federation.

Romania has also increased the total storage capacity of over 3 billions cubic meters in 8 storage facilities from only 1,3 billions cubic meters in the year 2000.

On short term the import sources are mainly based on the Russian Federation but there are also plans to interconnect the Romanian gas grid with the Hungarian through pipes between Arad and Szeged. With Ucraina linking Cernauti with Siret as a second step. In the same time Romania has as a priority to open a new transport network between Caspian Sea and Meddle East – the Nabucco project.

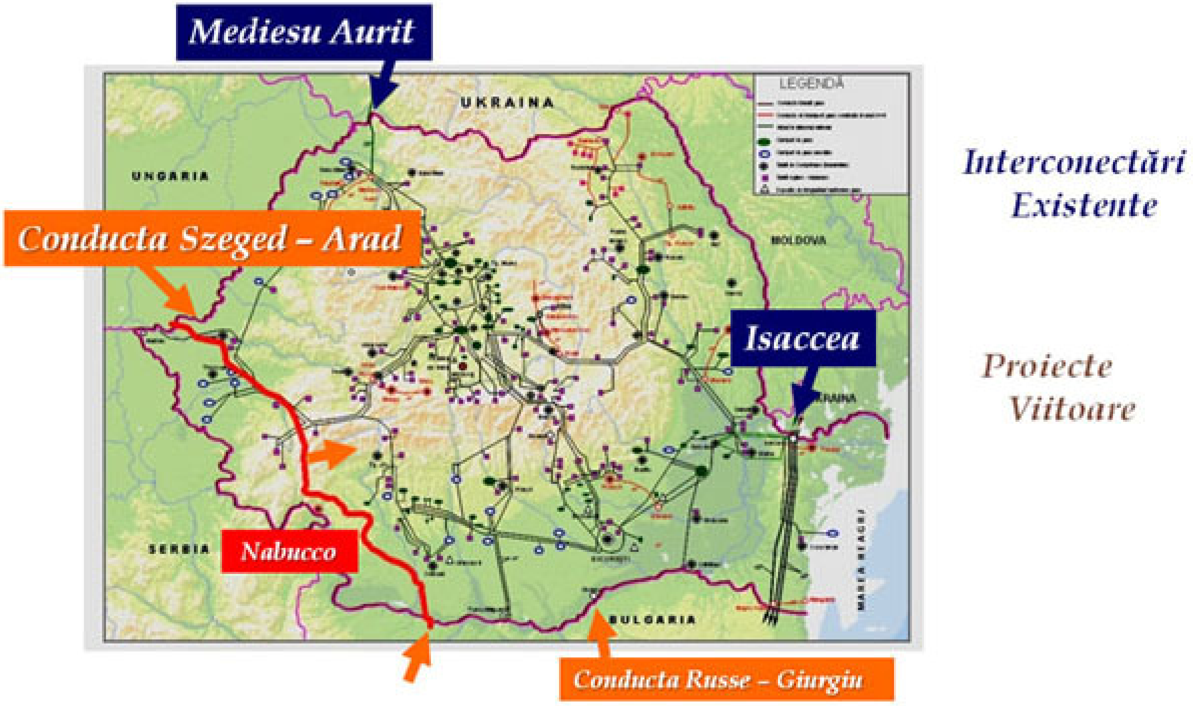


Illustration 19: Interconnections of the national gas grid – Romania; Source: Mangus

8.5.2 Characteristics of natural gas grids

National distribution network has a coverage of about 60 % from the total 3.140 localities only 1.822 having natural gas distribution systems in place at the end of 2006. The network increased during 2000-2006 with more than 665 localities (more than 4.400 km) due to investment effort in this area of about 646 million euro (ANRGN). The natural gas transmission system comprise mainly through Distrigaz North and South 13.830 km of pipelines from the total pipeline length. The total length of the pipelines (without the transportation highways in Romania is approximated at 28.960 km (INSS, 2006).

