Chapter 3

Biomethane as Transport Fuel

Magdalena Rogulska, Paweł Bukrejewski and
Ewa Krasuska

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Abstract

In the European Union (EU), the demand for energy in transport is growing, and at the same time, transport is almost entirely dependent on oil and is responsible for more than 30% of greenhouse gas (GHG) emissions in Europe. Biomethane is one of promising options for sustainable mobility. Technical requirements applied for biomethane in transport in both countries and at the EU level are presented as well as short overview of the main upgrading technologies. Sweden and Germany may serve as examples of effective implementation of biomethane in transport sector; however, it is done in different ways (Sweden (non-grid transport use) and Germany (mainly via injection to gas grid)). Their experience can be useful for countries starting development of biomethane production and use, e.g., Poland.

Keywords: biomethane, transport, quality requirements, good practices, Sweden, Germany, Europe

1. Introduction

In the European Union (EU), the demand for energy in transport is growing, and at the same time transport is almost entirely dependent on oil and is responsible for more than 30% of greenhouse gas (GHG) emissions in Europe, and related emissions will double by 2050 [1]. In the medium and long term, significant changes are needed regarding transport means (sustainable mobility); the implementation of biofuels (including biomethane) and renewable alternative fuels is a short-term solution.

Experts' reports prepared at the request of the European Commission (EC) clearly indicate natural gas and its renewable equivalent, biomethane, as a bridging fuel between conventional fuels and advanced biofuels of the next generations [2]. Methane fuels are perceived as an important supplement to the fuel market, especially during the transition period between the first generation of liquid biofuels and the commercial implementation of advanced biofuels.

Biogas upgraded to the quality of natural gas—**biomethane**—has the same advantages as natural gas but is more friendly for the environment from sustainable point of view (higher reduction of GHG emissions, use of local substrates, positive link with waste management). Several European projects (GasHighWay [3], Biogasmax [4], Biomaster, etc.) have shown that biomethane produced and used locally has a positive impact on local sustainable development (reduction of negative impacts connected with transport sector such as smog, creation of new markets, generation of news jobs, etc.). Biomethane and natural gas are recommended as fuels in urban traffic; the advantages of methane fuels related to noise reduction and emissions of harmful substances predispose them to be used in such fleets of vehicles as buses, municipal and delivery vehicles, and taxis. Moreover, biomethane is currently the only biofuel with the same chemical composition as the fossil fuel it replaces. It can therefore be mixed with natural gas in any ratio, without negative consequences for the engine.

In the EU about 11% of energy of the produced biogas is used for transport sector [5]. In 2015 in Sweden, the use of biomethane for vehicles amounted to 1124 GWh and in Germany 580 GWh, respectively. Globally, the leading position belongs to the United States with the use of biomethane for vehicles twice more compared to Sweden [6].

1.1. Technical options for natural gas vehicle (NGV) filling with biomethane

Biomethane for transport can be used in several different technical options, as presented in **Figure 1**. Option 1 is a biomethane filling station established directly at the biomethane plant.

