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Biomethane in Germany – lessons learned

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Background

In large parts of Europe, biomethane production is a growth market. Germany currently operates about 8.000 biogas plants with about 3.75 GW of installed capacity for power generation, of which approximately 150 inject with an annual injection capacity of about 0.75 billion m^3 biomethane directly into the natural gas grid (Fig. 1) [1]. In Europe, 282 biomethane plants with a total annual production of 1.303 billion m^3 are operated [2]. Biomethane offers a variety of excellences, e. g. in the fields of climate protection, sustainability, energy efficiency, reduction of import dependency, and can be applied to different utilization routes, such as delocalized combined heat and power generation (CHP), in the heat sector or in the transportation sector as fuel for CNG or LNG vehicles.

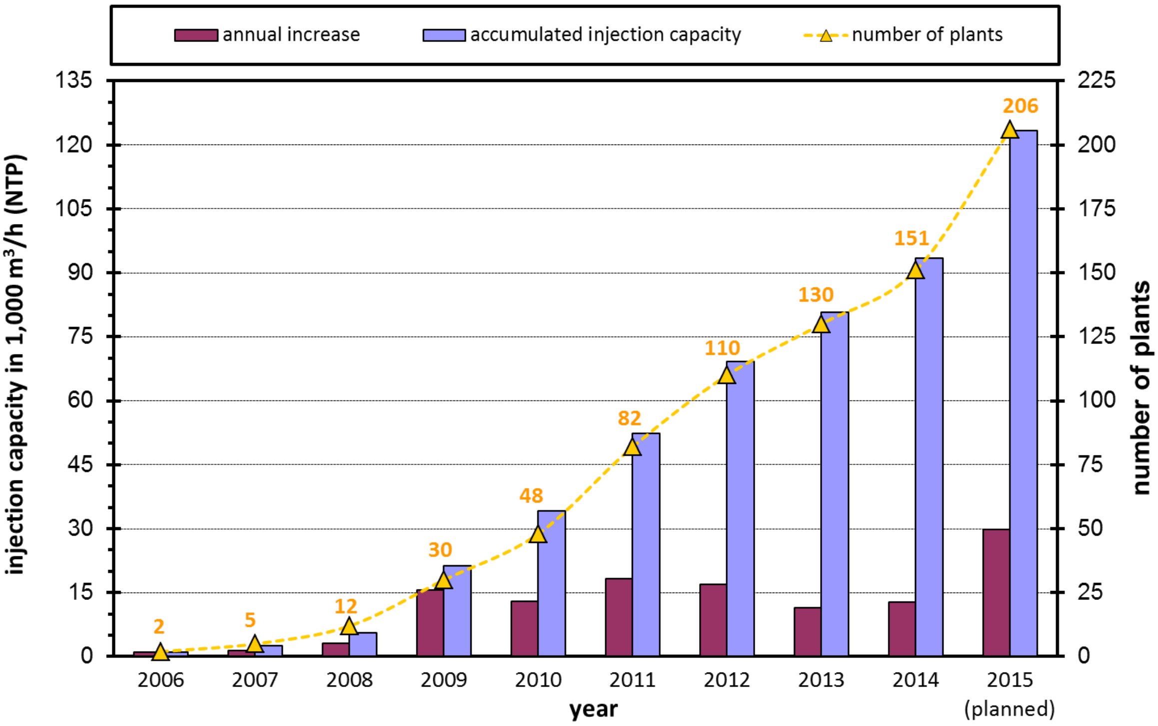

Fig. 1: Advance of biomethane injection capacity in Germany (data source: www.biogaspartner.de)

In the last decade, the development of Germany's biomethane capacity has benefited from national authorities, as the German renewable energy act (EEG) has set-up ambitious goals for biomethane injection and provided guaranteed remuneration for electricity fed into the grid, produced from biomethane and other renewables. Consequently, the EEG allocation on the electricity fee, an instrument for funding the transition to renewable energy sources in Germany, has increased up to 6,24 Ct/kWh for non-privileged customers (e. g. in the private sector). A situation, apart from various other renewables, biomethane admittedly also made its contribution. Besides, as large maize monocultures often located at large distances from the actual biogas plants arized, controversial discussions on agricultural diversity, sustainability of biomethane production and fuel-vs.-food aspects evolved in German society. In August 2014 a revised version of the EEG act came into force, including a sharp cut in financial support for new and existing biogas plants and therefore limits biomethane´s further extension in Germany.

Aims

Nevertheless, biomethane should remain a vital part of Germany's transition to renewable energy sources, as it exhibits manifold advantages over other renewables, such as sustainability, compatibility to natural gas infrastructure, industrial and real estate assets, base load capability, high efficiencies, and various options for utilization. Therefore, DVGW (German Technical and Scientific Association for Gas and Water) and its associated research institutes (e.g. DVGW-EBI) and member companies work on the optimization of the process chain of biomethane production, upgrading, and injection with respect to environmental, economic and energy efficiency factors. As core issues DVGW-EBI focuses on extension of raw materials especially with respect to biomass based residues, increase in flexibility of power generation from biogas by injection into the gas grid, technological improvement of the production and purification process, coupling of biomethane production with PtG-processes and utilization of biomethane as a vehicle fuel.

Methods

For further improvement of biomethane economy in Germany, identification of sustainable raw material potentials, technological advances and innovations in biomethane production and upgrading are the desired approaches. These need to bring in benefits from economic and ecologic point of view, in comparison with state-of-the-art technologies.

Results

Subsequently, the most important aspects of biomethane production, upgrading technology, sustainability and injection concerns will be addressed and recommendations, based on ten years of advisory activity in the biomethane-field will be given.

Potentials for the production of biogas in Europe and Germany

Compared to other processes, digestion of biomass is an efficient conversion route. Furthermore a wide range of feedstock, ranging from traditional energy crops via agricultural or forestry residues to municipal, manufacturing and industrial waste can be used for biogas production. Nevertheless, the overall potential is limited and substantial competition with other utilization option exists. In Europe the technical potential for biomethane production ranges around 70 billion m^3/a. Including thermochemical conversion of lignin-rich biomass via gasification and methanation up to 220 billion m^3/a could be produced [3]. With respect to costs, feasibility and competing utilization significant lower values are realistic.