Year (Development regions)	1990	2000	2002	2006
NORD-EST	741,9	1774,1	2018,4	2525,4
SUD-EST	391,1	1092,7	1197,1	1941,3
SUD-MUNTENIA	1733,4	2894,3	3258,5	4422,9
SUD-VEST OLTENIA	610	1367,6	1554,4	1938,2
VEST	859,4	2164,8	2564	3281,2
NORD-VEST	1392,8	3205,1	3528,6	4212,5
CENTRU	3303,3	6546	6818,3	7748
BUCURESTI - ILFOV	1745,7	2553,3	3128,5	2890,6

Illustration 20: Table of the length of the gas pipeline – selected years (without highways) - Romania Source: Mangus

Natural gas consumption degreased over years from a peak in 1990 as showed in the figure below, up to the values from 2000 (the lowest value 9.193.681 thousands cubic meters). The gas volume increased with a low tendency up to 2005.

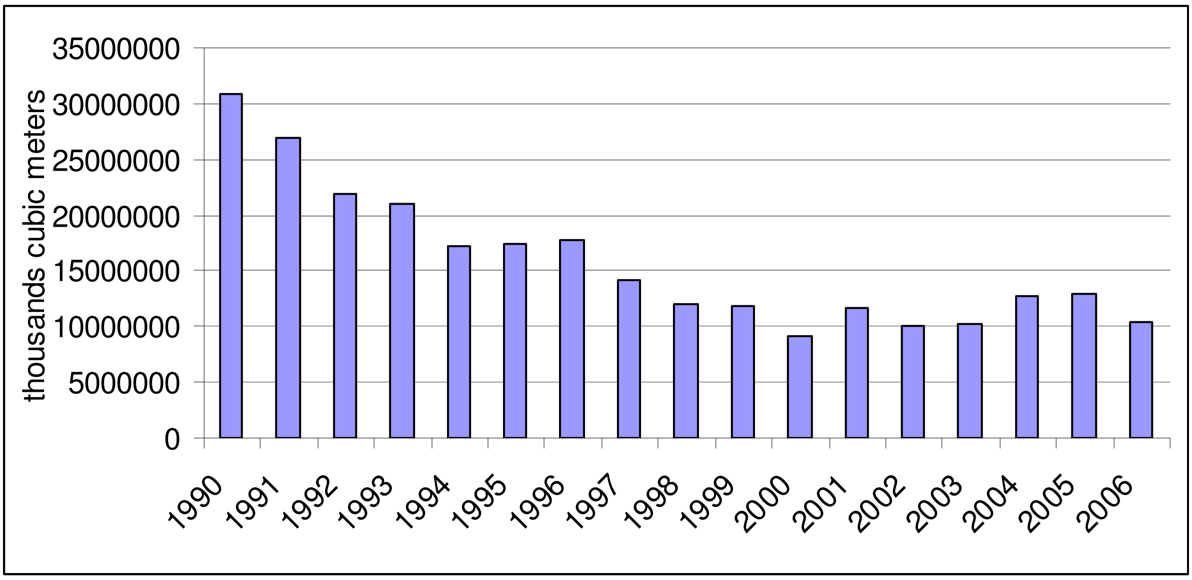


Illustration 21: **Time series of gas consumption (thousands cubic meters) 1990-2006 - Romania**
Source: Mangus

Transportation of gas in Romania is done on the so called transportation highways (pressure over 6 bar) and distribution (middle pressure 6-2 bar and intermediary pressure 2-1 bar and low pressure under 0,05 bar). The network of gas pipelines (existing and planned) are shown in the figure 18 and 19.

8.5.3 Technical requirements for biomethane injection into the natural gas grid

No biogas characteristics are required in order to distribute the biogas to the network. This is because there are no technical criteria for biomethane injection to the grid. In the same time we can assume that biogas, in order to be distributed should have the same characteristics as the natural gas.
The quality of the natural gas is mentioned in the “technical code for natural gas” and in the SR ISO 13686 quality of natural gas. We can speculate that in order to have access to the natural gas grid the biomethane has to fully comply with the standards of the natural gas.