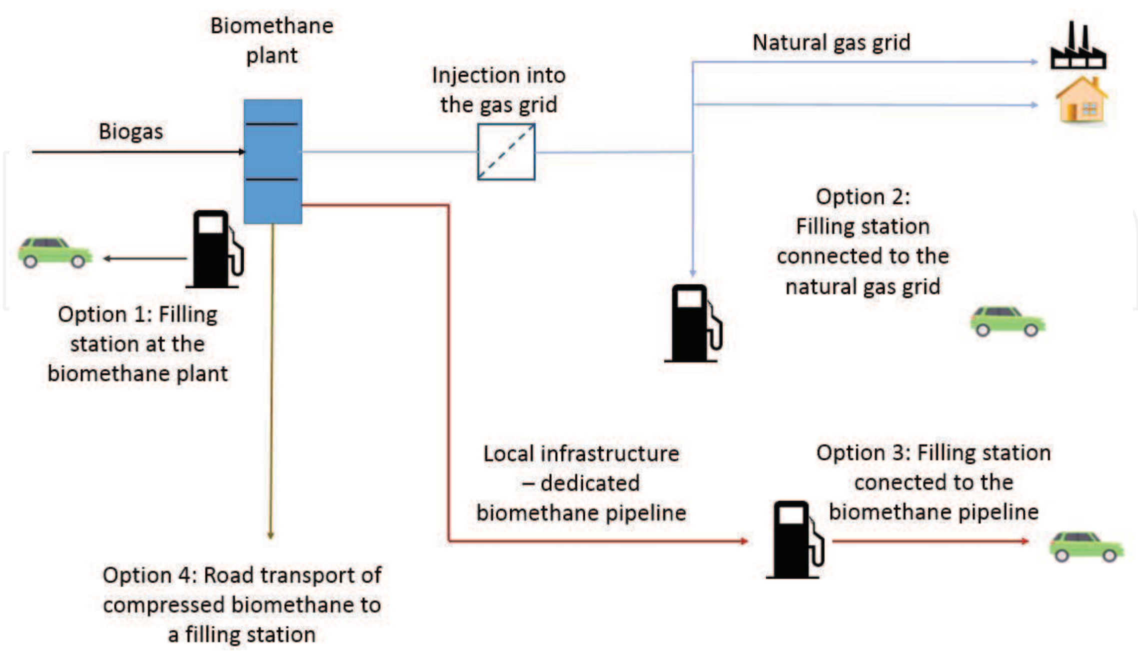

Figure 1. Technical options of filling biomethane for vehicles.

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Option 2 is feeding biomethane into the grid of natural gas; then, a mixture of biomethane and natural gas is supplied to filling stations. This technical solution is very common, for example, in Germany, where the grid of natural gas is well developed and a significant number of CNG filing stations are established. In option 3 biomethane is transported by a local infrastructure to a filling station—a dedicated biomethane pipeline is constructed. In option 4 compressed biomethane is transported in containers via road vehicles to the filling station. Options 3 and 4 are common in Sweden.

2. Examples of biomethane markets in selected EU countries

In many European countries, the production and use of biomethane have increased within the last 10 years. In the end of 2016, biomethane was produced in nearly 500 plants in 16 countries [7, 8]. Germany is still the biggest European biomethane producer, the United Kingdom (UK) with 80 running plants has become the second largest biomethane producer, and Sweden is in third position. In the UK nearly all the plants have been created in the last 5 years due to extensive support policies, such as the introduction of an attractive Renewable Heat Incentive (RHI) providing a bonus paid on top of the market value of the gas injected [9].

In the following subsections, more details will be provided on biomethane markets in Germany (as the European leader in biomethane production) and Sweden (as the European leader in the transport use of biomethane).

2.1. Biomethane in Germany

Germany has a strong biogas industry with more than 10,000 biogas plants and is the EU leading country in terms of biomethane production. In 2016 there were 193 biomethane plants connected to the natural gas grid with a total estimated capacity of 1.71 billion m^3 of raw biogas processed [10]. It is an equivalent to about 940 million m^3 of biomethane fed into the German gas grid. This contributes to about 12.3% of the natural gas production or 1% of natural gas consumption in Germany.

Biomethane fed into the gas grid is primarily used in CHP systems for combined heat and power production, i.e., more than 90% of total biomethane volumes, about 4% is used for transport sector and 3.5% for heat production. In Germany there are currently (September 2017) about 900 CNG filling stations which sell a mixture of natural gas and biomethane with different mixture ratios [11]. The current total number of NGV amounts at some 100,000.

One interesting example of promoting biomethane as a transport fuel is in Berlin. Biogas production from 60,000 tons of selectively collected biowaste from households is upgraded into biomethane, which is used to fuel 150 waste collection tracks [11].

Biomethane has higher production costs than natural gas. The support for biomethane market in Germany is realized particularly in the electricity sector which was the key driver for development of biogas installations in recent years [5]. Currently, feed-in tariff is offered for systems with a capacity of up to 100 kW and a market premium for systems with a capacity up to 20 MW. The change in the past feed-in tariff system of 2011 resulted in a strong fall in the development of new installations.

