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Biomethane from Biogas: Expectations from Established vs. New Technologies

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Abstract
The use of biogas has undergone a rapid development in Germany as well as throughout the whole of Europe. Indeed, the growth of this sector has led to development of a number of technologies, underlining the presence of numerous problems to be overcome. In particular this situation has been created by the current legislative framework providing for development and high level research has thus been carried out.

Recent discussions have focused on one of the future utilization technologies, namely the upgrading of biogas to biomethane for application as a substitute for natural gas. Several technologies to this regard have already been operational for approx. the last decade, whilst others are undergoing development. The present paper illustrates the state of the art and prospects of the following technologies:

→ Water scrubbing
→ Pressure swing adsorption
→ Chemical absorption
→ Membrane technologies
→ Cryogenic separation

Further to the various advantages and disadvantages. the economy, ecology and technical possibilities of the different technologies and future perspectives for development will be discussed. Summing up, conclusions will be drawn as to the future contribution of upgraded biogas within an environmentally sound energy system.

1 Introduction
Biogas is rarely directly affected by energy crises, being an indigenous energy source (i.e. in most cases, biogas is produced close to the place where it is used) characterized by short supply chains with low risks of failure. Moreover, the production and utilization of biogas is widely accepted, affording advantages for application in rural areas with regard to increased employment, rural infrastructures, the conservation of cultivated areas, and hence an enhanced attractiveness of rural regions.

To raise the efficiency of biogas utilization and to improve the flexibility of its use, technologies providing for upgrading of biogas to natural gas quality have recently been developed and introduced onto the market. In view of the background of political and technical discussion surrounding this biogas utilization technology, further research should be performed to investigate technical, economical and ecological opportunities and risks.

2 Development of biogas upgrading

Biogas has been used as a source of energy for more than 100 years, therefore man is continuously seeking to improve biogas utilization. One of the obstacles of biogas utilization is represented by the content of different organic compounds, H_2S, NH_3 and carbon dioxide, all requiring specifically adapted equipment for incineration (table 1). Thus, technologies from natural gas cleaning have been adapted to biogas plants and have now been operational for more than ten years. Nowadays, the input gas is supplied from waste water treatment plants, biogas plants for agricultural biomasses, industrial organic wastes, source separated municipal organic wastes and in one case also from a landfill. Today, upgraded gas is mainly used as vehicle fuel in Sweden, Switzerland and Germany. Use is typically on a local level near the biogas production plant or, in a few cases, following injection into the natural gas grid. The gas is sometimes used for heat or electricity production. The means of gas utilization selected depends largely on the political framework. Due to intensive investments, the majority of existing plants are situated in Sweden and Switzerland, although the political situation in Germany, Austria and Luxemburg has also enhanced development of good conditions for siting of these plants. In Germany 10 large plants are currently at the planning stage. The potential for production of upgraded biogas remains high, reaching, in Austria and Germany for example, as much as 10 % of today's natural gas consumption. (Hofmann et al. 2005a, Hofmann et al. 2005b, Hofmann et al. 2006, Ramesohl et al. 2005)

Tab. 1: Composition of biogas and natural gas

Component	Biogas	WWTP gas	Natural gas
Methane	50-70 %	60-70 %	93-98 %
Carbon dioxide	25-40 %	30-40 %	1 %
Nitrogen	< 3 %	4 %	1 %
Oxygen	< 2 %	1 %	-
Hydrogen	traces	traces	-
H_2S	up to 10000 ppm	up to 1000 ppm	-
NH_3	traces	traces	-
Ethane	-	-	< 3 %

Propane	-	-	< 2 %
Siloxanes	traces	< 6mg/ m^3	-

3 Upgrading technologies for biogases

Upgrading technologies for biogas are based mainly on technological applications from the natural gas sector where partly comparable upgrading tasks have to be solved, although on a far larger scale. Several technologies have been used in long-term experiences, although in line with the background of political discussions, new company decisions have been taken and considerable research performed in this field. The following paragraphs will characterize the main technologies available.

Generally, all companies marketing upgrading plants pledge to reach a biomethane quality of more than 96 % methane content and a methane loss of less than 3 %. Additionally a very high availability for all technologies is promised and confirmed in practice, with most plants achieving values of approx. 95 % (Persson 2003). Practical measurements in Sweden have shown different results, irrespective of the type of technology used. It appears to be particularly important to focus on methane losses, reported to reach values of up to 10 %, due to the strong influence of the latter on ecological and economical parameters of these plants.

3.1 Water scrubbing

One of the most widely used technologies in biogas upgrading is the water scrubbing process which is very common in Sweden and features a very long history of applications.