The gas composition requirements for grid injection is reglemented by the “Natural Gas Law”, Law 288/2005 and for the standard by National Regulatory Body for Natural Gases, through “Technical code for the natural gas sector”.
Herein it is stipulated that the minimal technical requirments for grid injection are setted by the national standard SR ISO 13686, pct. 3.6. According to that, the quality of the natural gases is established by a number of tests:

- Caloric power/ Wobbe indice
- Density and compression charactheristics
- Relative density and condense point

The quality is tested by the Authority by random samples. Selling to the grid is conditioned by the proof of regular tests made by the suppliers.

8.6 Slovenia

8.6.1 Natural gas grids in Slovenia

Company Geoplin d.o.o. is a supplier of earth gas in Slovenia. Gas is bought in Russia and Algeria. Geoplin is also in chard of international transport of gas to Slovenia and operates national gas pipeline. Company suppliers almost all distribution companies for gas and industry.
From 1 January, 2005, Geoplin plinovodi d.o.o. operates the Slovenian gas pipeline transmission system as natural gas system operator (www.geoplin-plinovodi.si).

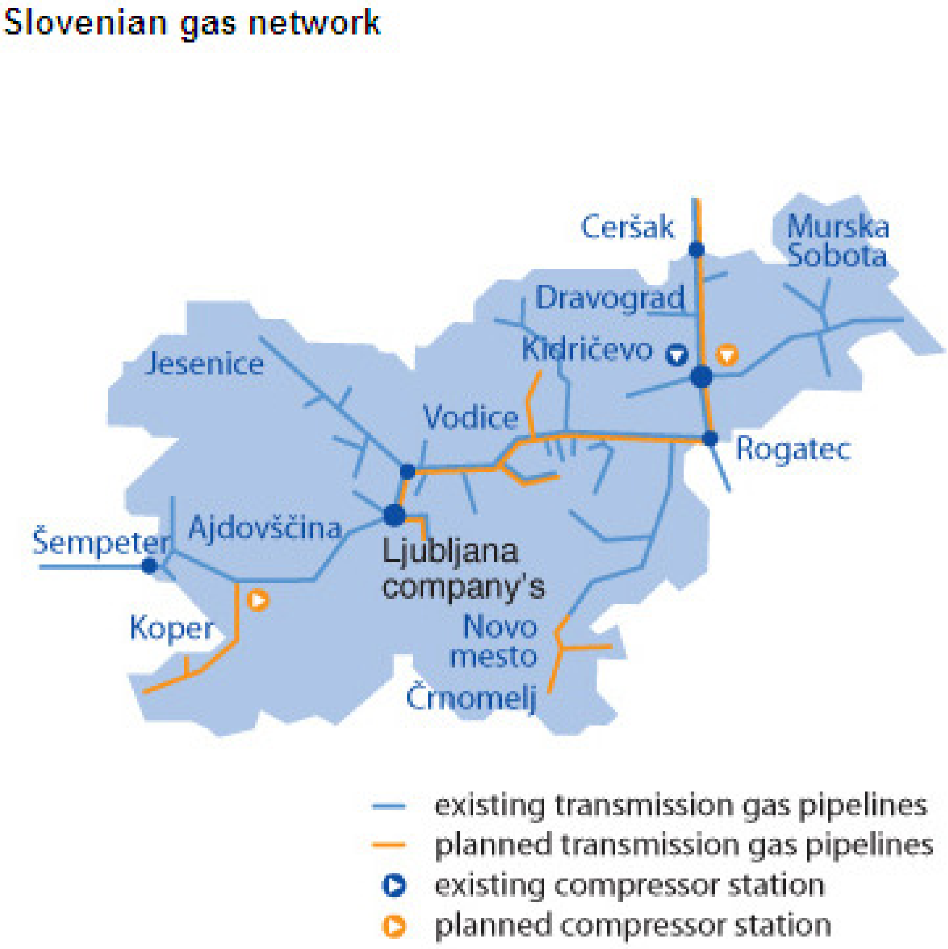


Illustration 22: Slovenian gas network; Source: Geoplin d.o.o.

For local distribution of gas are in charge some public companies in bigger cities (such as Ljubljana, Maribor, Celje and other) and private companies based on issued concession.