In transport sector a tax reduction is offered till 2018 for the use of natural gas; however, for biomethane used as a transport fuel, no tax benefits are granted since January 2016 [12]. There is also no incentive to feed-in biomethane into the natural gas grid anymore. The main instrument in the transport sector in Germany is currently the GHG quota, which in 2015 replaced the biofuel quota obligation [11]. The GHG quota is an annual target for GHG emission reduction as a "decarbonization strategy" for transport sector. The use of biomethane offers a mean to achieve this. Biomethane and other biofuels have to fulfill the national regulations established by the Biofuel Sustainability Ordinance.

With regard to a relatively slow rate of the GHG emission reduction in the transportation sector, the German government gave more attention to the increased use of natural gas and biomethane for transport. The Round Table for Natural Gas Mobility set a goal to reach 4% share of natural gas in transport by 2020 and 20% share of biomethane in the natural gas used for transport [12].

2.2. Biomethane in Sweden

Biomethane has quickly found a place in Sweden because Sweden's natural gas prices have always been higher than in Europe and Sweden does not have an extensive gas network.

Sweden has well developed non-grid-based transportation of biomethane. The biomethane is transported mainly not only in compressed form in mobile storage units but also in liquefied form or by local gas grids [13].

In Sweden the most of the biogas is produced from sewage treatment plants, and the amount of landfill gas decreases due to EU regulations (since 2005, the ban on landfill for organic waste has been in force in Sweden). The growing sector is centralized biogas plants that process organic waste, including food waste separated at the source [14]. Food waste collection is growing: in 2016 already 212 municipalities from 290 introduced such systems.

In Sweden natural gas and biomethane are complementary fuels; in 2016 almost 70% of the produced biogas was upgraded and used as transport fuel. In the end of 2016, there were in the operation 62 biogas upgrading plants: 43 water scrubbers, 6 PSA, 11 amine scrubbers, and 2 membrane units [15].

At the end of 2016, Swedish natural gas vehicle (NGV) fleet had 54,439 light duty vehicles, 2331 buses (18% of national market), and 821 HD trucks (in that 50 LNG trucks) [15].

Sweden as the first country in Europe has reported to the European Commission the consumption of biomethane in transport in the annual reports on the implementation of the biofuel directive (2003/30/EC) to the European Commission [16].

Biomethane is the very interesting option with a lot of opportunities for municipalities, because local governments are responsible, among others, for waste management (biowastes—the potential source of biogas) and municipal services such as transport (potential user of biomethane as a fuel). Therefore, they have possibilities to create local supply and demand. Municipalities can use locally produced fuel in their own vehicles, municipal buses, and waste trucks. Swedish experience showed that municipalities were creating local markets with a lot of benefits for their communities [17, 18].

Besides using their existing companies, municipalities were active in establishment of new ones for this sector, e.g., gas enterprises Svensk Biogas and Fordonsgas. Local governments implemented effectively public purchasing policy not only for procurements of vehicle purchases (e.g., city buses and waste trucks) but also for municipal services. New expertise has arisen for local enterprises—production of equipment for upgrading systems (e.g., Malmberg, Purac) and production of gas engines and vehicles (e.g., Scania and Volvo).

In the regions of Västra Götaland (Western Sweden) and Skåne (Southern Sweden), the impressive development of the biogas sector resulted from a unique interaction between research, local governments, and industrial partners [19, 20]. Their experience may be used as an example of good practices in developing local biogas and biomethane deployment strategies in other regions and countries, e.g., in Poland.

In Kristianstad (capital of Skåne), digestion of organic matter into biogas has become the most important way to reduce the negative environmental impacts of waste and instead use it as an energy resource. The biogas plant, as well as the units for upgrading gas, is owned by the municipal company, Kristianstad Biogas, which is a part of the municipal energy company. In **Figure 2** biomethane filling station for buses located nearby Kristianstad biogas plant is presented. The municipality is aiming to have a fossil fuel free fleet by 2020, mainly running on biogas [21].

