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Injection of gases from renewable sources into the gas grid in Germany – potentials and limits

Authors: Frank Graf*, Thomas Kolb**

*DVGW-Forschungsstelle am Engler-Bunte-Institut des Karlsruher Instituts für Technologie (KIT)
**Engler-Bunte-Institut, Karlsruher Institut für Technologie (KIT)

1. Background

One of the main challenges for the future is to cover the enormously increasing worldwide energy demand with renewable and sustainable sources. Various technologies based on renewable sources are already used for generation of heat, electrical energy and transportation fuels (Fig. 1). In 2010 about 11 % of the final energy consumption was covered by renewable sources in Germany. In 2011 about 20 % of the power supply was generated by renewable energy. By the integration of gaseous fuels from renewable sources the existing natural gas infrastructure can play a mayor role in the future energy supply. With the injection of gaseous fuels into the available transportation and distribution grids a local and temporal decoupling of production and consumption is possible. Furthermore, volatile electrical energy from wind power and photovoltaic plants could be stored with the help of the gas infrastructure.
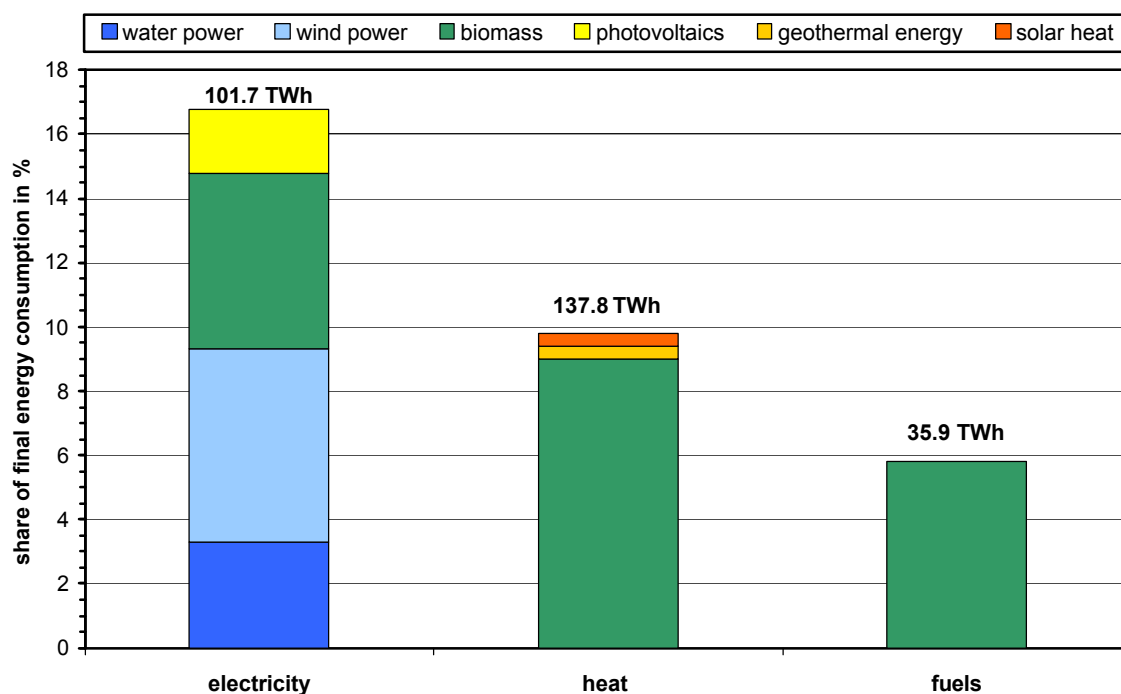

Fig. 1 Contribution of renewable source to final energy consumption in Germany 2010 [1]

In the following the potentials, limits and the technical challenges in generation and injection of gases from renewable sources are discussed. Hereby, practical experiences and challenges are discussed. Furthermore, innovative research and development approaches at Engler-Bunte-Institut will be presented.

2. Legal framework and technical standardization for injection of renewable gases

In Germany the legal, technical and economical conditions for biogas injection are regulated by EnWG (German Energy Act) [2], GasNZV (Gas Grid Access Ordinance) [3] and EEG (German act on granting priority to renewable energy sources) [4]. The German regulator BNetzA is responsible for controlling and monitoring of injection projects. For example the discrimination free access to the gas grid for biogas producers and the distribution of injection costs between producer and grid operator are important tasks. Furthermore, BNetzA is involved in the technical standardization for biogas injection. In 2011, a monitoring study evaluating the progress in the implementation of the political objectives was prepared [5]. Beside other aspects, investment and operating costs as well as trading prices of injected biogas were summarized for the years 2008 to 2010. In 2012 the GasNZV will be amended. According to the latest amendment of EnWG SNG and H_2 are defined as biogas if at least 80 % of the input educt gas/energy streams stem from renewable sources.

In Germany, the DVGW (Deutscher Verein des Gas- und Wasserfaches e. V. - Technical and Scientific Association for Gas and Water) has been providing technical and scientific support for the German gas and water industry since 1859. All the activities of the DVGW focus on safety, hygiene and environmental protection, taking efficiency and cost-effectiveness into consideration. As a technical standardization organization, the DVGW promotes technological development in its sector. The production, transportation, distribution and use of energy and drinking water always call for technical processes and plant. The technical standards of the DVGW lay the foundations for technical self-regulation under the responsibility of the German gas and water industry and ensure safe gas and water supplies at the highest international levels. Therefore, DVGW masterminds the development of technical conditions for biogas injection into the gas grid in Germany. Quality and safety aspects are discussed in several task forces and working groups and technical standards are revised and developed. Furthermore, gas and water specific aspects are examined in a perennial research program.

Since the WGC 2009 [6] the DVGW standardisation has been exceeded and modified in various fields (Tab. 1). VP 265-1 was complemented by G 265-2 describing the operation, servicing and maintenance of biogas upgrading and injection. Technical specifications for the construction of raw biogas pipelines are defined in G 415. Herby, the technical standards for the construction of natural gas pipelines have been adopted.

Most important is the revision of the technical rule G 262 which specifies the gas quality for renewable gases injected into the gas grid. Therein, the limits for CH_4, CO_2, H_2, O_2 and water were modified. A harmonisation with G 260 will take place in 2012. If injected biogas is used in CNG car filling stations DIN 51624 still has to be taken into account additionally. In Tab. 2 the updated gas quality requirements are summarized.