For Germany a sustainable biogas potential of 10 billion m^3/a by 2030 was estimated in a detailed GIS-based analysis (Fig. 2) [4]. Besides raw materials, sustainability factors (e.g. agricultural diversity, land-use competition and water management) as well as connectivity to the natural gas grid and to district heating are incorporated.

The latest biogas monitoring report of the BNetzA revealed that 38 mass-% of the substrates for biomethane stemed from residues and 62 % from energy crops. In Germany about 0.9 million hectares (approx. 5 % of the total acreage) were used for corn cultivation for biogas production in 2014. In some regions large monoculture evolved and the public resistance against energy crops and biogas plants grew significantly in the last years. Furthermore, the biogas production costs increased with rising substrate prices. For the existing biomethane plants the generation costs show a wide spread between 2.5 (residues) and 11.2 Ct/kWh (energy crops) with an average value of 7.5 Ct/kWh [5]. Compared to natural gas biogas is about 3-fold more expensive. With the novel conditions of the EEG 2014 new biomethane plants are only economically feasible if residues are used as substrates.

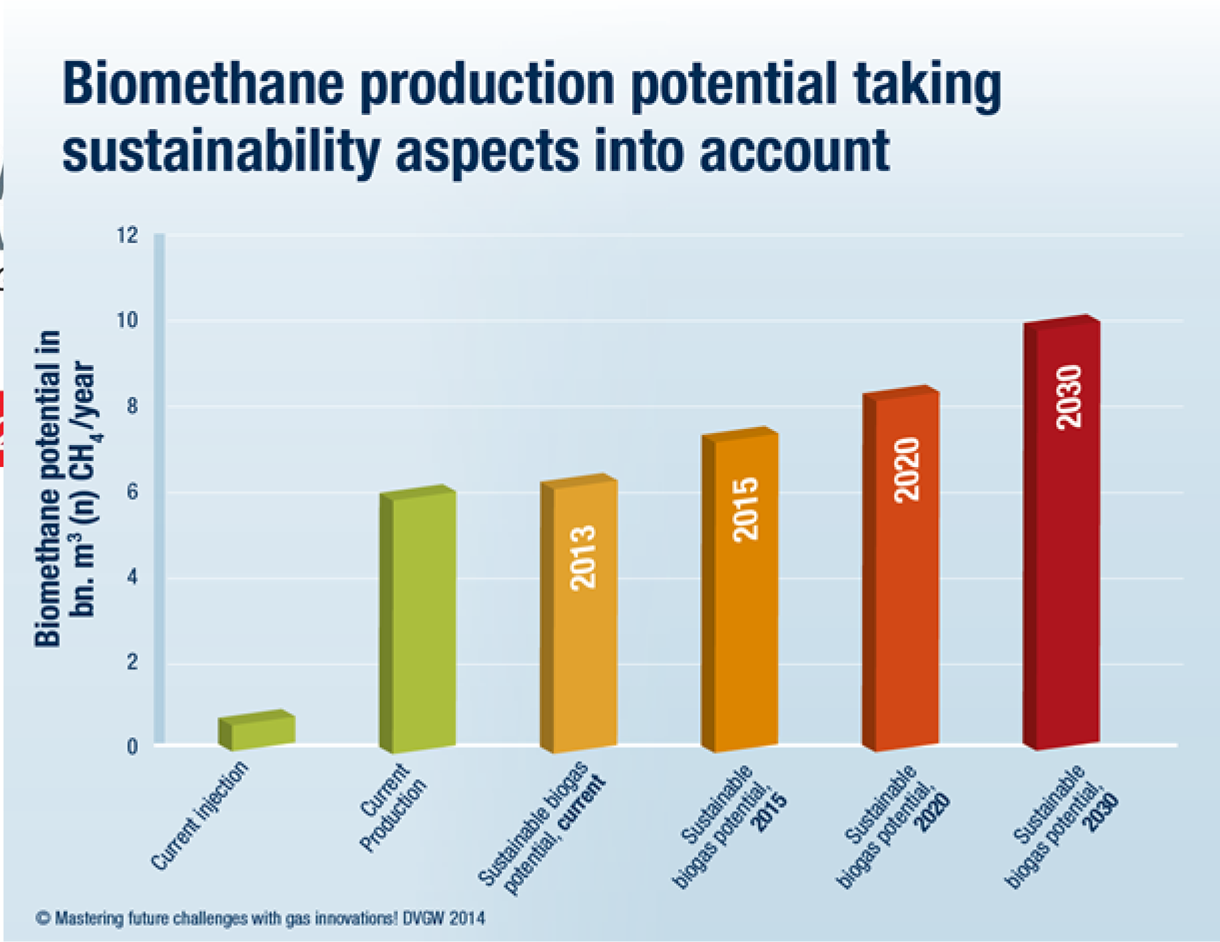

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Fig. 2: Biomethane production potential in Germany

Technical standards and gas quality aspects for injection of biomethane into the natural gas grid

In Germany the legal, technical and economic frame for biogas injection is defined by the EnWG (German Energy Act) [6], the GasNZV (Gas Grid Access Ordinance) [7] and the EEG (German renewable energy act, which grants priority to renewable energy sources) [8]. The German regulator (BNetzA) is responsible for controlling and monitoring of injection projects. According to the monitoring report 2014 the average injection capacity of a biomethane plant in Germany lies at 412 m^3/h (NTP). Depending on the plant size and the biogas composition the upgrading costs vary between 0.99 and 3.39 Ct/kWh (average value 1.68 Ct/kWh). The average selling price was 6.44 Ct/kWh. The costs for the grid access are divided between the biomethane producer and the grid operator with respect to the regulations in GasNZV. As the grid operator is strongly obliged to provide grid access and no adjusted design of the process chain from biogas production, upgrading and injection is mandatory the overall transferable costs for the grid access have increased to 131 million € in 2013 resulting in a perceptible apportionment for the gas customers of 0.51 €/kWh/h/a. To minimize the costs for integration of biomethane into the gas infrastructure smart gas grid solution have to be applied widely. In particular the enrichment of biogas with LPG has to be substituted by innovative options like gas quality tracking systems. E.g. the SMARTSim system from E.ON allows authorized gas quality tracking in distribution grids where most of the biomethane injection plants are located.