Figure 2. Biomethane filling station for buses in Kristianstad (photo by M. Rogulska).

3. Technical requirements for biomethane use in transport

Development of **technical standards** is important for market introduction of advanced biofuels, in that biomethane. Standards for biomethane need to meet not only requirements of automotive industry and vehicle users but also requirements of the natural gas sector.

For the use of natural gas and biomethane in transport especially, following issues are important [22]:

- *Hydrogen sulfide* as a toxic gas has high corrosive properties. The sulfur contained in it is converted to sulfur oxides, which have a negative impact on the natural environment.
- *Sulfur* has a huge impact on the size and type of exhaust emissions from the car and the corrosive properties of the fuel. Failure to meet the required sulfur content limit shortens the lifetime of the catalyst and consequently, in many modern engines, disruption of the fuel dose control system and problems with proper engine operation. There is also the danger of engine corrosion. Sulfur compounds are among the most technologically and environmentally troublesome.
- *Mercury* has been recognized as a metal that poses a significant threat to the natural environment and human health, and its specific behavior in various ecosystems makes it difficult to fully anticipate the ecological and health effects of contamination with this metal. Mercury in natural gas usually occurs in elemental form, and it can also exist in the form of HgCl2, CH3HgCH3, C2H5HgC2H5, and ClHgCH3. Mercury from aluminum creates amalgams which can cause damage to the materials it comes in contact with.
- *Smell*. Natural gas is lighter than air, is colorless, and does not have an odor, so it is odorized with a special chemical that gives it a characteristic smell, to detect even very low concentrations of gas from leaks (before the gas reaches a dangerous concentration in the air). Gas in combination with air can form an explosive mixture. The explosion limit is 5–15%.
- *Heat of combustion* is the amount of energy that is released during the combustion of a given substance. If the product of combustion is water vapor, the heat of combustion also includes the heat of condensation of water vapor. Of course, we assume that all fuel will be burned (total combustion) and that combustion is complete (i.e., no combustible substances in the exhaust). When *the heating value* is considered, we are dealing with the same amount of energy, but we do not take into account the condensation of water vapor. As they are similar in terms of definition, but quite different numerically, it is important to pay attention to all tables or statements on which quantity is given.
- *Water*. The most important safety requirement for BioCNG/CNG is the very low value of the water dew point, excluding the formation of liquid water. For this reason, the water dew point temperature in the gas fuel at the exit from the refueling station should be adequately lower than the lowest ambient temperature at which the refueling station and vehicles used will operate.
- *Liquid water* is a precursor to the formation of corrosive compounds because it combines with natural gas components such as carbon dioxide and hydrogen sulfide. The combination of

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corrosive components and variable pressure caused by fuel consumption and subsequent refilling of the fuel tank can cause metal cracks leading to damage and failure. Liquid water can also be harmful, creating liquid or permanent blockages in the fuel system.

- The supplied gas fuel should be technically *dust*-free.
- The content of *oil* in supplied gas should not have an adverse effect on the safe operation of the vehicle. If necessary, filters and separators can be used. A small amount of oil can have a beneficial effect on tank protection and lubrication of the injectors.
- *Oxygen* together with hydrogen sulfide can react, in particular with copper, which is detrimental to the installation.

Minimizing the content of pollutants to the limit values given in the standards is important due to their unfavorable effect on the combustion process in car engines.

3.1. Swedish technical regulations

Sweden has developed a standard for biomethane as a fuel; it has included biomethane in its legal regulations on transport fuels. The Swedish standard SS 155438 "Motor fuels – Biogas as fuel for high-speed Otto engines" developed in 1999 was the first standard regulating the use of biomethane as a fuel for vehicles in European countries [16, 23].