Tab. 1 DVGW-standards related to biogas injection

standard	name
G 262 (2011)	Usage of gases from renewable sources in the public gas supply
VP 265-1 (2008)	Biogas upgrading and injection plants – Part 1: gases produced by fermentation, planning, construction, testing and bringing into operation
G 265-2 (2011)	Biogas upgrading and injection plants – Part 2: gases produced by fermentation, operation, servicing and maintenance
G 290 (2012)	Re-injection of injected biogas into up-stream transportation pipelines
G 415 (2011)	Raw biogas pipelines
G 1030 (2010)	Requirements on qualification and organisation for operators of plants for production, transmission, upgrading, conditioning or injection of biogas
Water Information 73 (2010)	Cultivation of biomass for biogas generation in consideration of soil and water protection

Tab. 2 Quality requirements for biogas injection in Germany

parameter	unit	value	standard
condensation temperature	°C	soil temperature (at pipeline pressure)	DVGW G 260
dew point			DVGW G 260
water	mg/m^3	200 (MOP ≤ 10 bar)	G 262
	mg/m^3	50 (MOP > 10 bar)	G 262
	mg/kg	40	DIN 51624
dust, particles	-	technical free	DVGW G 260
ammonia, amines	-	technical free	DVGW G 262
O_2 (dry grids)	vol.-%	3	DVGW G 260
	ppm	10 (MOP ≥ 16 bar, cross border points and/or underground storage)	DVGW G 262
total sulphur	mg/m^3	30 (exclusive odorization)	DVGW G 260
	mg/kg	10 (CNG, inclusive odorization)	DIN 51624
mercaptan sulphur	mg/m^3	6	DVGW G 260
H_2S	mg/m^3	5	DVGW G 260
CO_2	vol-%	10 (natural gas L)	DVGW G 262
	vol-%	5 (natural gas H)	DVGW G 262
H_2	vol-%	< 10*	DVGW G 262
	vol-%	2	DIN 51624
CH_4	vol-%	≥ 90 (natural gas L)	G 262
	vol-%	≥ 95 (natural gas H)	G 262
propane	vol.-%	6	DIN 51624
butane	vol.-%	2	DIN 51624
superior calorific value	kWh/m^3 (NTP)	8.4 - 13.1	DVGW G 260
relative density	-	0.55 - 0.75	DVGW G 260
Wobbe number (natural gas L)	kWh/m^3 (NTP)	10.5 - 13.0	DVGW G 260
Wobbe number (natural gas H)	kWh/m^3 (NTP)	12.8 - 15.7	DVGW G 260

*subject to technical feasibility (e.g. CNG cars, turbines, PGC) and further scientific findings

3. Biogas Injection

3.1 Development of biogas injection in Germany

Currently, about 7,100 biogas plants with an electrical power of about 2.78 GW are installed in Germany [7]. The produced biogas gas is used mostly for decentralized power generation on site or nearby the biogas plants. As biogas plants are often located in rural areas the efficient use of co-produced heat is limited and therefore about 50 % of the chemical energy stored in biogas is lost as heat to the ambient. Hence, biogas injection into the gas grid with subsequent combined heat and power generation at suitable locations is a designated political objective. Up to 2020 policy demands that 6 billion m^3/a natural gas should be substituted by biogas. This ambitious goal can only be achieved if the availability of biomass is possible in a sustainable manner.

After a few demonstration projects for injection of upgraded landfill gas in the 1980s the injection of biogas into the gas grid started in 2006 with 2 plants. At the end of 2011 72 biogas injection plants with an injection rate of more than 45,000 m^3/h have been in operation (Fig. 2). The range of injection rate varies between 125 to 5,000 m^3/h per plant with an average injection capacity of approximately 620 m^3/h (Fig. 3). Various upgrading technologies are used in practice. Pressure swing adsorption, water scrubbers and amine scrubbers are the most common upgrading technologies. Details about upgrading technologies and processes can be found elsewhere [8].

Within 2012 40 more plants will be connected to the gas grid. Although the number of injection plants increased strongly within the last years, this is by far not enough to fulfil the ambitious guidelines mentioned before. To reach the political target more than 100 plants with an average injection rate of approximately 700 m^3/h have to be realized per year until 2020. It is a moot point whether the amendment (January 2012) of the German act on granting priority to renewable energy sources (EEG) brings a positive impulse for the biomethane market. On the one hand the new regulations are in favour of biogas injection plants, on the other hand the specific production costs will increase further as the share of corn as substrate is limited to 60 % of the feedstock to avoid corn monocultures. Thus, co-substrates with less specific methane output have to been used in future. Currently, the costs for injected biogas exceed the cross border prices of natural gas by the factor of three to four.
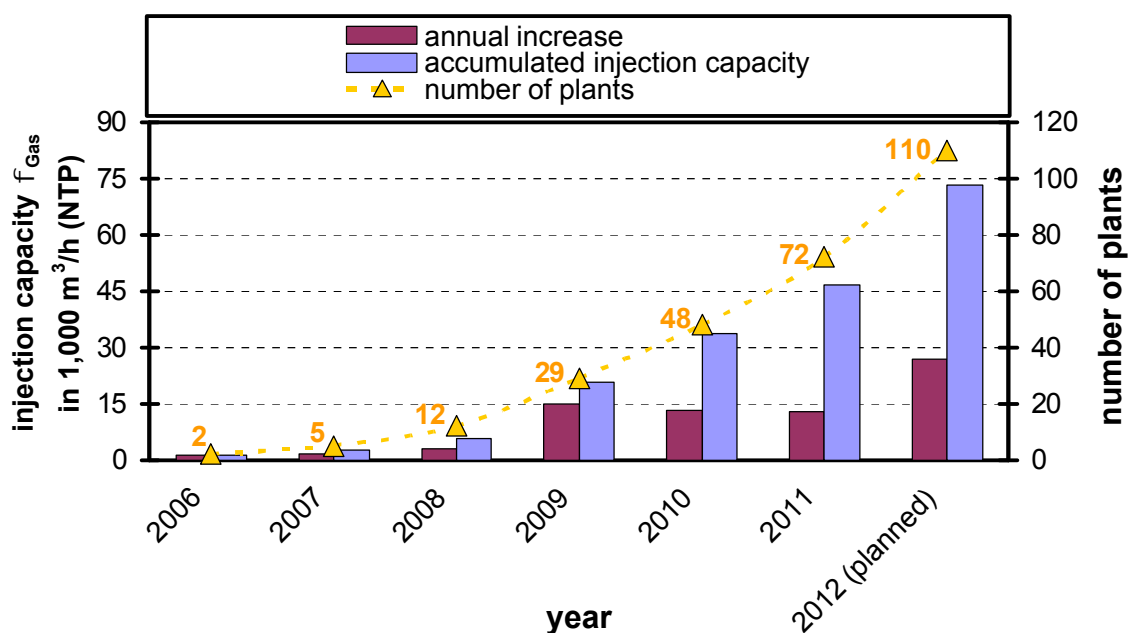

