# Biomethane for future mobility

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## Abstract

The upgrading of biogas into biomethane as a renewable resource for future automotive strategies is a promising and trendsetting concept. Fossil fuel resources will shorten more and more and due to this their prices will increase significantly in the near future. In comparison to other alternative fuels like bio diesel and bio ethanol the fuel yield of biomethane out of one field hectare is significantly higher. One European wide role model for biomethane production out of different biogases and their utilisation as vehicle fuel has been implemented in full technical scale in a local mobility strategy in the Swedish city of Västerås. In this biogas and biomethane production plant an overall biogas flow of 550 m$^3$/h is upgraded into a biomethane flow of 400 m$^3$/h by using water scrubbing technology. The produced biomethane is sold to the local public transport company for operating buses and garbage trucks on the one hand and as well to the free local fuel market on the other hand. Within the EU-project AGROPTI-Gas all technical installations have been balanced and evaluated by FAL's Institute of Technology and Biosystems Engineering in cooperation with other partners. Within this evaluation efficiency rates for the biogas plant on the one hand as well as efficiency rates and methane losses of the gas upgrading installations on the other hand have been appraised.

*Keywords: biogas, biomethane, water scrubbing, gas upgrading, vehicle fuel*

## Zusammenfassung

### Biomethan für die Mobilität der Zukunft

Die Bereitstellung von Biomethan aus landwirtschaftlichen Roh- und Reststoffen ist eine vielversprechende Option für die Produktion von Biokraftstoffen im Rahmen einer zukünftigen Mobilitätsstrategie. Fossile Kraftstoffe wie Öl oder Erdgas haben ihr Produktionsmaximum erreicht oder werden es in Kürze erreichen. Um die Ziele des Klimaschutzes und der Ressourcenschonung zu erreichen, ist fernerhin die verstärkte Nutzung erneuerbarer Energien eine zwingende Notwendigkeit. Biomethan besitzt im Vergleich zu anderen Biokraftstoffen wie Biodiesel oder Bioethanol in Deutschland die höchsten Brutto- und Netto-Hektarerträge. Eine zukunftsweisende Strategie für die Produktion von Biomethan und dessen Integration in die regionale Kraftstoffversorgung wurde in der schwedischen Stadt Västerås realisiert. Hier wird das aus landwirtschaftlichen Rohstoffen sowie kommunalen und agroindustriellen Abfällen erzeugte Biogas zu Biomethan aufbereitet. In der Gasreinigung wird neben dem Gas der Biogasanlage auch das Faulgas der kommunalen Kläranlage behandelt. Der Rohgaseingang beträgt 550 m$^3$/h, dieses wird kontinuierlich zu einem Volumenstrom von 400 m$^3$ Biomethan pro Stunde aufgereinigt. Dieses Biomethan wird zum einen für den Betrieb von kommunalen Nahverkehrsbussen eingesetzt, zum anderen wird damit über eine öffentliche Tankstelle der freie Markt bedient. Die gesamte technische Installation wurde im Rahmen des EU-Projektes AGROPTI-Gas vom Institut für Technologie und Biosystemtechnik der FAL evaluiert und bilanziert. Die Ermittlung von Effizienzen und Wirkungsgraden der Biogasanlage und der Druckwasserwäsche erfolgte unter besonderer Berücksichtigung ökologischer und ökonomischer Aspekte.

*Schlüsselworte: Biogas, Biomethan, Druckwasserwäsche, Gasaufbereitung, Kraftstoff*

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## 1 Introduction

The finiteness of fossil resources is foreseeable; furthermore the emissions of climate relevant $CO_2$-emissions must be reduced to avoid the imminent risk of global climate change due to the greenhouse effect. Today's mobility concepts are nearly completely focussing on fossil fuels like oil or natural gas. European wide today already 4 million vehicles are operated with compressed natural gas (CNG); the number of gas vehicles in Germany increased to more than 40.000 during year 2006 (www.gibgas.de, 2007). Natural gas can be utilised as vehicle fuel in each available quality level and these different quality levels can be ensured with biomethane too, see Table 1. Due to this each CNG operated vehicle can also be operated with compressed biomethane out of biogas.