The guidelines contained therein are presented in **Table 1**. Values for type A biometric relate to fuel for engines without regulation of the lambda mixture composition ratio used in heavy vehicles, such as trucks and buses. Values for type B biomethane relate to fuel for engines with controlled mixture composition, used for stoichiometric combustion, e.g., passenger cars [23].

Parameter	Unit	Biomethane (type A)	Biomethane (type B)
The Wobbe index	MJ/m^3	44.7–46.4	43.9–47.3
Methane content	% vol.	97 ± 1	97 ± 2
Dew point at the highest storage pressure (t—the lowest average daily temperature over the month)	0°C	t-5	t-5
The maximum water content	mg/m^3	32	32
The maximum $CO_2 + O_2 + N_2$ content	% vol.	4.0	5.0
with oxygen maximum	% vol.	1.0	1.0
Maximum total sulfur content	mg/m^3	23	23
Total maximum content of nitrogen compounds (excluding N_2) calculated as NH3	mg/m^3	20	20
The maximum particle size	μm	1	1

Table 1. Swedish requirements for biomethane use in transport [23].

3.2. German technical regulations

In Germany the successful biomethane injection to grid was possible thanks to the fact that clear regulations have been included in the Gas Network Access Ordinance (Gas NZV) [24].

Technical regulations concerning the quality properties of biomethane and natural gas are provided in worksheets G 260 and G 262 published by the German Technical and Scientific Association for Gas and Water (DVGW)—a standardization body for the gas and water industry [11, 25]. The basic requirements for the quality of gas from renewable sources are given in the worksheet G 262. If the gas is to be fed into the public gas grid, it needs to meet the regulations of DVGW worksheet G 260.

Table 2 presents the quality requirements for the biogas injection to the gas grid according to DVGW G 260 [25].

Technical requirements for design, construction, and operation of biogas and biogas upgrading installations specify worksheet DVGW G 265. Technical requirements are defined separately for:

- Biogas plant: production of biogas from organic raw materials through methane fermentation.
- Biogas treatment plant: removal of hydrogen sulfide, carbon dioxide, and other trace gases and drying.
- Installations injecting biomethane to the gas grid: calibrated measurement of quality and quantity for billing purposes, if necessary, increases the pressure to the network pressure, conditioning with liquefied hydrocarbon gas and odorization.
- Recovery systems: an increase in gas pressure in order to transfer to a higher-level network.

Parameter	Unit	Value
The Wobbe index	MJ/m^3	48.96–56.52
Heating value	MJ/m^3	30.24–47.16
Relative density		0.55–0.75
Total sulfur content	mg/m^3	<8 (short term to <30)
Hydrogen sulfide content	mg/m^3	<5
Water content	mg/m^3	< 50 in grid> 10 bar < 200 in grid ≤10 bar
Hydrogen content	%(v/v)	< 2 in exceptional cases to <10
CO_2 content	%(v/v)	In gas grids L < 10 In gas grids H < 5
Oxygen content	%(v/v)	<3 injection to a dry network <0.5 injection to wet network

Table 2. Quality requirements for biomethane injection to grid in Germany [11].

The biomethane supplier is responsible for the warranty of the gas compositions stated in the worksheets.

3.3. European technical regulations

Standardization is important for market access as it brings legal and technical security. Countries producing biomethane have introduced standards, respectively, for injection (e.g., Germany) or vehicle fuel use (e.g., Sweden), but they were very different. To solve this problem, the European Commission (EC) has given to the European Committee for Standardization (CEN) the mandate M/475 for elaboration of European biomethane standards for grid injection and vehicle fuel use. Technical Committee CEN TC 408 formed on this basis started to work in 2011, and final result of their work was published in 2016 (Part 1) and 2017 (Part 2) [26].

Due to the differences in the legal acts and standards regarding the quality of biomethane for transport applications and for injection into the gas grid as well as the expectations of both the gas and automotive industries, it was decided to prepare a standard subdivided into two parts. Developed norms are not looking on the biomethane production pathways (e.g., biomass fermentation process or gasification process) nor origin of the substrates.