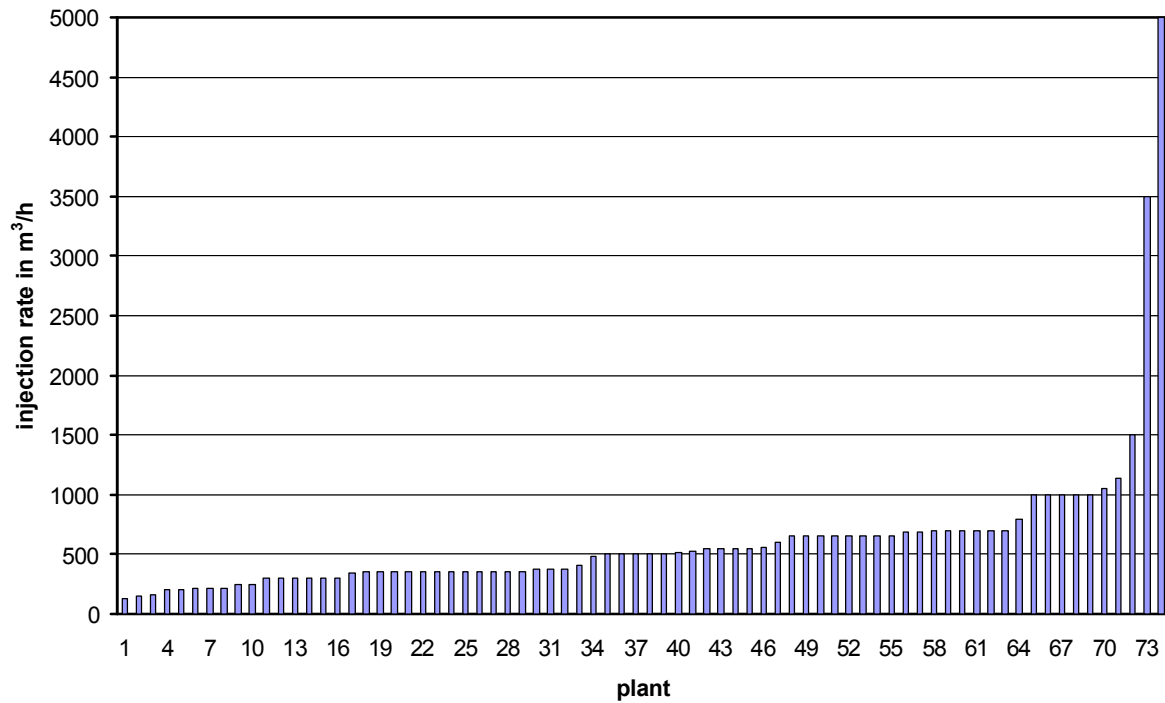Fig. 2 Development of biogas injection in Germany [9]

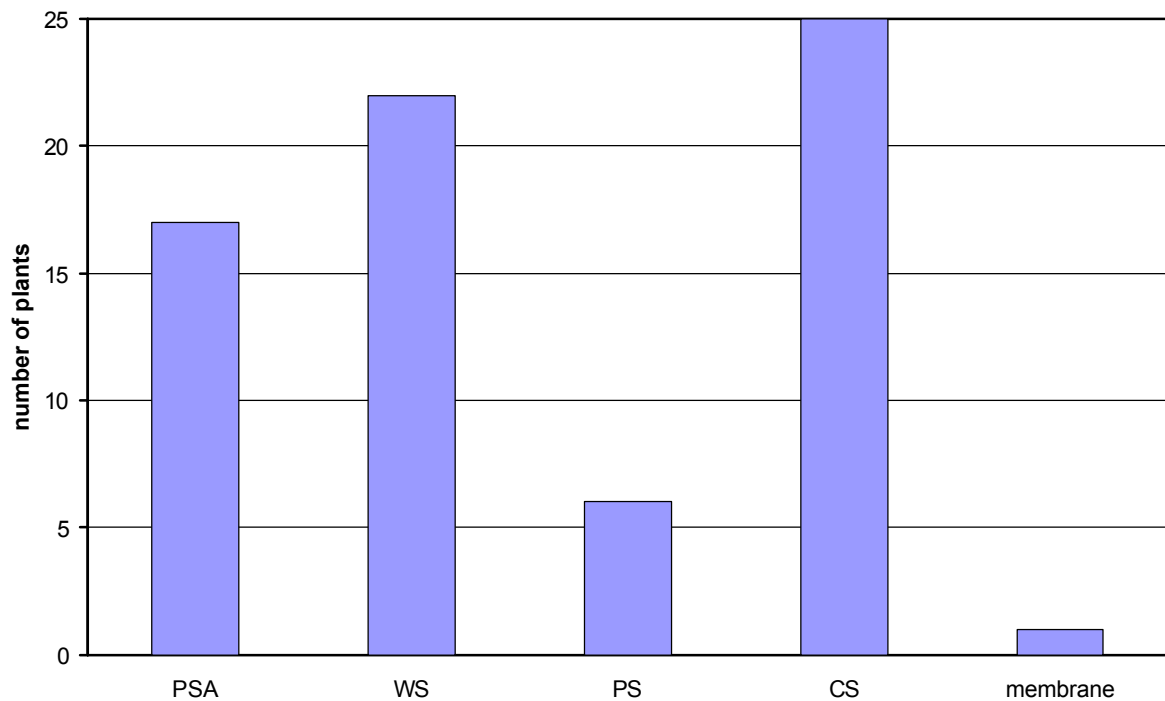Fig. 3 Distribution of plant capacities in Germany [9]

Fig. 4 Used upgrading technologies in Germany [9] (PSA: Pressure swing adsorption, WS: Water scrubber; PS: Physical scrubber; CS: Chemical scrubber)

One option for the further development of biogas injection in Germany could be the advantages of biogas as renewable fuel for CNG which have to be emphasised more strongly in the public discussion. Compared to other renewable fuels like bio diesel and bio ethanol, biogas offers considerable pros concerning specific energetic yield and climate relevant parameters [10]. This could also rectify the situation on biomass cultivation due to a lower spe-

cific demand of land. With increasing use of biogenic residuals like bio waste from rural and industrial sources further improvements are possible.

A new aspect represents the injection of biogas from the distribution grids into upstream high pressure systems due to capacity bottlenecks in summer time. Hereby, additional purification efforts for drying, O_2-removal [11] and deodorization can be required. Technical recommendations are summarized in DVGW code of practice G 290 (s. Tab. 1). In addition, technical and economical aspects were examined in detail in the DVGW study "Avoiding and removal of oxygen in the biogas process chain".

Within the last years biogas technology was developed further. Especially in the fields of biogas production and upgrading new processes were designed and optimizations of existing processes are going on. By now, a wide range of contractors provide biogas technology and the industry is growing fast in Germany. R&D activities and process optimizations focus especially on

- process intensification and integration
- energy efficiency
- reliability
- reduction of investment and operating costs.