DVGW supervises the development of technical guidelines for biogas injection into the gas grid in Germany. Gas quality and safety aspects are discussed in several task forces and working groups. Technical standards are developed and revised. Since our contributions in WGC 2009 [9] and 2012 [10] the DVGW standardization has been exceeded and modified in various fields (see Tab. 1).

Concerning the gas quality for renewable gases to be injected into the gas grid the technical guidelines G 260, G 262 and for CNG DIN 51624 are relevant. Table 2 gives a summary of gas quality requirements in Germany. In Europe the gas quality standards will be harmonized in the near future. For natural gas H CEN/TC 234 has developed the draft standard prEN 16726, for biogas CEN/TC 408 has designed the preliminary standards prEN 16723-1 and prEN 16723-2 in 2014.

Tab. 1: DVGW-Standards related to the injection of biogas into the natural gas grid

Technical Standard	Title
G 100-B1 (2010)	Qualification requirements for DVGW authorised experts for gas supply - 1. Supplementary sheet: Qualification requirements for DVGW authorised experts for biogas upgrading and injection plants
G 262 (2011)	Usage of gases from renewable sources in the public gas supply
G 267 (2014)	Oxygen content in high pressure grids
G 265-1 (2014)	Biogas upgrading and injection plants – Part 1: gases produced by fermentation, planning, construction, testing and bringing into operation
G 265-2 (2012)	Biogas upgrading and injection plants – Part 2: gases produced by fermentation, operation, servicing and maintenance
G 265-3 (2014)	Plants for the injection of hydrogen into the gas grid; Planning, manufacturing, erection, testing, commissioning, operation
G 267 (2015)	Oxygen content in high pressure grids
G 290 (2012)	Re-injection of injected biogas into upstream transportation pipelines
G 291 (2013)	Recommendation for the interpretation of the Gas Grid Access Ordinance
G 292 (2012)	Supervision and controlling of biogas injection plants with with respect to dispatching issues
G 415 (2011)	Raw biogas pipelines
G 493-1 (2012)	Qualification criteria for planers and manufacturers of gas pressure regulating and metering plants and biogas injection plants
G 1030 (2010)	Requirements on qualification and organisation for operators of plants for production, transmission, upgrading, conditioning or injection of biogas
Water Inform. 73 (2010)	Cultivation of biomass for biogas generation in consideration of soil and water protection
DVGW-BGK-Information (2013)	Suitability of digestates from biogas plants for agricultural recycling in drinking water protective areas

Tab. 2: Gas quality requirements for biomethane injection into the natural gas grid

Term		**Unit**	**Typical Values for Raw Biogas (renewables)***	**Typical Values for Raw Biogas (residues)***	**Technical Standards G 260 / G 262**
Calorific Value		**kWh/m^3**	5.5 - 6.1	6.6 - 7.8	8.4 - 13.1
Relative Density			0.99 - 1.04	0.85 - 0.94	0.55 - 0.75
Wobbe-Index		**kWh/m^3**	5.4 - 6,1	6.8 - 8.4	H-Gas: 13.6 - 15.7 L-Gas: 11.0 - 13.0
Water Content		**mg/m^3**	Saturated at $T_{\text{Fermenter}}$, $P_{\text{Fermenter}}$ (typical: > 10,000)		200 (MOP ≤ 10 bar) 50 (MOP > 10 bar)
CH_4		**mol-%**	50 - 55	60 - 70	≥ 95 (H-Gas) ≥ 90 (L-Gas)
CO_2			45 - 50	30 - 40	regulated by min. CH_4 content
O_2	**MOP < 16 bar**		0 - 1		max. 3
	MOP ≥ 16 bar				max. 0.001
H_2			<< 1		< 10**
Carboxylic Acids		**mg/m^3**	trace		-
Alcohols			trace	< 22	-
BTEX			trace	< 10	-
Higher organic compounds			trace	< 1,250	condensation point: -2 °C (1 bar ≤ p ≤ 70 bar)
Sum of H_2S and COS			< 3,000	< 30,000	max. 5
NH_3			< 1	< 10,000	technical free
Si_{total}			< 30		< 5***

* Own measurements and literature references.

** Subject to other restrictions (e.g. DIN 51624 fuel standards or requirements of certain gas applicatins).

*** no fixed limit, 5 mg/m³ is recommended with respect to the limt for engines. Gas turbines can be more sensitive

Optimization of plant management and current technical innovations

In the vast majority of cases, biogas is produced in an anaerobic one-staged fermentation process, where the four major degradation steps of the biomass: hydrolysis, acidogenesis, acetogenesis and methanogenesis are operated in one single digester at ambient pressure and mesophilic temperature level (30 - 45 °C). Typical biogas compositions for such a setup are given in Tab. 2 for two different types of substrates.

The prevailing purification tasks for biogas upgrading are desulfurization, removal of CO_2 and drying of the gas. As CO_2-content in biogas is considerably high, the total energy demand of the upgrading chain is dominated by the energy consumption for the removal of CO_2. Therefore, the process chain (see Fig. 3) typically is arranged by the requirements of the CO_2-removal process.