Table 1:

Biogas in comparison to natural gas (Fachagentur Nachwachsende Rohstoffe, 2006), (Pölz, 2005)

| | | Raw biogas | Natural gas L | Natural gas H | Natural gas as vehicle fuel |
|---|---|---|---|---|---|
| Volumetric content | % | 100 with 65 % $CH_4$ | 100 | 100 | 100 |
| Heating value | kWh/ $Nm^3$ | 6.5 | 8.8 | 10.4 | 8.4 - 13.1 |
| Wobbe index | kWh/ $Nm^3$ | 7.0 | 10 - 13 | 12 - 15.7 | 12.8 - 15.7 |
| Density | Kg/ $Nm^3$ | 1.2 | 0.83 | 0.79 | 0.55 - 0.7 |
| Ignition temperature | °C | 650 - 750 | 640 | 640 | 640 |
| Ignition limit gas in air | Kg/ $Nm^3$ | 6 - 12 | 5 - 15 | 4 - 16 | 4 - 16 |

Figure 1 shows the biogas potentials in Germany which can be utilised for biomethane.

Roundabout 85 % of this biogas potential have their origin in the agricultural sector. The postulation of 55 Vol.- % as average methane content in biogas leads to a German biomethane potential of roundabout 13 Bill. $m^3/a$. The average fuel consumption of a passenger car with a CNG engine can be estimated to 6 $m^3$ of natural gas per 100 km (Volkswagen AG, 2006). Under postulation of a complete utilisation of all German biogas resources as origin for fuel a yearly mileage of 240.000 Mio. km can be covered. If biogas would only be used as a vehicle fuel in the mobile sector roundabout 25 % of the actual fuel consumption could be replaced.

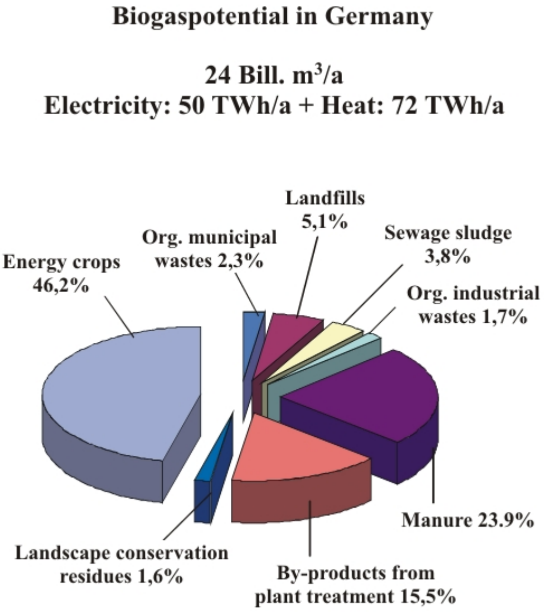

Figure 1:

Biogas potential in Germany (Weiland, 2006)

### *1.1 Biomethane and the market situation*

Nowadays fuel strategies are more or less focussing on liquid fossil fuels, due to this both political deciders and automobile traders have a strong interest in biofuels which are liquid, too. One imaginable reason for this is that liquid biofuels need no significant change in strategies for fuel distribution and technical solutions in the car. From a more technical point of view only minor modifications in engine characteristics and on-board fuel storing technology need to be fulfilled for a wider spread utilisation of gaseous fuels including biomethane. Furthermore after the opening of the natural gas grid in Germany for biomethane injection, the distribution of biomethane will even be easier and more comfortable as nowadays liquid fuel distribution. In several European countries, e.g. Sweden, biomethane already gained an important role in the fuel market, although the fuel distribution cannot be performed via a natural gas grid. From this point of view the situation in Germany would be much better; this has been proved within several studies, e.g. (Fachagentur Nachwachsende Rohstoffe, 2006 or Ramesohl, 2006). The technical feasibility for the injection of biomethane into a natural gas grid has been proved in actually 5 locations in Germany, where biomethane is injected into the natural gas grid. A comparable installation is located in Pucking, Austria (Dorninger, 2006).

The acceptance for biomethane as a vehicle fuel in Germany is very high, too; this is a clear result out of the initial operation of Germany's first biomethane filling station which is located in the village Jameln. In Jameln almost 100 biogas driven cars have been bought by customers during the first 6 months of operation of the filling station and all these cars are provided with biomethane every day (Neumann, 2006).