In conclusion, the injection of biogas is a promising possibility to integrate a renewable source in an existing and well developed infrastructure coupled with energy efficient and environment-friendly gas appliances.

3.3 R&D topics at Engler-Bunte-Institut

3.3.1 Pressurized fermentation
Improvements in the biogas production regarding process intensification and biogas yield/composition can be achieved by multi-stage process concepts. Thereby, the biochemical fermentation process takes place in different reactors with optimized process conditions (e. g. temperature, pH-value).
The typical fermentation process, however, is so far neither designed nor optimised for a subsequent gas upgrading step. An innovative concept optimizing the fermentation process with respect to biogas injection is examined by DVGW Research Station at the Engler-Bunte-Institute of the Karlsruhe Institute of Technology (DVGW-EBI) and the State Institute of Agricultural Engineering and Bio-Energy at the University of Hohenheim (LAB) within the BMBF project "B2G" [12]. The basic flow sheet of this new process is shown in Fig. 5. In a two-phase pressurized fermentation process two approaches to improve biogas production are combined: on the one hand, spatial separation of the two main decomposition phases (hydrolysis/acidogenesis and methanogenesis) and on the other hand pressure fermentation in the second (methanogenesis) reactor.
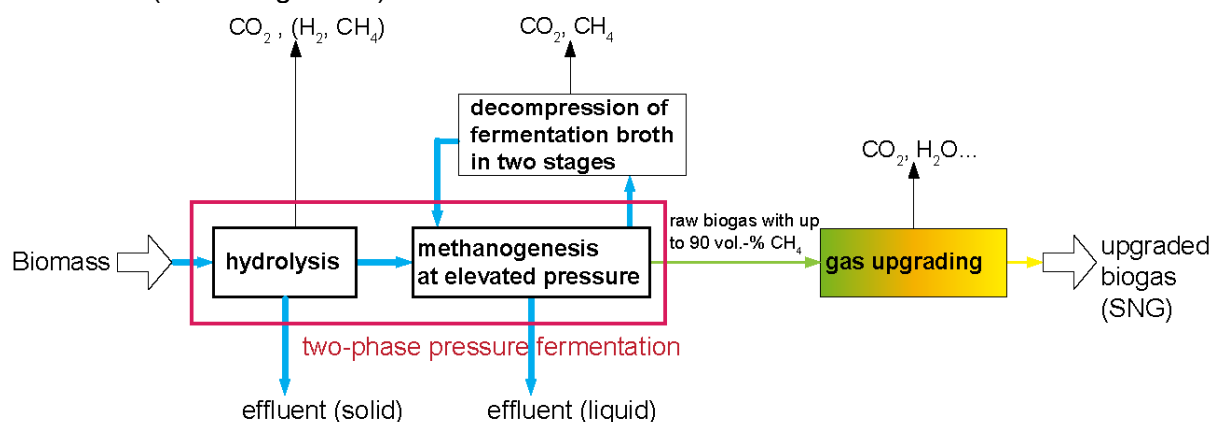

Fig. 5 Block flow diagram of the two-phase pressure fermentation

The substrate (energy crops, organic waste, farm fertiliser) is hydrolysed and acidified in the first reactor (hydrolysis) at ambient pressure by "bioleaching", a method developed at the LAB [13]. In this process decomposed components and solvable contents like 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 pressure fermentation the methanogenesis takes place, i.e. the solved nutrients are decomposed into CH_4 and CO_2. The produced biogas has advantages concerning the biogas composition. A conventional biogas consists of about 50 vol.-% methane and 50 vol.-% carbon dioxide. These main components show different solubilities in aqueous solutions as 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 during the fermentation. Methane contents can reach up to 90 vol.-% leading to savings in the upgrading process [14].

3.3.2 Biogas upgrading with ionic liquids

In the field of biogas upgrading innovation takes place as well. New solvents for chemical scrubber systems are developed to minimize the energy demand for regeneration and to increase the tolerance against oxygen [15]. Within the aforementioned BMBF-project "B2G" the applicability of ionic liquids for biogas upgrading is examined. Experimental and theoretical investigations (e.g. solubility tests) are undertaken to design a suitable scrubber system based on ionic liquids. Ionic liquids (molten salts, which are liquid at room temperature) as solvents for biogas upgrading provide promising opportunities, e. g. a high solubility of impurities, such as carbon dioxide and hydrogen sulfide and on the other hand a poor solubility of methane, which results in a good selectivity for carbon dioxide removal (as shown in Tab. 3). Furthermore, ionic liquids feature a negligible vapour pressure, which prevents the loss of solvent and therefore a contamination of the product gas and implicates a reduction of costs, induced by condensation or replenishing efforts.

Tab. 3 Comparison of solubility (Henry coefficients) and selectivity CO_2 vs. CH_4 for different solvents

Solvent	H_{CO2} in bar	H_{CH4} in bar	$S_{CH4/CO2}$ = H_{CH4}/ H_{CO2}
Water	1650	40100	24.3
Genosorb®	26	400	15.5
Ionic Liquid [16] (e.g. [MMIM][MeSO$_4$])	130	4500	> 34

4. Thermochemical conversion of biomass to SNG

4.1 Introduction

The possibilities and benefits of SNG production based on coal have been studied intensively after the first oil price and supply crises in the 1970s and -80s. One plant running with lignite as feedstock was realised in North Dakota in 1984. This plant with a fuel power of 2 GW is still operating successfully [17]. The transformation of coal or biomass into SNG via thermochemical gasification can be described by the process steps shown in Fig. 6. In the first step the feedstock is gasified with oxygen and/or water to produce a raw synthesis gas. To avoid poisoning of catalysts in the catalytic SNG synthesis step various components like dust, tars, sour gases and halogens have to be removed in several gas cleaning processes. Finally, CO_2 and H_2O have to be removed from the product gas. In the case of biomass as a feedstock the composition of the product gas leaving the methanation step is very similar to biogas from fermentation processes. Therefore, the final upgrading processes are nearly the same for thermochemical and for biochemical gasification. More technical details can be found elsewhere [18].

coal/ biomass → gasification → gas cleaning → gas conditioning and methanation → SNG upgrading → SNG
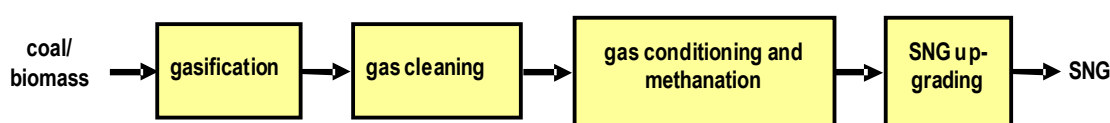
Fig. 6   Block flow diagram for SNG-synthesis

The technologies used for the 2 GW coal based SNG process can not directly be converted to biomass based gasification plants because of the lower energy density and the decentralised production of biomass, in contrary to fossil fuels. These factors demand new concepts especially for biomass gasification and will result in much smaller plant capacities. Within the last years, the SNG production from biomass was scope of various research and development projects. One pilot plant with a SNG output of 1 MW was built in Güssing (Austria) [19].