In 2016, Part 1 of the European standard EN 16723–2 *Natural gas and biomethane used in transport as well as biomethane injected into the natural gas network* was published. This part concerns the requirements of biomethane injected into the network [27].

Part 2 published in 2017 refers to the specification for fuels for motor vehicles. This standard specifies the requirements and test methods for natural gas (group L and H), biomethane and blends of both at the point of use as vehicle fuels and applies to these fuels irrespective of the storage state (compressed or liquefied). In **Table 3** requirements, limit values and related test methods for natural gas and biomethane use as vehicle fuel are presented [28].

The technical requirements and safety conditions for the use of biomethane-powered vehicles are identical as those for CNG vehicles, so also their use must be in compliance with regulations and standards such as EN ISO 15403–1:2010: Natural gas—Natural gas for use as a compressed fuel for vehicles—Part 1: Designation of the quality [22].

The standard provides manufacturers, vehicle users, service station operators, and other entities associated with the natural gas vehicle (NGV) industry with information on the quality of fuel for NGV vehicles necessary for the efficient development and operation of gas-fueled equipment.

It is recommended that fuels meeting the requirements of this part of ISO 14503 enable:

- To ensure the safe operation of vehicle and equipment used to refuel and service
- To protect the fuel system against corrosion, poisoning, and secretion of sediments or liquids
- To achieve satisfactory operation of the vehicle in all climatic and road conditions

Parameter	Unit	Limit values[a]		Test method
		Min	Max	
Total volatile silicon (as Si)	mgSi/m^3		0.1 or 0.5[b]	EN ISO 16017-1:2000 TDS-GC-MS
Hydrogen	% mol/mol	—	2	EN ISO 6974-3 EN ISO 6974-6 EN ISO 6975
Hydrocarbon dew point temperature (from 0.1 to 7 MPa absolute pressure)	°C	—	−2 (as in EN 16726)	ISO 23874 ISO/TR 11150 ISO/TR 12148
Oxygen	% mol/mol	—	1	EN ISO 6974 series EN ISO 6975
Hydrogen sulfide + carbonyl sulfide (as sulfur)	mg/m^3	—	5 (as in EN 16726)	EN ISO 6326-1 EN ISO 6326-3 EN ISO 19739
S total	mgS/m^3		[c]	EN ISO 6326-5 EN ISO 19739
Methane number	Index	65[d] (as in EN 16726)		Annex A of EN 16726
Compressor oil			[e]	ISO 8573–2
Amine			10	VDI 2467 Blatt 2:1991-2008

[a]Limit values are absolute, and the number of the decimal places shall not imply the accuracy of the test method.

[b]A silicon content of <0.1 or 0.5 mg/m^3 is considered as a safe level. Further research is needed for a decision whether a higher limit value is acceptable.

[c]Currently, there is a difference between the automotive industry needs for sulfur content (10 mgS/m^3 including odorization) and the values, and the gas industry can provide (30 mg/m^3 including odorization) (see Annex B). It is possible to cover this parameter in a national foreword.

[d]The methane number depends on the composition of the distributed natural gas.

[e]The fuel shall be free from impurities other than “de minimis” levels of compressor oil and dust impurities. In the context of this European standard, “de minimis” means an amount that does not render the fuel unacceptable for use in end-user applications.

Table 3. Requirements, limit values, and related test methods for natural gas and biomethane use as vehicle fuel [28].

The operator of the refueling station for vehicles is responsible for any changes in the composition of natural gas supplied to refueling stations to meet these requirements and complements ISO 15403-1.

4. Biogas upgrading technologies

Biogas upgrading is a process of removing carbon dioxide (CO_2) from the initial mixture, which increases the methane content (CH_4) in the gas obtained, and purifying it from hydrogen sulfide, water, and other trace constituents. The treatment allows to adjust the quality parameters of biogas to natural gas parameters.

The selection of an effective and economically attractive method for the purification of biogas from compounds that are toxic to the environment and damaging the engines, combined with the adjustment to natural gas parameters, is a key element for the successful introduction of biomethane into the gas grid and/or transport sector.