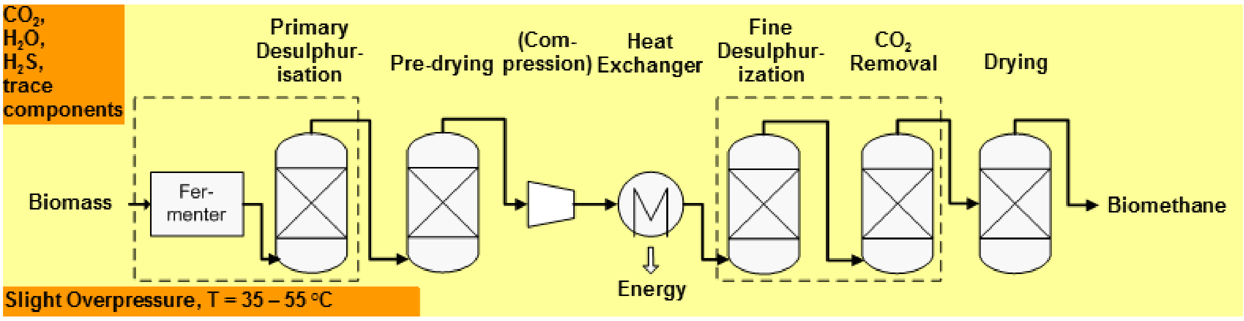


Fig. 3: Typical configuration of a biogas production and upgrading chain [11]

In the biogas sector physical scrubbing (PS) and the pressure swing adsorption (PSA) are most widely used for removal of CO_2 (see Tab. 3). For physical scrubbing typically water (WS) is applied as scrubbing fluid. In some cases Genosorb is used (GS). Besides, chemical scrubbing processes (CS) with diethanolamine (DEA) and activated methyldiethanolamine (aMDEA) are commercially available. In the recent past, membrane separation processes (MS) have been developed, but only feature relatively small market shares by now.

Tab. 3: Market-Shares of technologies for CO_2-removal from biogas in Germany [12]

State-of-the-art processes for CO_2-removal from biogas in Germany	**Market Share**
Chemical Scrubbers (CS)	25 %
Physical Scrubbers (PS)	42 %
Pressure-Swing-Adsorption (PSA)	29 %
Membrane Separation (MS)	4 %

Because of the possibility to remove CO_2 solely or in combination with H_2S, the purification steps are typically arranged in two different ways. In any case, the primary desulfurization is carried out as first purification step by e. g. admixing ferrous salts directly into the digester. Pre-drying typically follows in order to avoid condensation in downstream equipment. Fig. 3 shows one of two options, with H_2S being removed prior to CO_2 by fine desulphurization. In this case, the pre-dried gas is desulfurized by activated carbon. H_2S fluctuations in the biogas are buffered in the fine desulfurization unit and (if required by CO_2-removal) nearly no H_2S passes through.

Commercially available CO_2-removal systems further produce an off-gas consisting of CO_2, but also certain amounts of CH_4 and H_2S (if removed in-situ with CO_2: the second option of upgrading chain configuration), which have to be burned in order to avoid undesired emissions into the ambient. When CO_2 is removed by PSA, in many cases a final dryer is not necessary, as PSA produces an upgraded biogas with a dew point below - 40 °C. When physical scrubbing with Genosorb liquid is applied, a dew point of about - 20 °C may be reached, which can be sufficient for certain sections of the natural gas grid.

Tab. 4 summarizes the most important operating data and gives additional information Besides the mentioned, other gas treatment technologies are under development e.g. cryogenic processes.

Tab. 4: Comparison of State-of-the-art processes for CO_2-removal from biogas [11]

	Water scrubber	**Genosorb®-Scrubber**	**PSA**	**Chemical Scrubber**	**Membrane Separation**
Operating Principle	A**b**sorption		A**d**sorption	A**b**sorption + Reaction	Permeation
y_{CH4} in Biomethane	< 99 vol.-%	< 98 vol.-%	< 98 vol.-%	> 99 vol.-%	< 98 vol.-%
Desulphur-isation?	< 500 ppm	< 100 ppm	< 1 - 2 ppm		
Subsequent treatment?	drying, desulphurisation, CH_4-removal from lean gas	(drying), desulphurisation, CH_4-removal from lean gas	CH_4 removal from lean gas	Drying	(drying), CH_4 removal from lean gas
Operating Pressure	8 bar	8 bar	5 bar	1 bar	8 - 17 bar
Electrical Energy demand $\frac{W_{el}}{\dot{V}_{Biogas,raw}}$	0.23 kWh/m³	0.29 kWh/m³	0.25 kWh/m³	0.07 kWh/m³	0.2 kWh/m³
Thermal Energy demand $\frac{W_{therm}}{\dot{V}_{Biogas,raw}}$	-	0.11 kWh/m³	-	0.60 kWh/m³	-

For injection of biomethane into high pressure gas grids connected to underground storages, respectively, the threshold value of oxygen has been reduced to 10 ppmv to avoid corrosion effects in the grid and storage infrastructure. Any of the presented processes for CO_2-removal are capable of removing significant amounts of O_2 and N_2.

However, there are commercial processes available for this task: The chemical adsorption with Cr and Cu as sorbent. It must be pointed out that temperatures above 150 °C and hydrogen are required for sorbent regeneration. An economically more feasible option is the selective catalytic combustion of hydrogen, carried out with platinum or palladium-catalysts or mixtures of both noble metals. Major drawback of this process is that the typical hydrogen content in biogas is by far not sufficient to remove all oxygen. Therefore, hydrogen has to be added from external sources, which is a considerable cost factor.