The evaluation of the plant in Västerås has shown, that the technology for biomethane production is well developed and extremely high efficient. The substrate situation of the biogas plant in Västerås is conditioned by the local situation, especially from the agricultural point of view. In Sweden the most common energy crop is ley crop, which is a mixture of several herbage seeds; under German conditions ensiled corn would be favoured instead of ley crop due to the fact that both crop yield and methane yield are significantly higher for ensiled corn in comparison to ley crop. Figure 2 gives an overview over the resulting mileage which can be covered out of the fuel yield of one field hectare; the average fuel consumption as basis for Figure 2 has been set to 6 litres of diesel for 100 km distance.

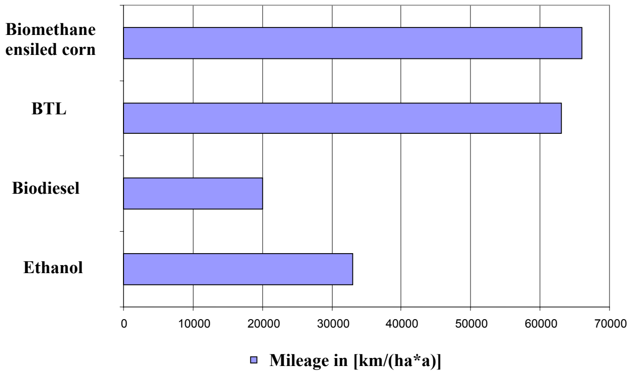

Figure 2:

Resulting mileage for biofuels in [km/(ha*a)] (Weiland, 2006), (Ahrens report technical evaluation, 2006)

The coverable mileage of nearly 70.000 kilometres per one field hectare via the utilisation of biomethane out of ensiled corn is an impressing value and significantly higher as for liquid biofuels. From this point of view the utilisation of biomethane is clearly the most efficient way of biofuel production.

### *1.2 Technical solutions for biomethane production out of biogas*

Biogas is a mixture of methane, carbon dioxide, both in concentration areas of Vol.- %, and hydrogen sulphur with values up to 3000 ppm. Additionally and depending on substrate and process conditions a certain spectrum and variation of characteristic trace gases (concentration rates 100 ppb to 2 ppm) like different carbohydrates and sulphur compounds is likely, too. The methane concentration in biogas is varying between 50 and 60 Vol.- %, also depending on substrate and process conditions.

All technologies for methane enrichment have in common, that the accompanying gas compounds besides to methane are removed by using physical, biological or chemical applications (Weiland, 2003). Common technologies for removal of hydrogen sulphur are:

- Biological desulphurisation,
- Adsorption with activated carbon or iron and zinc oxide.

With the perspective of biofuel production a biological pre-desulphurisation has the disadvantage that the cleaned gas flow is diluted with atmospheric nitrogen. This nitrogen enters the product gas and reduces the heating value of the produced biomethane. Adsorption technologies which are applied for desulphurisation do not cause any dilution but are non-continuously operated and not self-cleaning, which causes increasing costs of operation.

For the removal of carbon dioxide the following strategies are well known:

- Refrigeration,
- Membrane separation,
- Adsorption technologies,
- Absorption technologies.

All technologies for removal of carbon dioxide are basing on certain chemical or physical properties of methane, which are differing in comparison to the compounds to be removed. Both refrigeration and membrane technology are not common for full scale applications and have no mentionable position in the market yet. Adsorption technologies like pressure swing adsorption (PSA) are well developed and well established in the market. The major disadvantage of this technology is the fact that the inlet gas has to be pre-desulphurised. Absorption technologies are mainly focussing on scrubbing technologies with different physical solvents like water or Genosorb® respectively Selexol® for example.

Table 2 shows exemplary the solubility of the main biogas compounds in water, depending on temperature and pressure.

Table 2 clarifies the increase of solubility of carbon dioxide and hydrogen sulphur in water according to increasing pressure and decreasing temperature; due to this water is an applicable solvent for biomethane production with scrubbing technology. On the other hand the needs of energy for gas and water compression as well as for gas and water cooling have to be considered and calculated to an overall efficiency rate of the technology.