There are four main types of commercially available biogas upgrading technologies: (i) absorption methods (scrubbing), (ii) membrane separation, (iii) pressure swing adsorption (PSA), and (iv) cryogenic separation. Upgrading should take place with the lowest possible biomethane losses and low energy input.

The share of different biogas upgrading technologies in Europe in the end of 2016 is presented in **Figure 3** [7, 29]. The most popular method of biogas upgrading is water scrubbing, which belongs to absorption methods [8]. Membrane separation is the second most commonly applied technology. Then, chemical scrubbing and PSA come, and the next is physical scrubbing. The cryogenic treatment has so far the lowest market contribution [29]. In Germany, in 2016 taken as a separate year, 11 new upgrading plants were established, of which 6 were different scrubbing methods, 3 membrane separation method, 1 PSA, and 1 biological methanation [30].

4.1. Water scrubbing and physical scrubbing

The most popular biogas upgrading method is water scrubbing, which is based on the difference of the solubility of CO2 and CH4 in water in lower temperatures. In the water scrubbing column, CO2 dissolves in water, while the concentration of methane in the gas phase increases. In the absorption column, there is also the process of H2S removal. Commonly, raw biogas is compressed to the absorption pressure of 4 to 10 bar and then cooled to increase the efficiency of the gas mixture separation process. Biogas is introduced in the lower part of the column, in which the flowing water absorbs carbon dioxide and hydrogen sulfide. Water is a harmless, low-cost solvent that is easy to handle. In physical scrubbing technologies, organic solutions are used (e.g., polyglycol) instead of water.

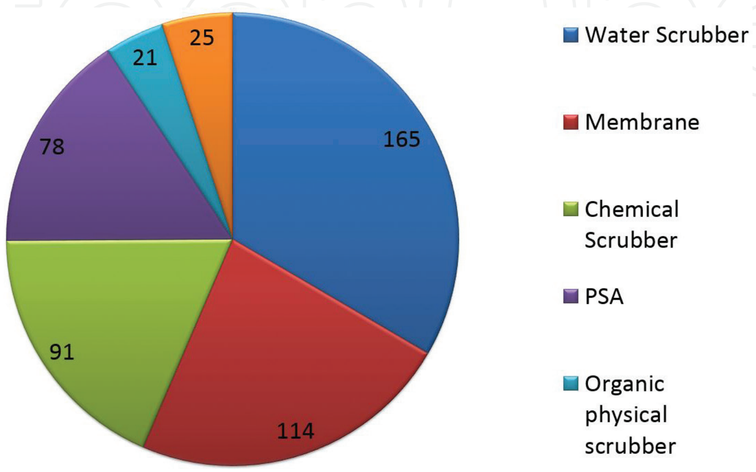

Figure 3. Biogas upgrading technologies in Europe, data for 2016 [7, 29].

The scrubbing technologies assume the regeneration of an aqueous solution (or organic) in the desorption column by depressurizing or passing the stream of air in a countercurrent (stripping). Passing the air stream is not recommended at higher levels of H_2S, because the precipitating elemental sulfur causes operational problems of the installation. The scrubbing technologies in general do not require the supply of heat to the process and the use of chemicals, while they assume heat recovery and minimization of water consumption. Depending on the design of the column, the efficiency of upgrading with water scrubbing method is at the level of 90–99% of pure biomethane in the output gas [11].

4.2. Chemical absorption

This technology is purifying biogas by absorption and chemical binding of carbon dioxide in aqueous solutions of amines (most often monoethanolamine (MEA) or dimethylethanolamine (DMEA)). Due to the high selectivity of the reaction of CO_2 with amines, the process is more efficient than physical absorption. The gas obtained contains methane in an amount above 99% (even 99.4%), and methane losses can be limited to <0.1%. Raw biogas is pretreated with activated carbon to reduce the sulfur content (up to 0.5 ppm). In the case of increased H_2S content, an additional pretreatment plant is needed.