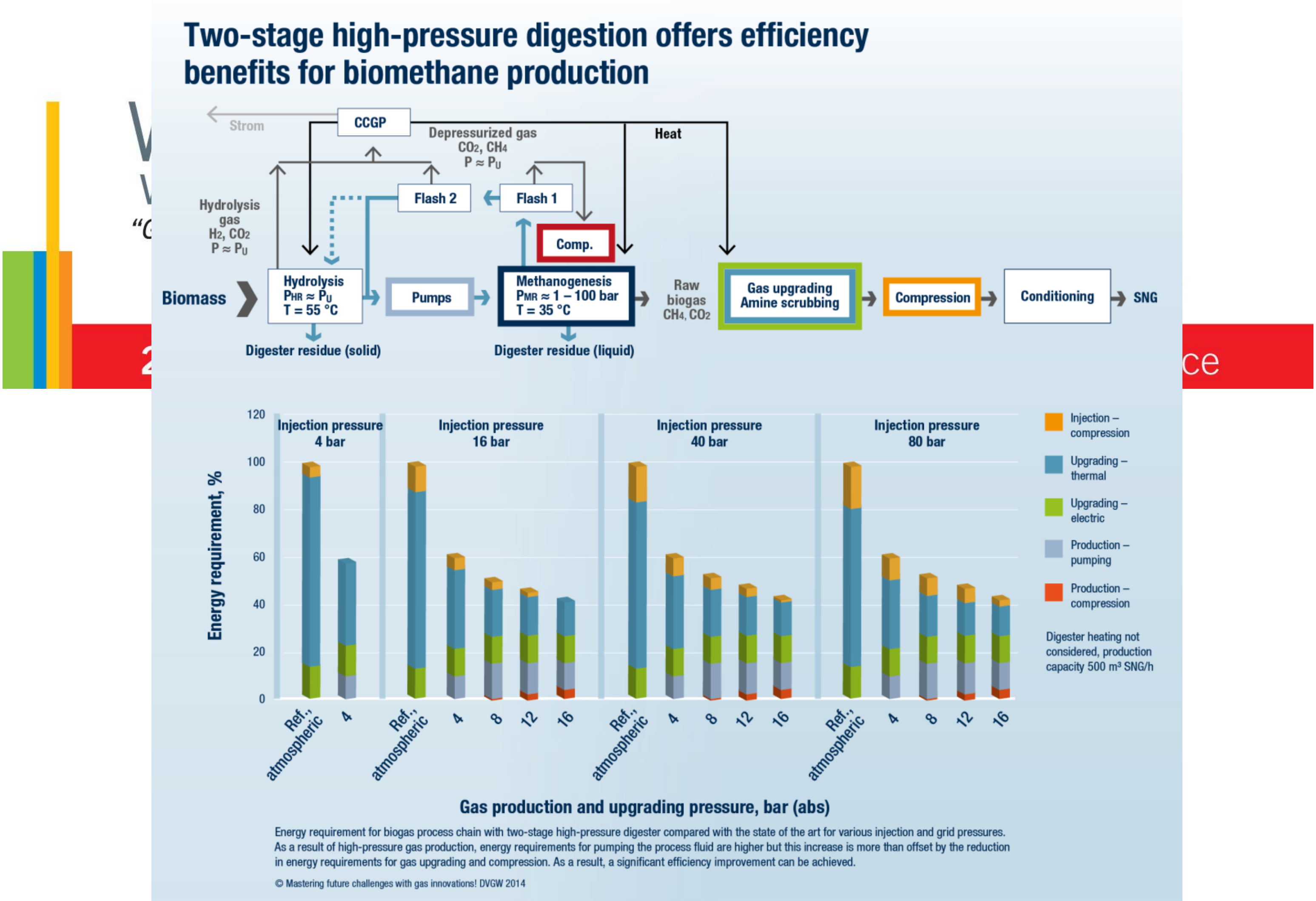
Optimization of plant management

Besides the development of new technologies, existing biomethane processes can be optimized for saving costs. But, unlike in case of photovoltaics or wind energy, optimization of a biomethane plant requires more detailed knowledge in process engineering (in order to understand the interrelationships of a biomethane production and upgrading chain and therefore being able to actually define a maxima of plant performance), controlling, but also in sales market issues. Canstein and Bauer [13] give an extensive overview and point out optimization potentials for existing systems.

Technological improvements

Concerning new technologies, the biogas production process can be optimized by applying a multi-stage fermentation concept, whereby the different biochemical degradation steps are carried out in separate reactors which are operated at optimized process conditions (e. g. temperature, pH-value, see Fig. 4) [14].

While the classical fermentation process, however, is neither designed nor optimized for a subsequent gas upgrading step, the so called two-staged pressurized fermentation process is an innovative concept for biomethane production with respect to injection into the natural gas grid. The process is examined by DVGW-EBI the University of Hohenheim within several research projects. In the two-staged pressurized fermentation process two approaches to improve biomethane production are combined: spatial separation of the two main decomposition phases (hydrolysis/acidogenesis and methanogenesis) and fermentation under increased pressure in the second (methanogenesis) reactor.



Energy requirement for biogas process chain with two-stage high-pressure digester compared with the state of the art for various injection and grid pressures. As a result of high-pressure gas production, energy requirements for pumping the process fluid are higher but this increase is more than offset by the reduction in energy requirements for gas upgrading and compression. As a result, a significant efficiency improvement can be achieved.