Table 2:
Solubility of biogas compounds in water (Kaltofen, 1994)

| Gas | Validity of Henry's law | Solubility coefficient $\lambda \left[ {}^{Nl}/_{kg(H_2O)\cdot at} \right]$ with $\vartheta$ in °C | | | | |
|---|---|---|---|---|---|---|
| | | $\vartheta$ = 0 °C | $\vartheta$ = 10 °C | $\vartheta$ = 20 °C | $\vartheta$ = 30 °C | $\vartheta$ = 40 °C |
| $CO_2$ | 5 | 1.658 | 1.159 | 0.851 | 0.646 | 0.516 |
| $H_2S$ | 1 | 4.52 | 3.28 | 2.51 | 2.00 | 1.63 |
| $CH_4$ | 20 | 0.054 | 0.040 | 0.032 | 0.027 | 0.023 |

A further matter of importance is the imminent risk of methane losses, which have to be lowered to an acceptable level by an optimised plant design and construction due to the high global warming factor of methane.

## 2 Materials and methods

### *2.1 Full scale technical application*

A full scale technical application of both biogas production and biogas upgrading technology and furthermore its utilisation as vehicle fuel has been implemented into the local infrastructure of the city of Västerås, Sweden. The project was subsidised by the EU within the 5th framework and technically evaluated by the FAL's Institute of Technology and Biosystems Engineering.

The main objectives of the project are:

- To extract biogas and plant nutrients from ley crops.
- To establish a sustainable circulation of plant nutrients and organic material between the community and the agricultural sector in such a way that the use of residues is optimised.
- To contribute to an environmentally adapted and sustainable way of farming.
- To provide opportunities for a reduction of biocide use and for cultivation of cereal without artificial fertilizing.
- To extract and efficiently utilize high grade bio-energy from waste and normal farm crops with no net-contribution of carbon dioxide to the atmosphere.
- To treat clean, source-separated organic waste from households, restaurants and other enterprises in an environmental correct manner.
- To upgrade biogas into biomethane under observance of recommended vehicle fuel standards.
- To establish biomethane in the local fuel market.

For ensuring these ambitious goals several partners from the local community have been involved into the technical implementation and the operation of the whole plant. Figure 3 gives an overview concerning the flow of material from and to the plant installations and each single partner who is responsible. These partners are a group of local farmers who are also participators of the Växtkraft Company, the local waste management company (Vafab), the sewage treatment plant of the city of Västerås and the

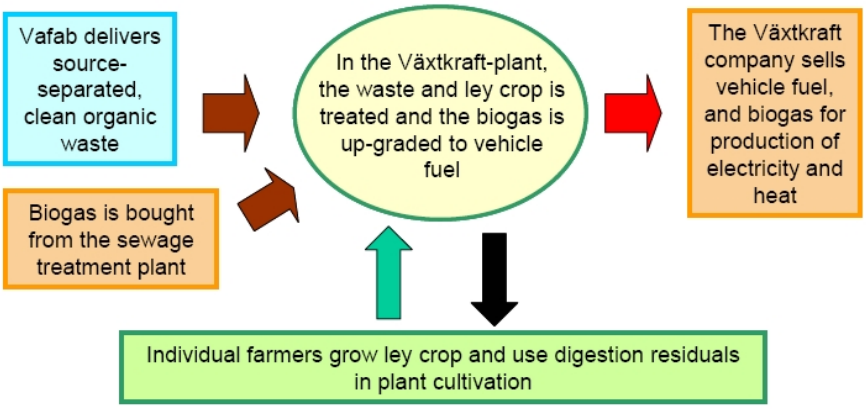

Figure 3:
Flow of material from and to the plant installations (Agropti-Gas Progress report, 2003)