The process is based on sorption of carbon dioxide in water at high pressures of approx. 10 bar and desorption of carbon dioxide at lower pressures in another vessel to separate carbon dioxide and methane. The majority of trace gases, such as H_2S, are separated during this process. As water source circulated fresh water or cleaned waste water without circulation can be used. Advantages of waste water use are compensated by biofouling in the scrubbers due to the relatively high organic content.

Due to the long research and development period the technology has reached a very high level of development and its efficacy in practice has been demonstrated. Thus, it is to be expected that the technology may be called on to compete economically with other technologies, however representing a state of the art application.

3.2 Pressure swing absorption

Numerous upgrading plants install pressure swing absorption technologies for biomethane production. This technology is based on high pressure absorption of carbon dioxide at molecular sieves or activated charcoal in at least two steps.

Other trace gases have to be separated e. g. in filter systems before carbon dioxide absorption. Absorption materials are long lasting, although they require substituting from time to time.

This technology has been used in long-term applications, is well established and is a competitive solid and reliable technology.

3.3 Chemical absorption

Chemical absorption can be achieved by means of a number of substances (e. g. Selexol, MEA, DEA, etc), capable of absorbing carbon dioxide at ambient pressure combined with heat demand or at raised pressure. Information available as to the efficacy of the processes vary considerably, although numerous experiences have been carried out and research is on-going. The advantage of chemical absorption is represented by the fact that the substances used are selective for carbon dioxide (and sometimes for H_2S - H_2S-separation is often performed prior to upgrading); accordingly, no methane is absorbed, resulting in higher methane concentrations in the purified gas. Absorption processes under pressure seem to be comparable to water scrubbing processes. However, environmental pressure systems (only pilot plants have been operated) guarantee a lower electrical energy demand for the continuous process, possibly proving to be of particular interest for applications where only low pressure following upgrading and the availability of heat is requested. (Persson 2003)

To summarize, it can be concluded that some chemical absorption technologies are reliable and well established whilst others are still undergoing development.

3.4 Membrane technologies

Due to the different molecule size of methane and carbon dioxide, both gases can usually be separated through membranes. Smaller methane molecules pass through the membrane, resulting in the production of a gas with very high methane or carbon dioxide content. Technologies have been developed for dry separation (transportation through the membrane is forced by very high pressure) and wet separation (transport is forced by a very low concentration of methane in a fluid in which methane is absorbed). To date, both these technologies have only been tested in pilot plants and no details are available as to efficiencies regarding methane losses and energy demand.

3.5 Cryogenic upgrading

In addition, differences displayed in dew and condensation point of methane and carbon dioxide can be exploited. Indeed, it has been shown on a small scale that both gas components can be separated by cooling down of biogas to less than -45 °C at about 80 bar pressure. Applications of this process are currently undergoing research in Sweden and Germany but are not available on the market.

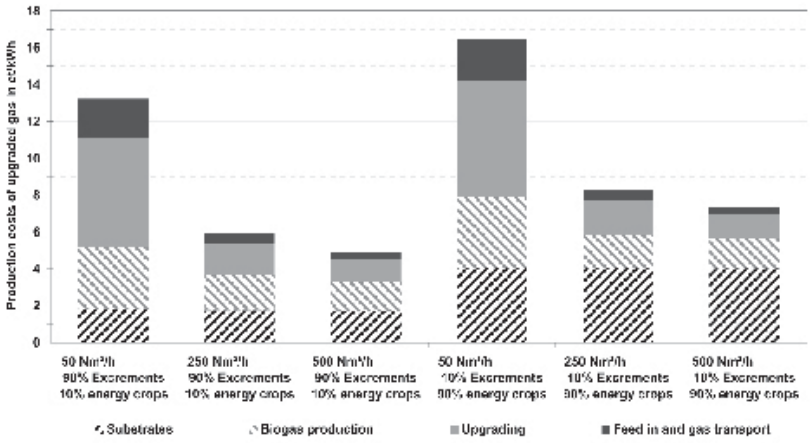


Fig. 1: Production costs of upgraded biogas

4 Economics of biomethane supply

A technology to be introduced onto the market has necessarily to compete with existing technologies in economical terms. Thus, it is essential to investigate costs of biomethane production and compare these with the costs of conventional energy carriers. An extremely detailed analysis of the economical situation of biogas production, upgrading, feeding into natural gas grids and transportation in the gas grid was performed for several typical cases (Hofmann et al. 2005a, Ramesohl et al. 2005). The results obtained with regard to the upgrading of biogas to natural gas quality for plants with a distance of 1000 m to a 10 bar natural gas pipe and transportation of 10 km through this pipe are shown in figure 1. The plants analyzed were characterized by different biogas production rates ranging between 50 and 500 m³/h raw biogas and different substrate input (90 % cattle excrements and 10 % maize silage vs. 10 % cattle excrements and 90 % maize silage by weight; maize silage costs are 30 €/t wet substrate). For upgrading technologies a medium cost estimation was chosen. Costs for upgrading technologies vary slightly but are more dependent on the local situation mostly regarding required pressure, heat availability and gas quality.