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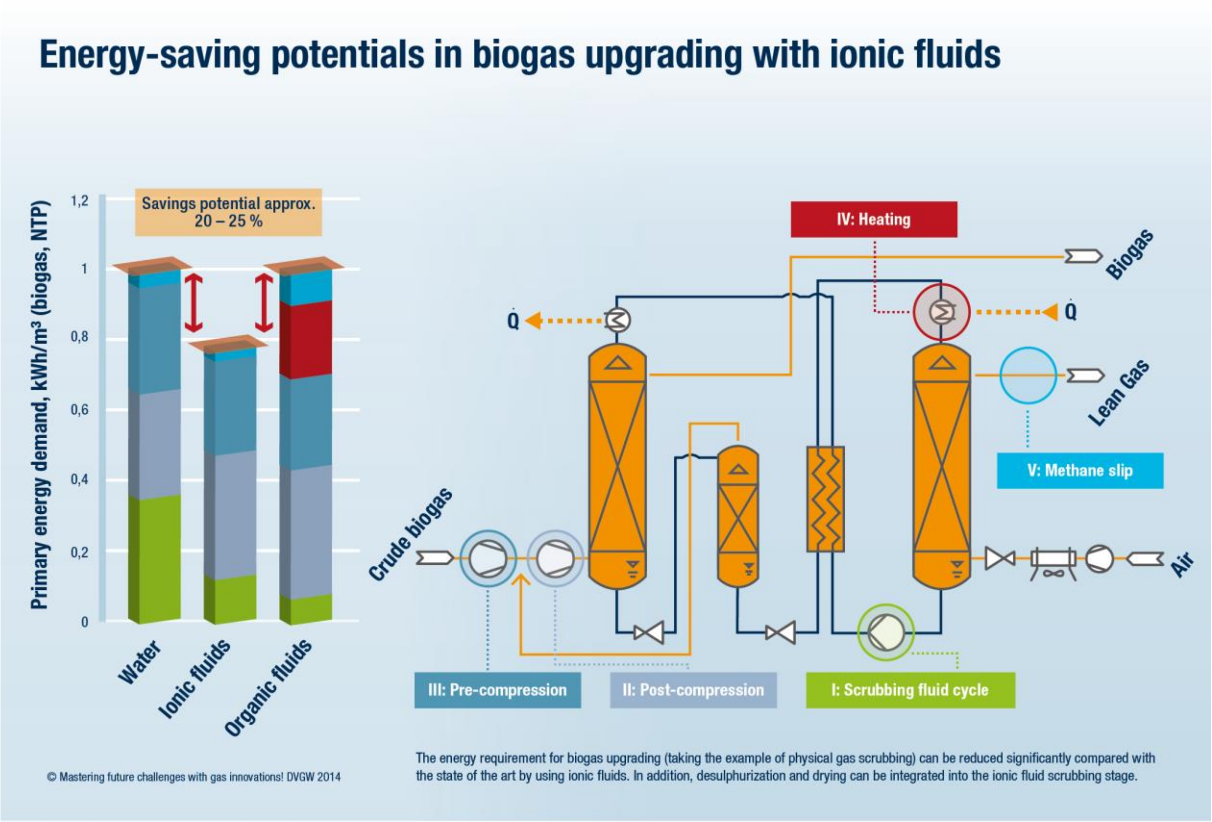
Fig. 4: Benefits by applying the two-staged pressurized fermentation process

The substrate is hydrolysed and acidified in the first reactor (hydrolysis) at ambient pressure. In this process, decomposed components and solvable contents such as glucose are extracted from the substrate, being percolated by a fluid. The nutrient loaded fluid or percolate is pumped into the second reactor which is based on the fixed or fluidized bed technique operating at elevated pressure. In this reactor, the methanogenesis reaction takes place, i.e. the solved nutrients are decomposed to methane and carbon dioxide.

These two main gas components show different solubilities in the aqueous fermentation broth. The solubility of carbon dioxide in water at 30 °C is about 23 times higher, than the solubility of methane. This leads to an enrichment of methane in the gas phase of the methanogenesis reactor, when operated at elevated pressure. While conventional biogas consists of about 50 vol.-% methane and 50 vol.-% carbon dioxide, methane contents of up to 90 vol.-% are possible in this new setup. Due to the advantages of this process, the costs of the following gas upgrading and injection processes can be significantly reduced (20 % savings are possible) as less CO_2 has to be removed and the need for energy-intensive compression of the biogas is reduced or even eliminated.

Another process engineering innovation, which is under ongoing research within several R&D projects, is a physico-chemical scrubbing process for CO_2-removal, based on the application of ionic liquids. This class of substance exclusively consists of ions and exists in the liquid state at temperatures as low as ambient (molten salts) [15]. Ionic liquids feature a negligible vapor pressure, predestinating the class of substance for gas absorption processes, as a contamination of the gaseous phase is nearly completely omitted. Ionic liquids can be applied for CO_2-removal as physical solvents, chemical solvents or in mixtures of both. In any case, energetic savings can be generated (Fig. 5). Again, considerable benefits in terms of lower energy consumption and a higher degree of process integration can be achieved and additionally, biogas upgrading with ionic liquids offers the possibility of generating synergy effects with the aforementioned two-staged pressure fermentation process.



Energy-saving potentials in biogas upgrading with ionic fluids

The energy requirement for biogas upgrading (taking the example of physical gas scrubbing) can be reduced significantly compared with the state of the art by using ionic fluids. In addition, desulphurization and drying can be integrated into the ionic fluid scrubbing stage.

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Fig. 5: Application of ionic liquids as physical scrubbing fluids

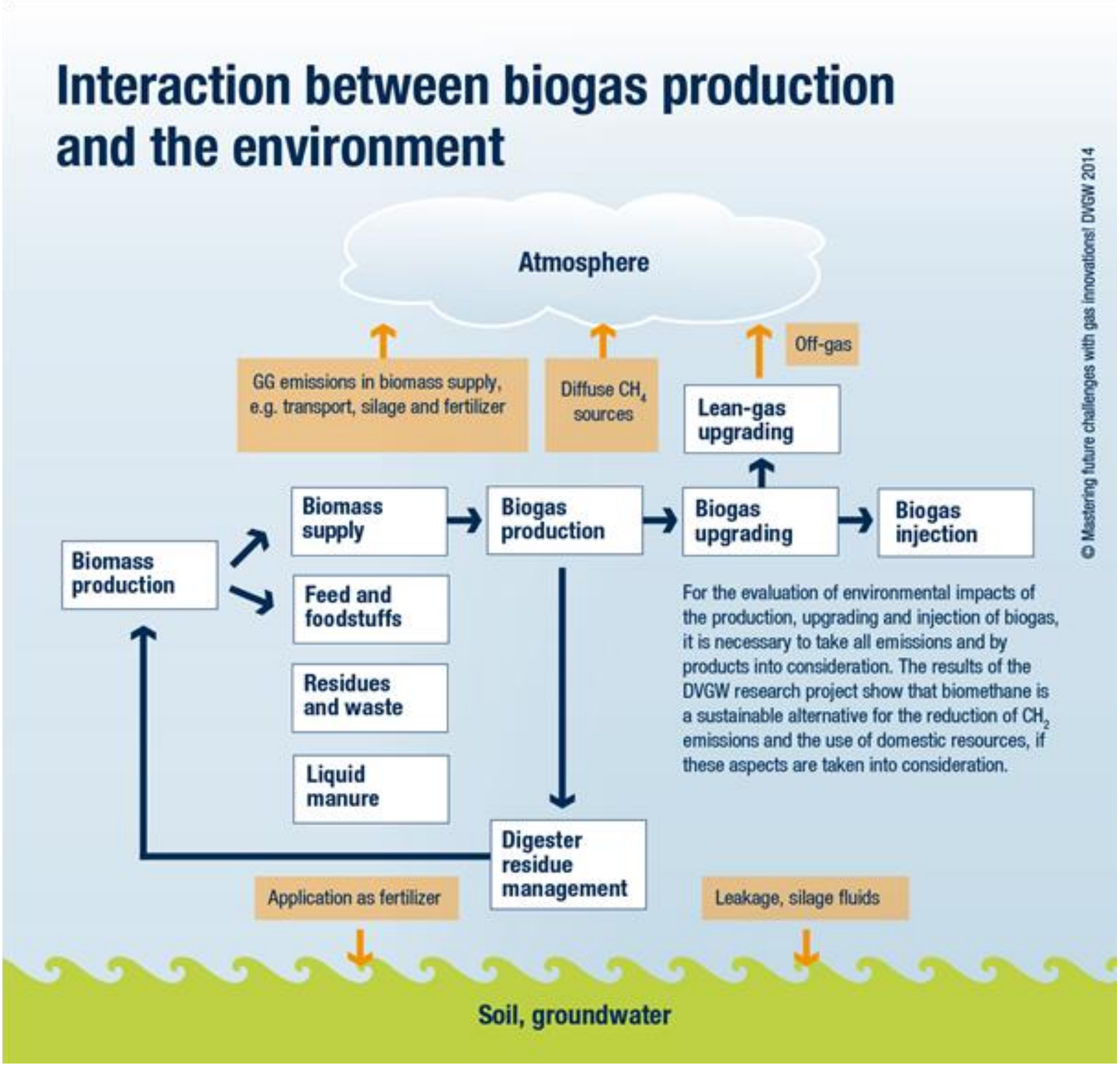
In summary, even after ten years of experience with the existing technology, efficiency and costs of biomethane production and upgrading can still be optimized by optimization of operation management of existing plants. Furthermore, new technological developments show significant potentials for additional savings.