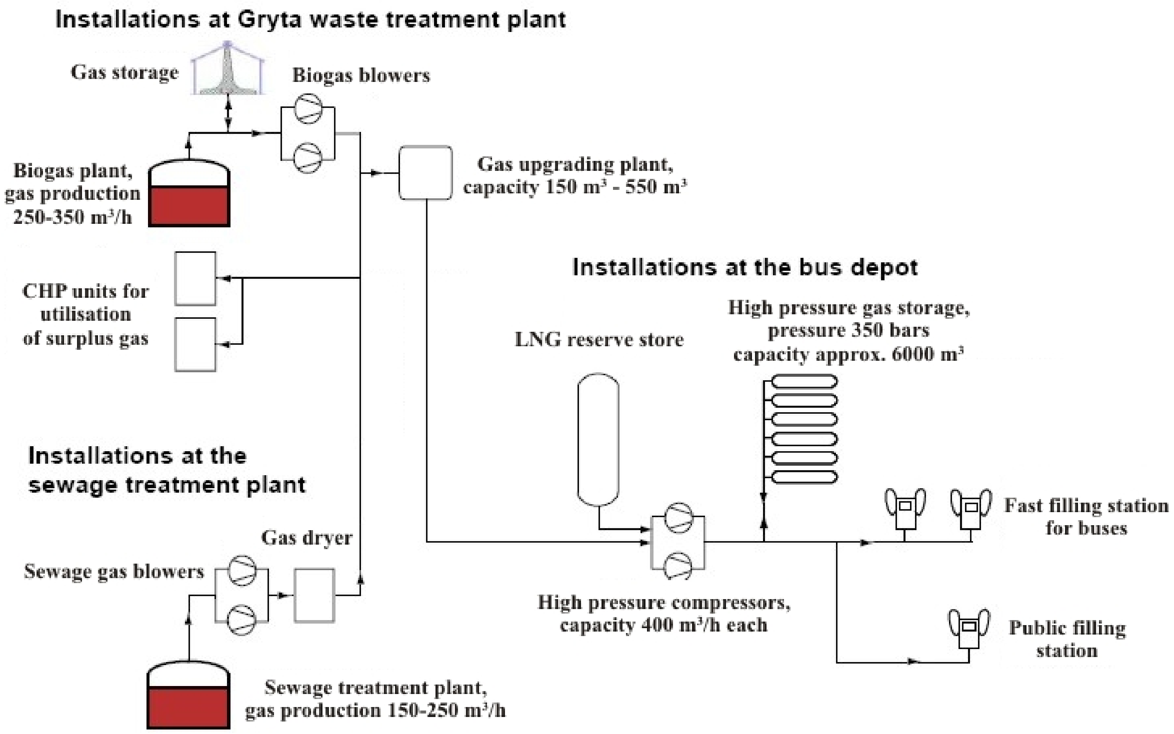

Figure 4:
Overview over the technical plant installations (Agropti-Gas Progress report, 2003)

Växtkraft facility.

This type of technology implementation into a rural infrastructure might be some type of role model for Germany, too. Under the topic of biofuel production there is a high interest in closing circles for ensuring an optimal waste and resource management together with a high energy production rate. Additionally it is extremely important to close nutrient circles for ensuring an environmentally friendly and reliable way of farming. Both demands were fulfilled within the Swedish strategy.

Figure 4 gives an overview over the whole technical installation.

Both biogas plant and sewage treatment plant are connected to the biogas upgrading plant. Under full load operating conditions the biogas plant has been designed for the annual treatment of:

- 5.000 tons of ensiled ley crop with an average dry matter content of 35 %.
- 14.000 tons of clean, source-separated organic waste with a dry matter content of averagely 30 %.
- 4.000 tons of grease trap removal sludge with a dry matter content of averagely 4 %.

Under full load operating conditions the following annual yields are expectable:

- Biogas from the biogas plant with an energy content of 15.000 MWh.
- Biogas from the sewage treatment plant with an energy content of 8.000 MWh.
- Biomethane with an energy equivalent of 2.3 Million litres of petrol.
- Digestion residuals with an expected content of 150 tons of nitrogen, 30 tons of phosphorus and 100 tons of potassium.

During the period between December 2005 and May 2006 ca. 515 tons of silage, 1.084 tons of grease trap removal sludge, 6.086 tons of biowaste, 3.733 tons of digestate, 7.271 tons of process water and 3.840 m$^3$ of fresh water entered the process. The overall outlet of the process during the evaluation period was ca. 18.650 tons of liquid digestate, 1.280 tons of solid digestate, 690 tons of sorted material and 753.500 m$^3$ of methane. The quality of the produced liquid digestate is comparable to other effluents in farming (e.g. cattle manure) and the amount of heavy metals is below actual thresholds, see following Tables 3 and Tables 4.

The biogas process will reach its full load capacity during the beginning of year 2007. Under full load operating conditions a methane production of the digester of ca. 8500 m$^3$/d is expected.