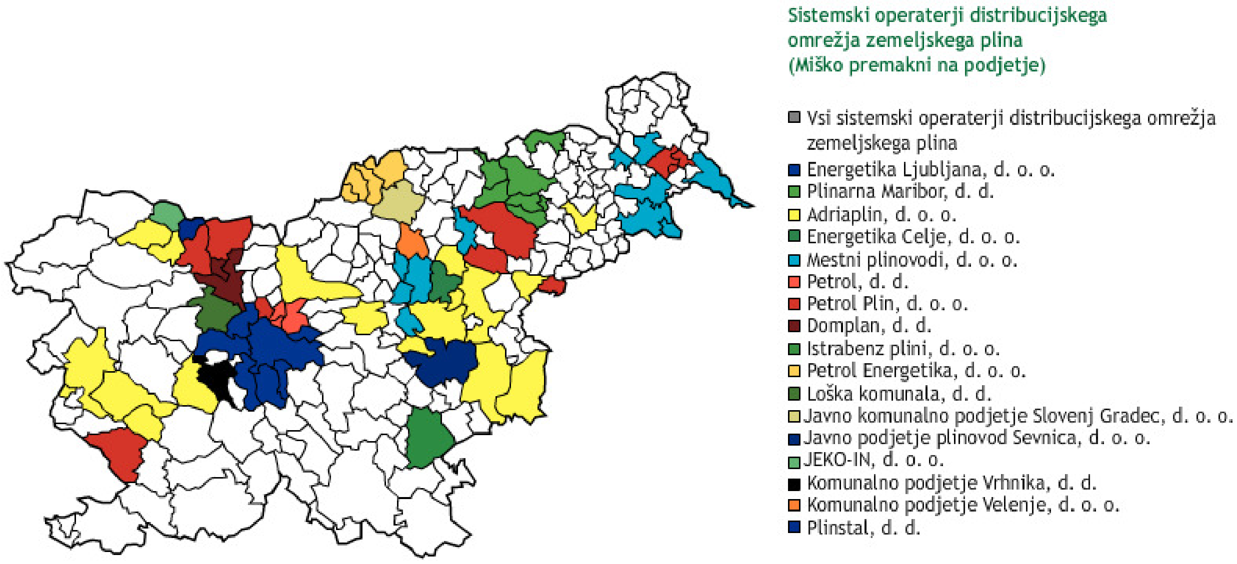


Illustration 23: Slovenian local distribution of natural gas; Source: http://www.giz-dzp.si/?s=zemljevid

8.6.2 Characteristics of natural gas grids

There are three different levels of natural gas pipelines in Slovenia.

Low pressure grid:
Planed pressure 4 bar
Max. utilization pressure 100 mbar
Min. utilization pressure 50 mbar

Medium pressure grid:
Planed pressure 4 bar
Max. utilization pressure 4 bar
Min. utilization pressure 0,5 bar

High pressure grid:
Planed pressure 16 bar
Max. utilization pressure 16 bar
Min. utilization pressure 6 bar
Higher utilization pressure than minimum can be used in calculations of safety-regulation elements only in consensus with system operator.

8.6.3 Technical requirements for biomethane injection into the natural gas grid

Company Geoplin plinovodi operates the Slovenian gas pipeline transmission system as natural gas system operator. Pressure of the gas in transmission pipeline is 3 bar. When biogas plant decides to connect to the pipeline than this plant is treated as natural gas supplier. Plant operator should contact company Geoplin plinovodi if the injection point is in the transmission pipeline. Otherwise it should contact local distribution company, listed above.
Supply of purified biogas is in the location where special station is build for measuring and controlling gas quality and characteristics. If the requirements are not satisfied than the supply is stopped. Since there are no project is Slovenia they have no experiences and also the allocation of the costs should be negotiated and what will be the costs for gas transport.

Characteristic of purified biogas that is supposed to be transported in the existing gas pipeline should meet the following requirements.