The overall energy efficiency for the process is similar to the production and upgrading of biogas for injection into the gas grid. Problematic are the specific production costs which are about 5 times higher than current natural gas cross border prizes. Rising biomass costs due to limited availability as well as limited revenues from co-generation of thermal energy increase the financial risk of biomass to SNG projects. Within the last years, the SNG production from biomass was scope of various research and development projects.

4.2 R&D topics at Engler-Bunte-Institut

4.2.1 Gasification of biomass, KIT´s bioliq® process

Synthetic fuels from biomass (also referred to as BTL, biomass to liquids) may contribute to the future motor fuel consumption to a considerable extent. To overcome the logistical hurdles connected with the industrial use of large quantities of biomass, the de-central-centralized bioliq® concept has been developed at Karlsruhe Institute of Technology, KIT. It is based on a regional pre-treatment of biomass for energy densification by fast pyrolysis. The intermediate referred to as biosyncrude allows for economic long-range transportation. Collected from a number of those plants, the bio-syncrude is converted into synthesis gas, which is cleaned, conditioned and further converted to fuels or chemicals in an industrial plant complex of reasonable size. Gasification is performed in a high-pressure entrained flow gasifier at pressures adjusted to those of the subsequently following chemical syntheses. For increased fuel flexibility and conversion of ash rich feed materials the gasifier is equipped with a cooling screen operated in slagging mode. At the Karlsruhe site a pilot plant has been erected for process demonstration along the whole process chain. The 2 MW$_{th}$ fast pyrolysis plant is already in operation since 2009; the 5 MW$_{th}$ gasifier, the hot gas cleaning section, and a gasoline synthesis via DiMethylEther, DME are to be finished in 2012. Commissioning

of that plant complex will follow in 2012. Fig. 7 shows a principle process flow sheet of the bioliq® plant
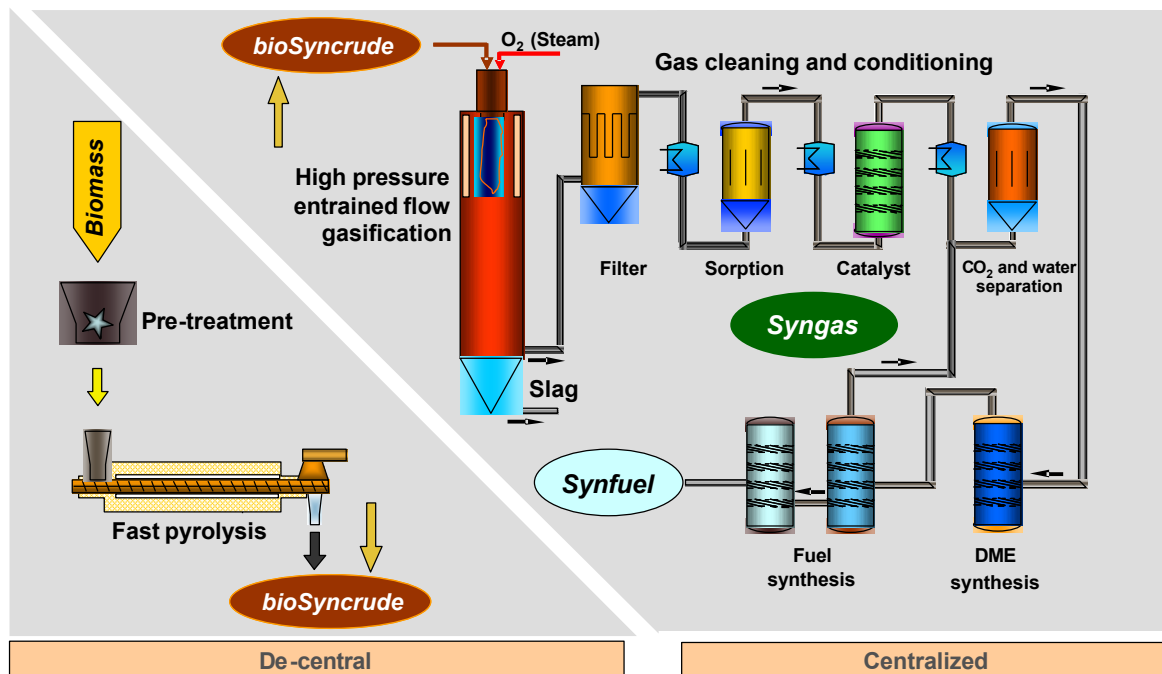

Fig. 7 Principle process flow sheet of the bioliq® plant

The bioliq plant, with pyrolysis and high pressure entrained flow gasifier will be the back bone of KIT´s Energy Lab. This large research facility will be operated in Karlsruhe in order to develop and demonstrate energy conversion technologies for future energy supply systems. Electricity supply in future systems will be dominated by electricity production from renewable energy sources with high production volatility. The challenges of energy storage and transportation have to be addressed. Amongst other technologies to be established at the Energy Lab, the biomass fed gasifier will be coupled with a gas turbine and alternatively a methanisation process step in order to demonstrate the potential of an IGCC/synthesis-coupled process with respect to load and product flexibility. The flexible switch between electricity and SNG production in order to balance electricity demand and production has to be demonstrated with this process chain.
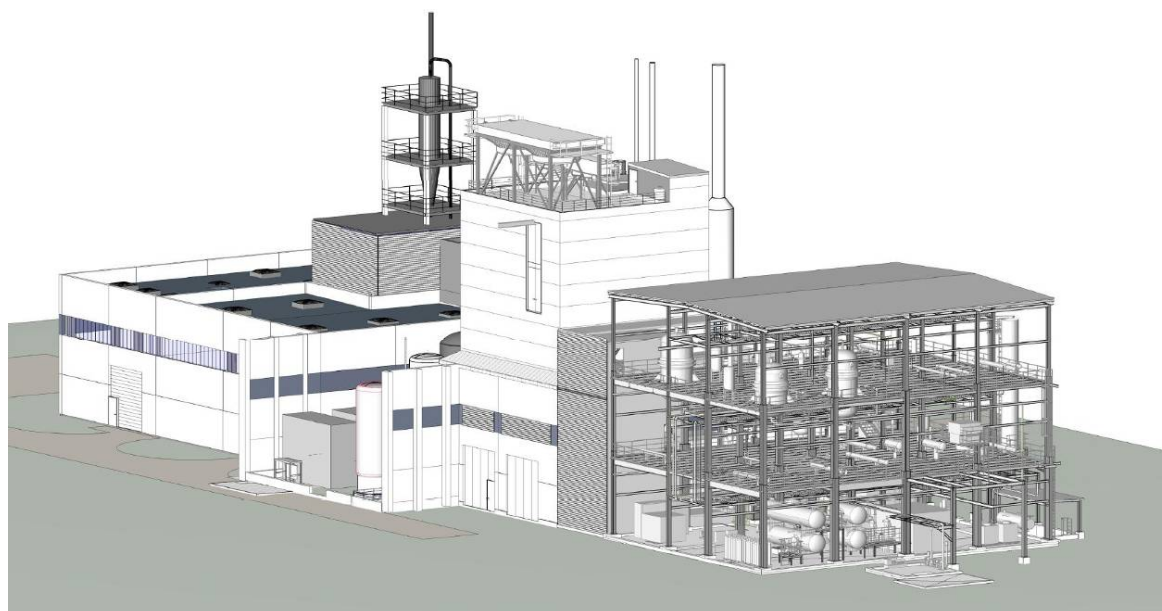