Due to the costs of maize silage an increase of approx. 2 ct/ kWh in biogas production costs in comparison with the use of excrements and energy crops is shown. Comparison between the three different plant sizes underlines an evident decrease of specific production costs for the raw biogas itself, and even more so for upgrading of the biogas and feeding of the same into the natural gas grid as scale effects. To conclude, upgraded gas can be produced at a cost of approx. 6 to 8 ct/ kWh, the large plants fueled by excrements will very rarely be constructed

due to excessive amounts of excrements required. At the current time no economical technology is available for use in smaller plants. Hopefully on-going research studies will solve this issue, although even when small scale upgrading technologies are available at comparable costs, subsequent specific costs for feeding of energy into the gas grid are much higher in comparison to those of larger plants. Thus, it should be expected that plants with a production rate of approx. 200 m^3/h will be the smallest ones for economical operation.
With regard to economical operation of upgrading plants, the question of where and how the gas will be used has to be answered. Compared with costs incurred in natural gas supply, the prices practiced here are almost doubled in order to achieve the possibility of using upgraded biogas in various applications. Of greater interest is the use of CNG from biogas as vehicle fuel in localities lacking a natural gas grid. Sweden and Switzerland provide some excellent examples: in Sweden more than half of all CNG used as car fuel is obtained from biogas. All other applications in Europe are more or less dependent on financial funding and the majority of plants are constructed as pilot plants. In Germany the renewable energy act has decreed a special tariff for electricity from upgraded biogas, making large upgrading plants feasible.

5 Ecological aspects of biomethane supply

A technology which is largely dependent on funding resources must feature several particular advantages. Within the energy sector funding of a special kind of renewable energy should be associated with ecological advantages. Thus, the ecological feasibility of biomethane production technologies was analyzed on the basis of life cycle analysis following the standards of ISO 14040 (Ramesohl et al. 2005). Some selected results for greenhouse gas emissions are shown in figure 2.

The data calculated clearly emphasize the positive effect of biogas production from excrements – the typically high methane emissions from excrement storages can be avoided by means of a biogas plant. Thus, it can be concluded that the utilization of excrements in biogas plants is particularly favorable from an ecological point of view. Utilization of energy crops is connected with emissions due to expenditure associated with agricultural work, e.g. transportation, fertilizing, harvesting etc. Storage in silages may particularly give rise to emissions if not carried out properly. These emissions raise the question as to exactly how useful the production of biogas from energy crops really is. Therefore, detailed investigations were carried out to investigate the possibility of using biogas in substitution of typical fossil fuels (Ramesohl et al. 2005). The main results are shown in figure 3.

From this figure it can be concluded that utilization of upgraded biogas indeed contributes towards decreasing greenhouse gas emissions with regard to all typical modes of energy utilization. Notably, the efficiency of electricity production depends on the level of heat use, but it can be assumed that a CHP plant situated in correspondence of a natural gas pipe connection can be located where heat is