Index	Technical requirement	
1. Chemical structure (in mol-%):		
a. methane (C(1))	minimum	89,7 %
b. etan (C(2))	maximum	6,3 %
c. propane, butane and		
d. harder (C(3), C(4), +)	maximum	2,1 %
e. oxygen (O(2))	without	
f. nitrogen (N(2))	maximum	2,1 %
g. carbon dioxide (CO(2))	maximum	1,575 %
2. Sulphur content:		
a. sulphur hidrogen (H(2)S)	maximum	6,3 mg/Sm^3
b. merkaptan sulphur	maximum	15,75 mg/ Sm^3
c. suplphurs total	maximum	105,00 mg/ Sm^3
3. Lower heating value	minimum maximum	33.650 kJ/ Sm^3 (15° C) 36.630 kJ/ Sm^3 (15° C)
4. Dew point:		
a. water	not higher as minus 7° C at pressure 39 bar	
b. hydrocarbon	not higher as minus 5° C at pressure from 39 bar to 69 bar	
5. Temperature	maximum	42 °C
6. Gas is without mechanical additions, resins or compounds that form reisns.		

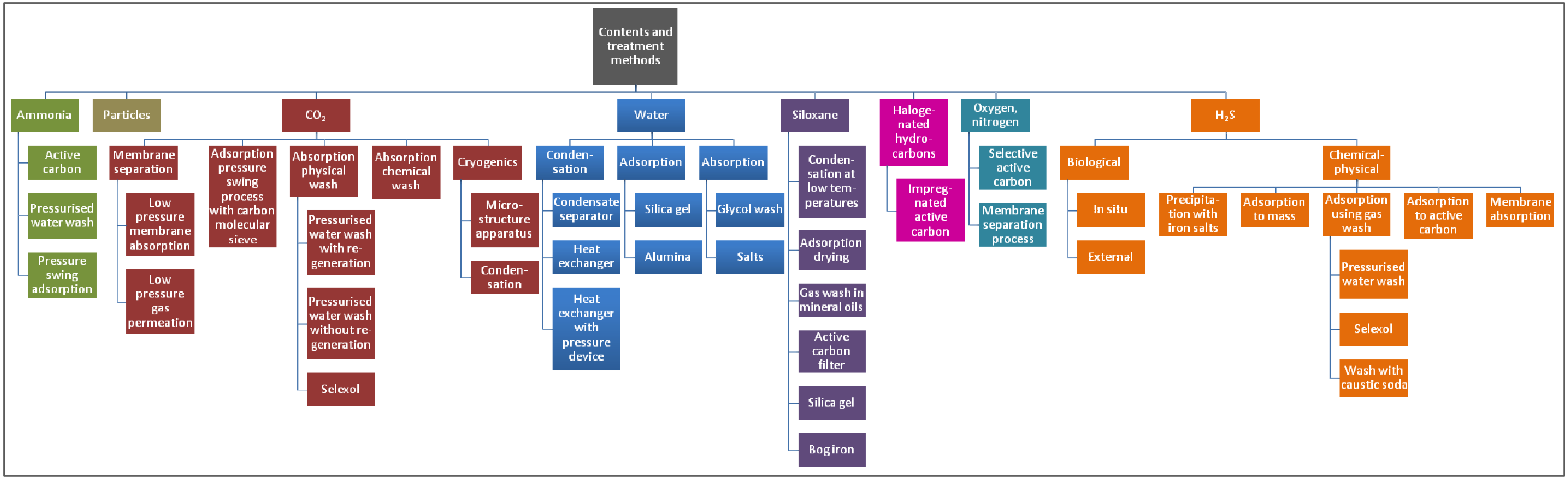
Table 25: Characteristic of purified biogas in Slovenia; Source: ApE

9. Index of figures and tables

9.1 Index of figures

9.2 Index of tables

10. Appendix



Overview of the contents of biogas with the respective conditioning methods; Source: H. Praßl, Ing. Gerhard Agrinz GmbH according Biogas-Netzeinspeisung – Rechtliche, wirtschaftliche und technische Voraussetzungen in Österreich, Bundesministerium für Verkehr, Innovation und Technologie (Wien, 2005)