Table 3:
Nutrient content of liquid digestate in comparison to different effluents (Dörfler, 1990)

| Effluent | Total nitrogen kg/m$^3$ | Ammonia nitrogen kg/m$^3$ | Phosphate kg/m$^3$ | Kalium kg/m$^3$ | Magnesium kg/m$^3$ | Calcium kg/m$^3$ | Dry matter % |
|---|---|---|---|---|---|---|---|
| Liquid digestate | 3.67 | 2.40 | 0.25 | 1.83 | 0.16 | 0.71 | 2.5 |
| Manure, | 2 – 2.7 | 1 – 1.3 | 0.9 – 1.0 | 2.7 – 4.0 | 0.5 | 1.0 – 1.3 | 5 |
| female cows | 1 – 1.35 | 0.5 – 0.65 | 0.45 – 0.5 | 1.35 - 2 | 0.25 | 0.5 – 0.65 | 2.5* |
| Manure, | 3.0 | 1.5 | 1.0 | 2.3 | 0.5 | 0.9 | 5 |
| male cows | 1.5 | 0.75 | 0.5 | 1.15 | 0.25 | 0.45 | 2.5* |
| Manure, | 4.0 | 2.8 | 1.7 – 2.0 | 2.0 – 4.2 | 0.6 – 0.7 | 1.6 – 2.0 | 5 |
| pigs | 2.0 | 1.4 | 0.85 – 1.0 | 1.0 – 2.1 | 0.3 – 0.35 | 0.8 – 1.0 | 2.5* |

*calculated to dry matter content of liquid digestate

Table 4:
Heavy metal contents of liquid digestate in comparison to actual thresholds (Kreislaufwirtschafts- und Abfallgesetz, 2001)

| | Bly g/t DM | Cadmium g/t DM | Chrome g/t DM | Copper g/t DM | Nickel g/t DM | Quicksilver g/t DM | Zinc g/t DM |
|---|---|---|---|---|---|---|---|
| Threshold | 150 | 1.5 | 100 | 100 | 50 | 1.0 | 400 |
| Liquid digestate | 6.1 | 0.4 | 8.1 | 65 | 8.5 | 0.15 | 222 |

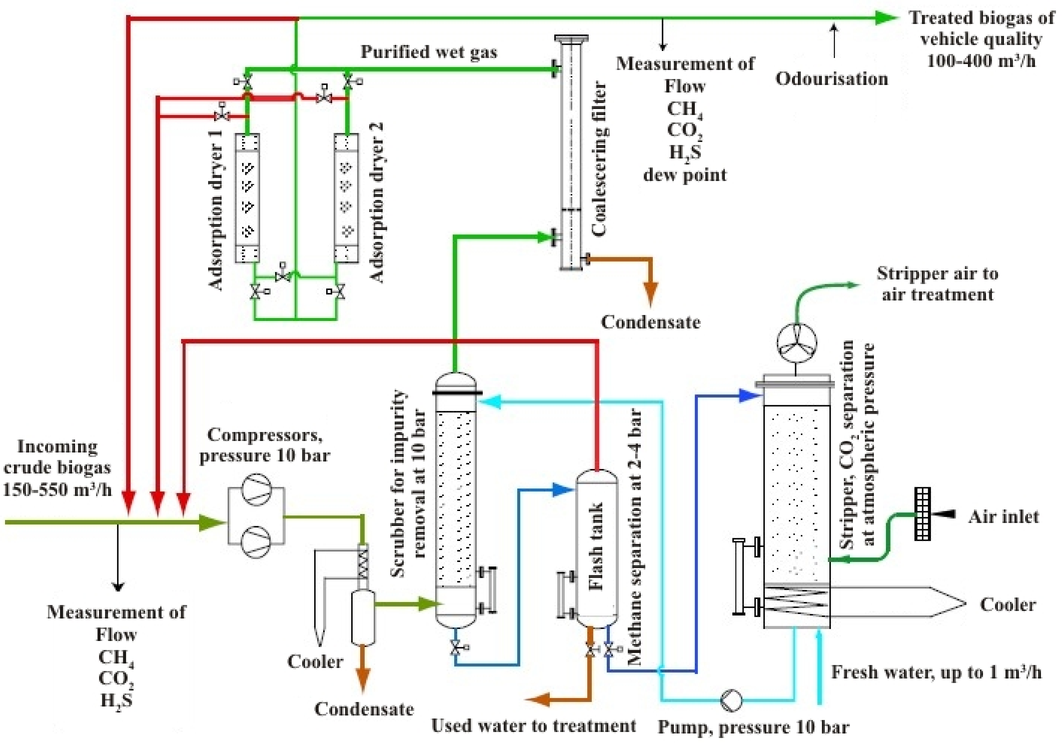

Figure 5:
Flow sheet for the gas upgrading plant (Agropti-Gas Progress report, 2003)