Fig. 8 Model of the bioliq® demo plant at KIT

4.2.2 Gas cleaning and methanation

For the thermochemical production of SNG from biomass fluidized bed gasifiers are commonly proposed as hydrogen and methane rich but also tar loaded raw gases can be generated. These raw gases have to be cleaned and upgraded before the conversion to SNG. The state of the art process for raw gas upgrading is a process chain of scrubber systems operating at low temperatures. This process suffers from high specific investment and operating costs and sulphur slip in the form of thiophenes with diesel or rapeseed oil methyl ester (RME) driven tar scrubbers. Furthermore, the energetic efficiency is limited by low temperature levels and required large heat transfer areas of the heat exchangers due to high heat fluxes. A typical SNG process concept is shown in Fig. 8.
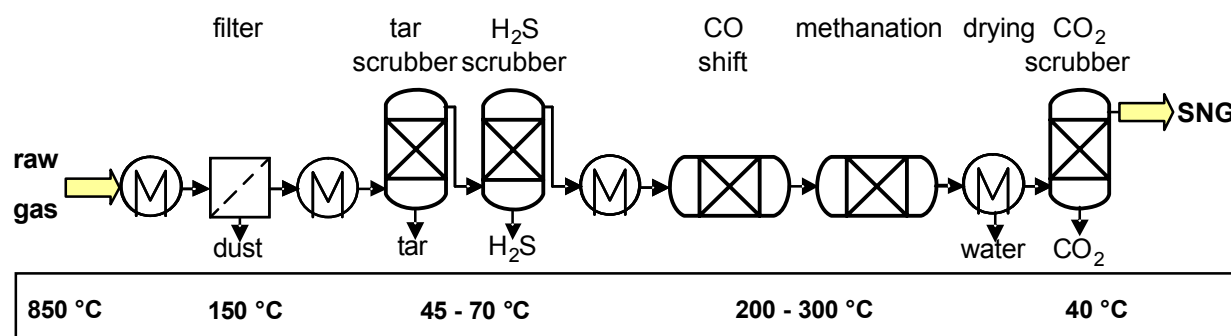

Fig. 8   Conventional SNG process

A promising approach with respect to an increased energetic efficiency and a lower specific investment is the application of a hot gas cleaning concept. The major obstacles for the application of this concept are the degradation of the catalysts used in these processes caused by sulphur and the required purities of the synthesis gas for methanation. To overcome these obstacles a new generation of tar reforming catalysts is investigated allowing tar conversion at moderate temperatures under presence of typical sulphur contaminations of raw gases from biomass gasification. Furthermore, these catalysts could convert thiophenes and mercaptanes into hydrogen sulphide, allowing a simplified absorptive desulfurization after tar reforming (Figure 9).
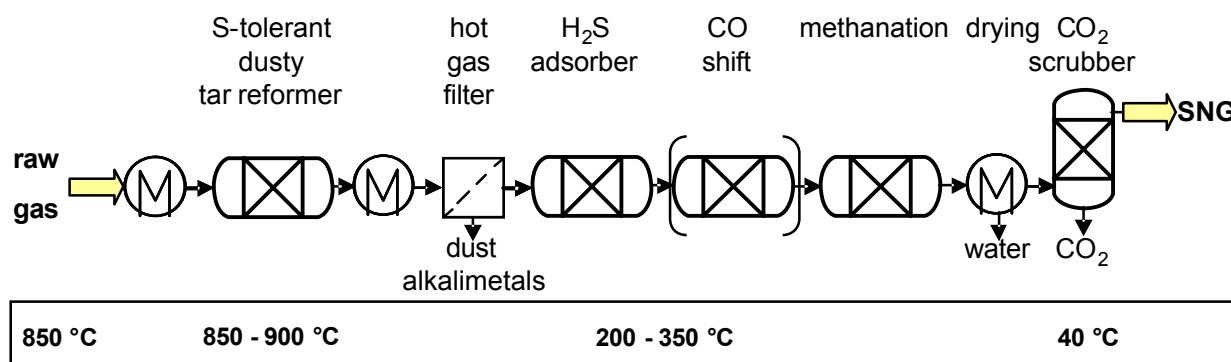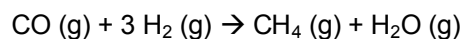

Fig. 9   Proposed alternative SNG process

The proposed hot gas cleaning concept will reduce exergetic losses by the reduction of required heat fluxes and increased temperature levels in comparison to the state of the art gas cleaning processes with scrubbers shown in Fig. 8.

The catalytic conversion of synthesis gas into methane is usually carried out on nickel catalysts according to the following reaction:

CO-methanation

$CO\ (g) + 3\ H_2\ (g) \rightarrow CH_4\ (g) + H_2O\ (g)$ $\Delta_R H^0 = -206$ kJ/mol   Eq. 1

For the highly exothermic methanation reaction (Eq. 1) conventional fixed bed reactors are used commonly. With this kind of reactors the heat management is very difficult because of its poor heat transfer rates in the fixed bed. Recent results on process intensification show high potentials of metallic structured packings for exothermic reactions [18]. The use of metallic honeycombs as shown in Figure 10 with a high specific surface as catalyst supports improves the heat transfer and allows a better temperature control in the reactor. Lab scale experiments are promising. At low methanation temperatures high conversion rates can be realized (Fig. 11). Test with real gasification gases will be examined in the next step.
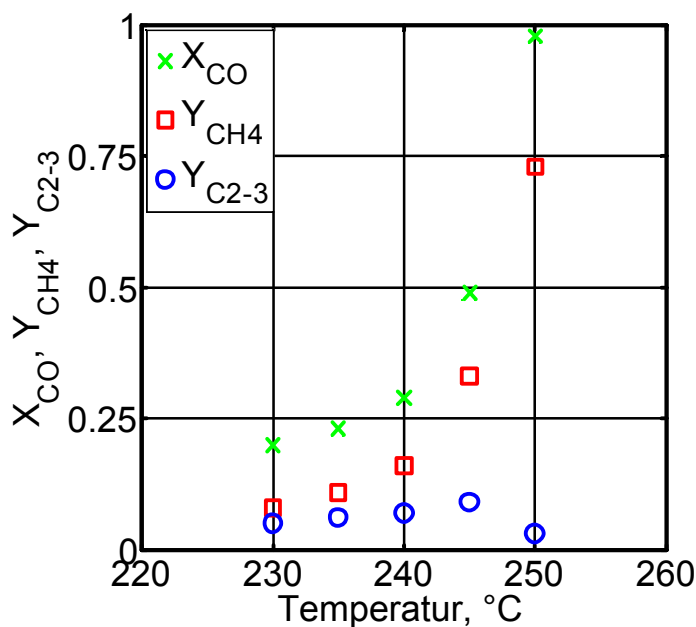