Sustainability aspects

Besides technological and economical aspects, sustainability plays an important role in the discussion on bioenergy. In case of biomethane, several facets need to be addressed concerning cultivation of substrates and substrate supply chain, substrate conversion, energy efficiency, greenhouse gas emission, waste streams, and utilization of digestates (see Fig. 6).

GHG-Emissions of power production from biomethane ($g_{CO2,equivalent}/kWh_{el}$) are considerably lower than compared to conventional power production. In comparison with a natural gas fired CHP, biomethane production, upgrading, injection and utilization (CHP) saves approximately 50 % of GHG-emissions (150 $g_{CO2,equivalent}/kWh_{el}$) [16].

Furthermore, comparison of energy efficiency of biomethane injection with subsequent combined heat and power generation with the power generation directly on site of the biogas plant is an issue. Obviously, direct power generation is favorable when adequate waste heat utilization concept is available. Unfortunately, heat demand is limited in rural areas. Except for digester heating, waste heat can often not be used reasonably. In Fig. 7 the overall energy efficiency for biomethane upgrading and injection including subsequent power generation with heat utilization is compared to the direct power generation on-site of a standard biogas plant. For the centralized CHP a total efficiency of 85 % is assumed (η_{el} = 40 %, η_{th} = 45 %). For the biomethane case, two different injection pressures are considered, 16 bar and the particular operating pressure of the upgrading technology. The total energy efficiency ranges between 59.3 and 66.5 % for the biomethane case. Thus the injection is a reasonable alternative if no heat sink is available near to the biogas plant.



For the evaluation of environmental impacts of the production, upgrading and injection of biogas, it is necessary to take all emissions and by products into consideration. The results of the DVGW research project show that biomethane is a sustainable alternative for the reduction of CH_2 emissions and the use of domestic resources, if these aspects are taken into consideration.

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Fig. 6: Interaction between biogas production and the environment

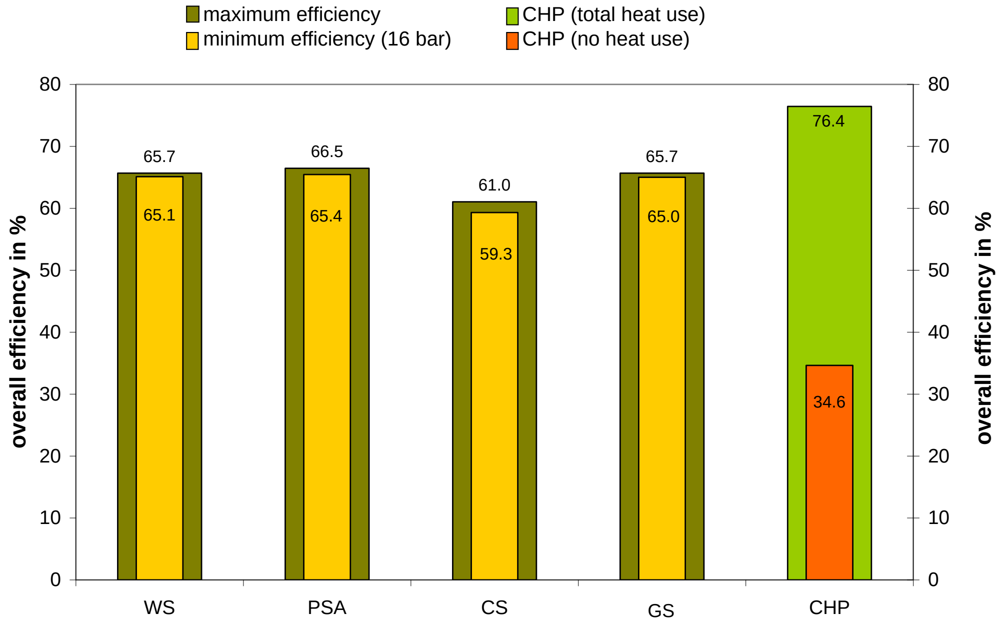

Fig. 7: Overall energy efficiency for biogas injection compared to decentralized CHP

Regarding greenhouse gas emissions several sources for methane emissions, essentially in old or poorly maintained plants are:

- storage of digestates
- leakages in the conversion and upgrading process
- off-gas from biogas upgrading (CO_2-removal, drying)

In modern plants, these difficulties are fairly eliminated due to legal requirements, operational experience and new technologies. For injection projects in Germany, methane emissions of the upgrading plant are limited to 0.2 % of the total biomethane capacity of the plant.