The process requires the use of heat, but does not require elevated pressure, so only the gas leaving the installation is compressed, which allows for a significant saving of energy. The amine solutions are regenerated by heating (110–160°C), and some of the heat is recovered.

4.3. Membrane separation

Biogas can be purified from both carbon dioxide and hydrogen sulfide with the application of a membrane technique. Membranes are typically combined in a tube bundle to provide maximum surface area. Typical operating pressures are 7 to 20 bar. The membrane acts selectively, i.e., only one component of the mixture passes through the filter freely, while the others are retained due to their size or affinity. Transport through membranes, as in the case of osmosis, occurs on the principle of difference of the potentials on both sides of the membrane. The difference of potentials stimulates the speed at which the particles pass through the membrane in order to compensate the concentration, pressure, or temperature.

Membrane separation is a relatively new technology for biogas purification and, within the last 10 years, has been significantly developed. The efficiency of one membrane is too low for biogas to achieve natural gas quality properties, so more than one membrane or additional purification technology should be used to achieve higher methane concentration. Moreover, in order to increase the separation efficiency, it is possible to recirculate the gas to be purified.

4.4. Pressure swing adsorption (PSA)

Pressure swing adsorption has been for years used in a gas industry, and recently it has been adapted for biogas upgrading. In this technology carbon dioxide is removed from biogas by adsorption on the surface-activated carbon, or on zeolite molecular sieves or carbon molecular sieves. CO_2 molecules are smaller than methane molecules and thus CO_2 accumulate on the surfaces or in the pores to a much greater degree than CH_4. The latter remains primarily in the gas phase. Adsorption is higher in higher pressures and in low temperatures. Biogas is cooled down to about 70°C and fed into the adsorption column. The biogas must be pre-purified in order to remove hydrogen sulfide and water vapor, which could, however, result in the deactivation of the active bed. The adsorption is a batch process and takes place in several columns. The methane loss is between 1.5 and 2.5% [11].

4.5. Cryogenic separation

Cryogenic separation is a new biogas upgrading technology. The process takes place under conditions of very low temperatures (up to −100°C) and high pressures (40 bar). Carbon dioxide condenses or sublimes and can be separated from biogas in the liquid or solid form, while methane remains in the gas phase. There are many options for the adjustment of temperature and pressure in order to perform the separation. Cryogenic separation can also be combined with other gas treatment methods. The advantage of the cryogenic separation is high methane purity with low losses. A disadvantage of cryogenic treatment is the energy required for refrigeration.

5. Conclusions

Biomethane is an attractive fuel, available now for support of the transition from the conventional fuels to sustainable low-emission mobility (advanced biofuels, e-fuels, hydrogen, etc.).

The use of biomethane is connected with very low GHG emissions if produced through biomass gasification or even with negative GHG emissions when produced from substrates such as organic municipal wastes or manure (otherwise emitting methane during its decomposition process).

The potential for development is huge when looking only on biogas sector: in Germany less than 2% of biogas units (around 190 units) are biomethane production plants; in France it is less than 3% (around 30 units), while in other EU countries, this rate varies between 4% and 12%. Only in Sweden 21% of biogas plants produce biomethane (62 units) [7].

In Sweden and Germany, biomethane markets are well established so they can serve as good examples for analyzing pros and cons of solutions and models implemented by them. Automotive Industry Institute (PIMOT) together with national stakeholders and international partners (e.g., Swedish-Polish Sustainable Energy Platform) is involved in promotion and development of biomethane market in Poland.

Nomenclature

Biomethane biogas upgraded to the quality of natural gas.

The Wobbe index (W) used as an indicator for the assessment of gas utilization properties—is a determinant of gas "calorific value"; it is the quotient of the Qc gas combustion heat in MJ/m^3 and square root of the relative density d. The change in Wobbe's number may affect the power and operation of the engine.

Author details

Magdalena Rogulska*, Paweł Bukrejewski and Ewa Krasuska

*Address all correspondence to: m.rogulska@pimot.eu

Automotive Industry Institute PIMOT, Warsaw, Poland

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