Fig. 10 metallic honeycomb

Fig. 11 Results of lab scale methanation tests with honeycomb reactors (X_{CO}: CO conversion, Y_i: Yield of component i)

5. Power to gas

5.1 Introduction

The increasing production of volatile wind and solar power in Germany requires new technologies for the storage of electrical energy. In Germany, for 2050 an energy storage capacity of about 17 - 25 TWh is anticipated [20]. For those quantities of electric energy and for storage durations of several days or weeks energy storage via gaseous fuels is a reasonable option. With an existing storage capacity of the gas infrastructure in Germany of approx. 330 TWh chemical energy the expected needs can be covered by far.

Hydrogen production via electrolysis and direct injection into the gas grid is the simplest form of PtG technology. About 70 - 75 % of the surplus electricity can be fixed in the versatile chemical energy carrier H_2. For domestic gas appliances hydrogen contents about 10 vol.-% seems to be unproblematic. Open questions arise for CNG cars, turbines and various industrial processes. If the hydrogen content exceeds the maximum limit SNG-generation is a promising alternative. This process variant converts H_2 from electrolysis and CO or CO_2 into CH_4. The carbon source can stem from gasification or combustion processes as well as from gas upgrading processes (e.g. biogas upgrading). Due to further conversion losses in the methanation step the overall efficiency (Power to SNG) lies at 56 - 60 %. However, the losses can be diminished by using at least part of the thermal energy from the methanation step in a suitable way.

5.2 PtG-Technology

The first step on the way of storing electricity in chemical energy carriers is the electrolysis of water to hydrogen. Operation of the electrolysers under elevated pressure is advantageous for downstream operations like methanation and/or injection in a high-pressure gas grid. As shown in Tab. 4, the two best established technologies for water electrolysis are the alkaline electrolysis and the PEM-electrolysis (Proton Exchange Membrane). Typical operation temperature for both processes is about 80 °C; the pressure can vary from 1 to 30 bar. The efficiency from electricity to chemical energy bound in hydrogen is about 70 - 80 %. Both alkaline and PEM-electrolysis are flexible with regard to fluctuating electricity supply. However, the peripheral devices like water conditioning and gas cleaning units are not as flexible as the electrolysis stack itself.

The alkaline electrolysis has the advantage of being a proven technology. Hence, the specific costs are comparatively low. Proven lifetimes can be more than 30 years. Units with a hydrogen production stream ${}^V\Phi_{H2,NTP}$ of up to 760 m³/h are commercially available. By modular combination of several units much bigger hydrogen flows can be realised. The electrolyte is a KOH-water solution which has to be handled in the process.

Tab. 5 Comparison of the alkaline electrolysis and the PEM-electrolysis [21 - 25]

technology	alkaline	PEM
electrolyte	25 %-KOH	membrane
max. sizes per module in m³/h	760	30
max. operation pressure in bar	< 30*	< 30*
temperature in °C	50 - 80	50 - 80
efficiency (at 1 bar) in %	≈ 80	≈ 80
electricity demand (at 1 bar) in kWh/m³	4.1 - 4.6	> 4.3
partial load range in %	20 - 100	0 - 100
investment in €/kW (target)	800 - 1500 (500)	2000 - 6000 (1000)

* Higher pressures are possible but not yet realised

By contrast, the PEM-electrolyser uses a membrane as electrolyte. This makes the system design simpler and more flexible to volatile electricity supply than the up to now more common alkaline electrolysers. Furthermore, the pressure resistant construction is simplified and no pumps for electrolyte cycles are needed. Currently, the PEM-electrolysis is only used for small scale applications ($^V\Phi_{H2,NTP}$ < 30 m³/h), but there is potential for bigger units with higher lifetimes and lower specific costs if there is a market for such applications.

In the same manner to SNG production based on thermochemical gasification of biomass discussed under chapter 4 this process variant converts H_2 from electrolysis and a suitable carbon source like CO or CO_2 following Eq. 1 or 2 into CH_4.

CO_2-methanation

CO_2 (g) + 4 H_2 (g) → CH_4 (g) + 2 H_2O (g)
$\Delta_R H^0$ = -165 kJ/mol   Eq. 2

water-gas shift reaction

CO (g) + H_2O (g) → H_2 (g) + CO_2 (g)
$\Delta_R H^0$ = -41 kJ/mol   Eq. 3

The basic process layout is shown in Fig. 12. The carbon source can stem from a gasification or a combustion process as well as from most other forms of gas upgrading processes producing a CO or CO_2 rich offgas. Obviously, renewable carbon sources are favourable. CO or CO_2-sources are available in different dimensions. For small quantities of CO_2 ($^V\Phi_{CO2,NTP}$ ≈ 250 - 1000 m³/h) biogas plants or combined heat and power units are conceivable. Fig. 13 shows the combination of a conventional biogas plant with the proposed process chain. For very large CO_2-streams the offgas of coal fired power plants could be used as carbon source. Another CO and CO_2 source with $^V\Phi_{i,NTP}$ = 10000 m³/h or more could be a biomass gasification plant. In this case there would be no need to shift CO into CO_2 (see Eq. 3) and consequently no need for CO_2 removal; both carbon sources could be converted completely into methane with H_2 from the electrolysis.
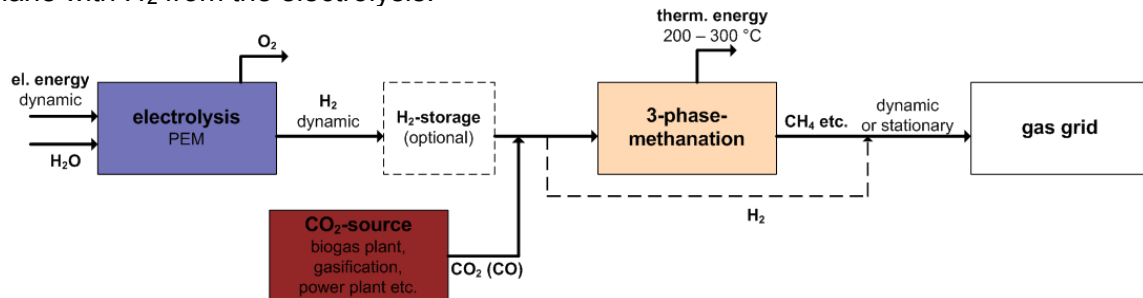