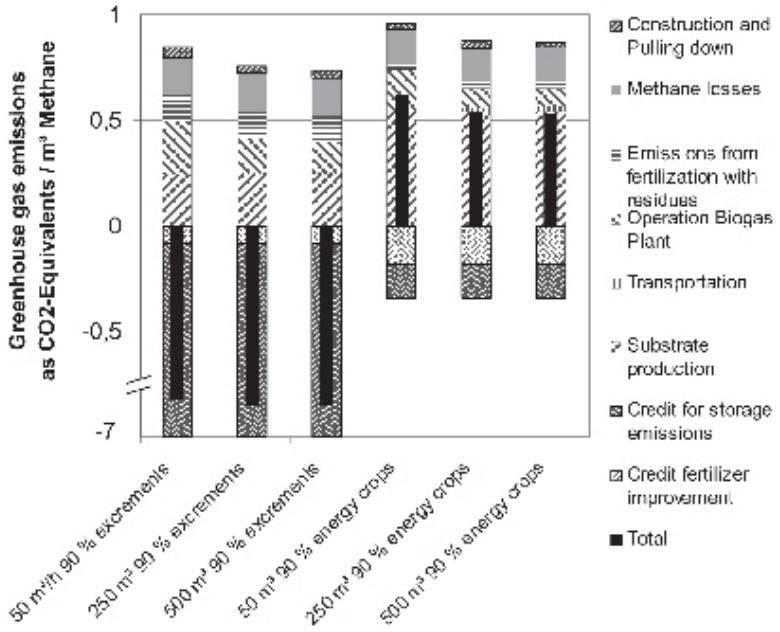


Fig. 2: Greenhouse gas emissions from production of upgraded biogas

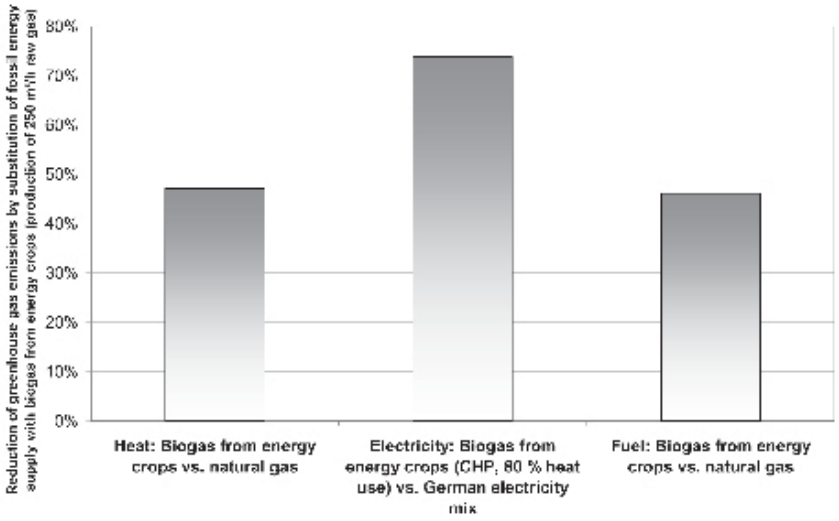


Fig. 3: Reduction of greenhouse gas emissions connected with final energy supply from upgraded biogas (substrate: 90 % energy crops) substituting typical fossil energy carriers

required. It has moreover been demonstrated how CO_2-emissions from upgrading are too high to warrant replacing, for ecological reasons, of a decentralized biogas utilization facility capable of using up to 40 % waste heat from a CHP plant with an upgrading plant and a centralized CHP unit where less than 70 % of waste heat is used.

All in all it is ecologically feasible to substitute fossil energies with upgraded biogas. If heat and power plants are operated as a combination, a high contribution to greenhouse gas emissions reduction will be afforded on production of electricity. When the quota of excrements increases, this effect is naturally enhanced irrespective of final energy use.

6 Perspectives of the technology and conclusions

From an ecological point of view, introduction of upgraded biogas onto the energy market leads to particularly favorable results when compared to the use of fossil fuels. It is noteworthy to underline the political significance of opening up a market which is as yet not available for other types of renewable energy. Upgraded biogas may provide the basis for a sustainable and secure gas supply system leading to a greater degree of stability in agricultural employment. For this reason the upgrading of biogas is viewed as a politically important issue in several European countries.

Within this framework the perspectives for using upgraded biogas in the energy system in Europe seem to be promising. However, as shown in the chapter on economics, this type of technology is fully dependant on economical support, although, in view of the continuously increasing prices for energy from fossil fuels, its economical feasibility will improve. In the future the production from renewable sources of a fuel which is as flexible as natural gas can only prove to be an advantage, based on the huge variety of technologies and applications available which function on natural gas.

To increase sustainability as well as economy it is the mission of research to:

- → Find small scale and economically competitive technologies for upgrading of biogas
- → Reduce methane emissions during the upgrading process to zero
- → Reduce energy consumption in upgrading processes
- → Identify the lowest quality of upgraded biogas required in view of security of natural gas grid operation, billing of gas customers and customer quality requirements
- → Develop market opportunities for upgraded biogas
- → Develop integrated technologies taking into account not only production rates and maximization of upgraded biogas
- → Define requirements for ecologically feasible utilization of upgraded biogas as a basis for political strategies and funding

Finally, it should be underlined how the upgrading of biogas may contribute to-

wards reducing greenhouse gas emissions. The potentials for production of upgraded biogas are still high, especially in typical agricultural countries. Calculations made with regard to Germany and Austria have shown that realistically approximately 10 % of the current natural gas market could be substituted with biogas. Accordingly, the market would no longer be obliged to rely on the availability and at times importation of natural gas.

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