Another two topics in which especially the German water suppliers are interested are the influences of the increasing cultivation of energy crops for biogas production and the output of digestates on the water and soil quality. Application of digestates as fertilizer is intended, but not always possible, e.g. in case wastes are used as feedstock for biomethane production, as such substances can contain considerable amounts of contaminations e.g. heavy metals or bacteria. Further advice is given in Water Information 73.

Flexibility and synergy effects

Flexibility of power generation from biogas and shares on electricity balancing market can be generated by, e. g. retrofitting biogas CHP with gas storages or pooling of raw biogas for an additional combined upgrading and injection unit, wherever distances and local circumstances allow for. In particular for raw biogas grids, the technical guideline G 415 was released by the DVGW in the year 2011, giving advice on conception and design, corrosion aspects and profitability, which is affected by many factors, e. g. heat supply, gas composition, operating pressure, pipeline length, diameter and topography and especially raw biogas capacity [17].

Synergetic effects can be generated by coupling of biomethane production with Power-to-Gas (PtG) processes [18]. Thereby, CO_2 from biomethane plants is used as carbon source for a PtG plant. By coupling PtG with a biomethane plant, the area-specific fuel yield almost doubles without competing with food or animal feed production, as the biomass inlet stream remains constant (Fig. 8). Another advantage of the coupling of biomethane production with PtG processes is the possibility to use the heat and the oxygen from the PtG plant.

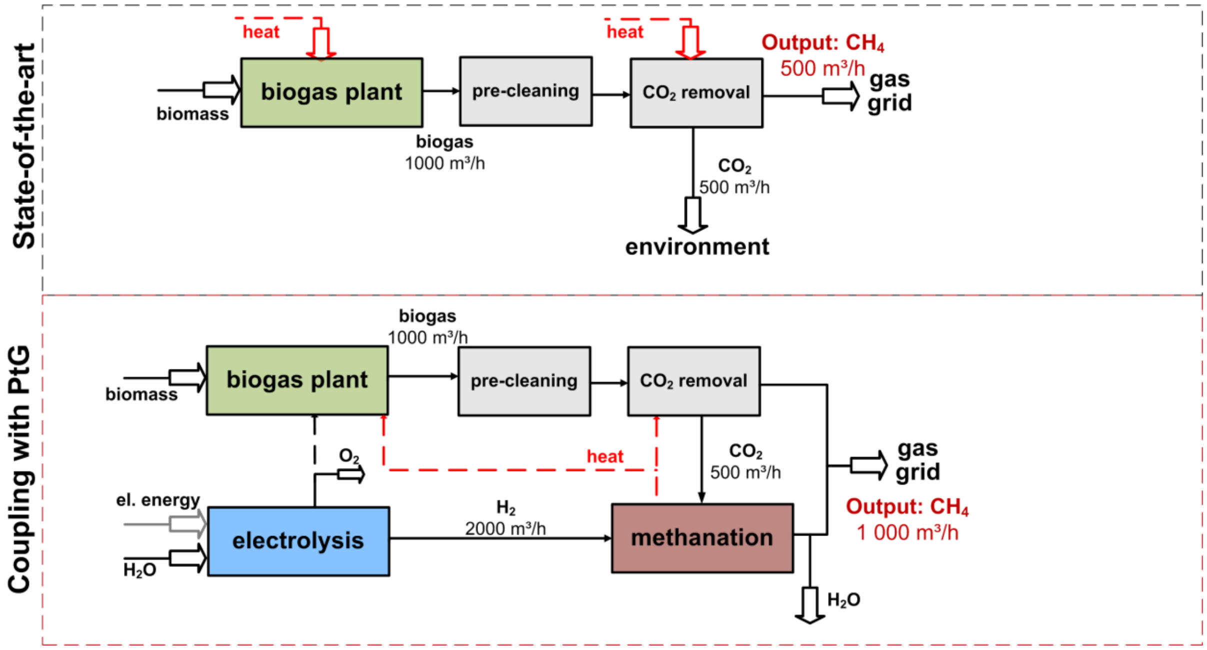

Fig. 8: Increase in biomethane production by integration of PtG processes

Further, oxygen can be utilized for biogas primary desulphurization purposes. The waste heat from methanation can be used to meet the demand of thermal energy for e.g. chemical scrubbing and for the digesters. For time periods when methanation is not operating, an alternative heat source is needed. For biogas upgrading by chemical scrubbing, typically 0.6 kWh/m³ of thermal energy are required for solvent regeneration [19]. The methanation reaction is able to cover this energy demand - approximately 60 % of the methanation´s waste heat would be used.

Conclusions

Biomethane is a promising option for the partial substitution of natural gas by a green energy carrier. With help of suitable production, upgrading, and injection processes and technologies biomethane is completely compatible to natural gas and offers noticeable CO_2 reduction compared to natural gas.

In the short- and medium term economics of biomethane cannot compete with natural gas prices, therefore the necessity for incentives persists and also will accompany the biomethane economy for a significant period of time. New process engineering developments and innovative gas grid injection indicate considerable potential for improvement of energy and cost efficiency and could therefore have a positive effect on public and political discussions concerning the future use of bio-energy. Furthermore, new business models and alternative ways for utilization can breathe fresh life into the sector. In particular, the supply of green transportation fuels (Compressed biogas (CBG), liquefied biogas (LBG)) is a promising option for passenger traffic and heavy duty transport. The coupling with PtG processes enables a maximum carbon utilisation and additional revenue options (e.g. balancing services).

Beside technical and economic aspects the environmental impact of biomethane production has to be addressed. The cultivation of energy crops is crucial with respect to land use, soil and water protection. Furthermore, greenhouse gas emissions during processing have to be limited strongly.

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