Fig. 12 Process chain to use surplus electric energy to produce SNG
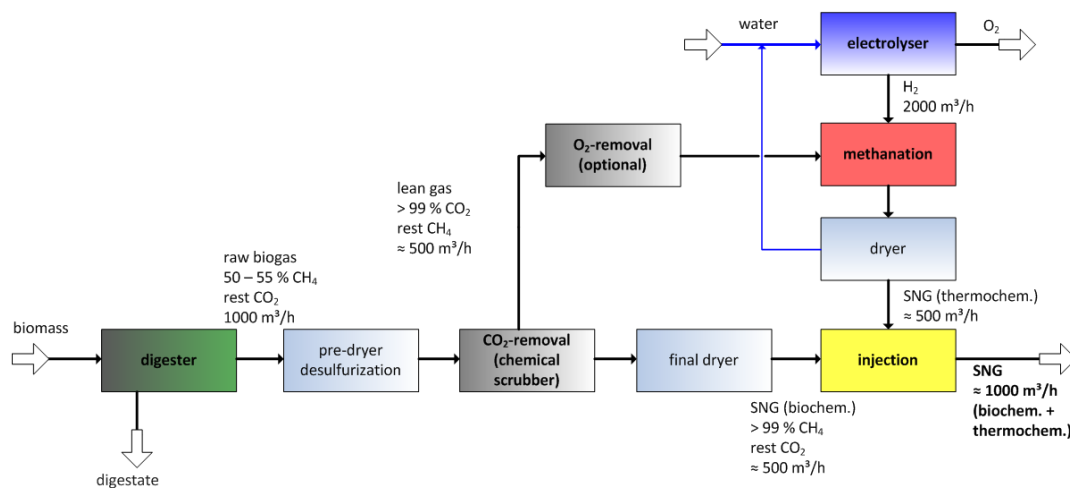

Fig. 13 Process layout for the combination of a biogas plant with an methanation plant

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5.3 R&D topics at Engler-Bunte-Institut

In order to exploit the potential of combining biogas production with the water electrolysis based on excess electricity, a new methanation process with increased flexibility to variable hydrogen flows is developed. This is necessary as the established 2-phase methanation reactor concepts discussed earlier in this article can only fulfil this requirement with high technical effort. Caused by the high heat capacity of the liquid phase, a 3-phase-reactor system (e. g. slurry bubble or flooded fixed bed reactor) is able to store the heat of reaction of the methanation step in order to buffer the effect of fluctuating feed streams in a very elegant way. Another advantage of the 3-phase methanation system is the easiness of temperature control and of the removal of the heat of reaction coupled with the exothermic methanation reactions. This can be achieved by pumping the liquid phase through external heat exchangers or by introducing heat exchangers directly into the 3-phase reactor. In the joint research project "SEE" (funded by BMBF) the described process chain is examined in detail [26]. Main research topics are fundamental investigations on mass transfer and flow regime in the 3 phase system, thermal stability of the heat transfer fluid and methanation tests in a lab scale apparatus [27].
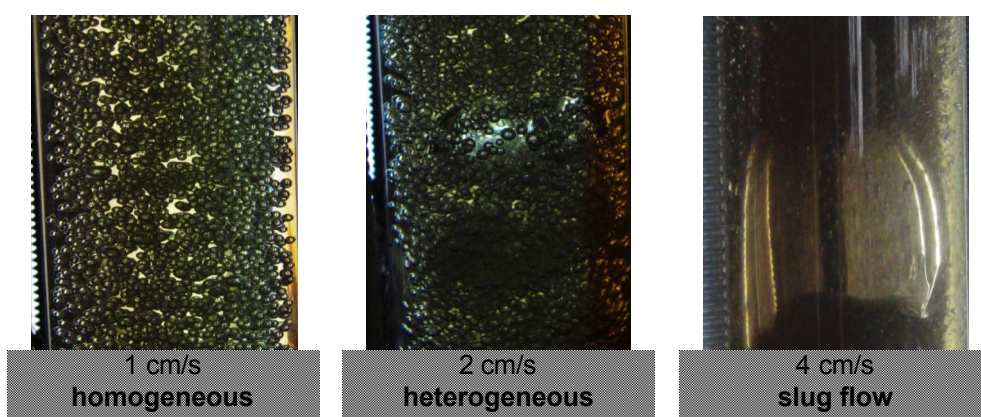

| 1 cm/s | 2 cm/s | 4 cm/s |
| homogeneous | heterogeneous | slug flow |

Fig. 14: Flow regimes for N_2 in polydimethylsiloxane at 250 °C and 1 bar

Beside the development of a new methanation concept also the synthesis of C_3-/C_4-hydrocarbons via FT-synthesis is investigated. Furthermore, several studies are accomplished within the DVGW research activities (G 1 07 10 "Concepts for storage of electrical energy"). Main topics are the technical and economical feasibility of PtG technologies and the evaluation of case studies.

5.4 Evaluation of the power to gas option

PtG seems to be an interesting option for storage of volatile electrical energy from renewable sources with respect to future needs for energy storage capacity. With an existing storage capacity of the gas infrastructure in Germany of approx. 300 TWh chemical energy the expected needs can be covered by far. From the technical point of view the necessary technologies are available. For the commercial appliance the concepts have to prove their applicability and reliability concerning the expected intransient process conditions. At the time being an economical evaluation is difficult because of unknown parameters like annual time of operation and prices for electrical energy. A first estimation by Sterner [28] results in 8 €Ct/kWh specific SNG production cost for annual operation times of 2,000 to 4,000 h and prices for electricity of 2 - 5 €Ct/kWh. First commercial applications for SNG generation based on volatile electricity are planned for 2013 [29,30].
For a more profound cost analysis the expected annual operation times are of mayor influence. As the amount of surplus electricity correlates with the extension of volatile renewable generation, reasonable prediction of operation times have to be adapted constantly. Furthermore, political and regulatory incentives have to be defined.

6. Conclusion

The natural gas infrastructure reveals various options for the integration of renewable energy sources. Together with high efficient gas appliance technologies the requirements for a sustainable energy system can be fulfilled. While biogas injection is a state of the art technology in Germany the production of SNG from biomass as well as the storage of electrical energy with help of the gas infrastructure are promising technologies which have to be developed to technical maturity and which have to prove the practical applicability within the next years.

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