The produced biogas is stored in an 800 m$^3$ gas store and afterwards transported to the biomethane production plant through blowers and pipes. Figure 5 shows the flow sheet of the gas upgrading plant. The gas upgrading system has been designed for a maximum incoming flow of 550 m$^3$ raw biogas per hour. In connection to the plant further installations were made for distribution of biomethane as vehicle fuel which are high pressure compressors, high pressure gas storage devices, LNG backup systems and gas dispensers for biomethane distribution (Figure 4). The biogas upgrading plant has been evaluated corresponding to different characteristic loading rates. These different loading rates were balanced in wintertime as well as in summertime for appraisal of efficiency and reliability. Table 5 shows the plant key data for a biomethane flow of 360 m$^3$/h for both winter and summer period.

Table 5

Upgrading plant key data, flow of biomethane = 360 m$^3$ (Ahrens report biological evaluation, 2006)

| Key factor | Unit | key data winter | key data summer |
|---|---|---|---|
| Biogas (Input) | | | |
| V(Biogas) | Nm$^3$/h | 550 | 550 |
| c(CH$_4$) | Vol-percent | 64 | 65 |
| c(CO$_2$) | Vol-percent | 34 | 34 |
| c (O$_2$, N$_2$) | Vol-percent | n.d. | n.d. |
| c(H$_2$S) | ppm | 900 | n.d. |
| Product gas (Output) | | | |
| V (product gas) | Nm$^3$/h | 360 | 360 |
| c(CH$_4$) | Vol-percent | 96 | 96 |
| c(CO$_2$) | Vol-percent | < 1 | < 1 |
| c (O$_2$, N$_2$) | Vol-percent | < 1 | < 1 |
| c(H$_2$S) | ppm | < 10 | < 10 |
| Flash gas | | | |
| V (flash gas) | Nm$^3$/h | 36 | 38 |
| Stripper air | | | |
| V (Stripper air) | Nm$^3$/h | 3700 | 3700 |
| Water circle | | | |
| V (Water) | Nm$^3$/h | 95 | 96 |
| V (removed water) | Nm$^3$/h | 1 | 1 |
| Absorption pressure | bar ü | 12.2 | 12 |
| Absorption temperature | °C | 13 | 17 - 19 |
| Flash pressure | bar ü | 3.0 - 4.0 | 3.0 - 4.0 |
| Stripping pressure | bar ü | 1 | 1 |
| Stripping temperatur | °C | 20 | 20 |

Most of the absorbed hydrogen sulphur (78 – 100 percent, depending on operating conditions) left the process via the removal of used water out of the flash tank (Figure 5), which gives the chance to use this removed water together with the remaining sludge from the biogas process as a soil improver.

Additionally to the well known and common biogas compounds also analytics concerning trace gas compounds and ammonia gas were performed. The corresponding GCMS and FTIR analysis (Ahrens, 2003) has shown that ammonia gas gets absorbed in the water; an accumulation of ammonia as ammonia carbonate in the circulating water seems to be likely but could not be proved yet. Table 6 proves that also most trace gases with a concentration below 1ppm are absorbed during the scrubbing process.

Table 6:

Trace gas analytics of raw gas and biomethane (Ahrens report biological evaluation, 2006)

| Gas | Raw gas | Biomethane | Reduction rate [%] |
|---|---|---|---|
| 2-Methylfurane | X | n. d. | 100 |
| 2-Butanethiole | X | n. d. | 100 |
| Toluene | X | n. d. | 100 |
| 1,6-Heptadiine | X | X | 60 |
| Carbonyl sulfide | X | n. d. | 100 |
| 3-Pentanone | X | n. d. | 100 |
| 5,5-Dimethylcyclohexane | X | n. d. | 100 |
| 3-Methyl-1,3-Butadiene | X | X | 50 |
| 1-Propanethiole | X | n. d. | 100 |
| Carbonyl sulfide | X | n. d. | 100 |
| Cyclopropene/Propene * | X | n. d. | 100 |
| Methane thiole | X | n. d. | 100 |
| Pentane dinitrile | X | n. d. | 100 |
| 1,5-Hexadiene 3-ine | X | X | 60 |

n.d. = not detectable
* not resoluble

Due to these results water scrubbing technology for biomethane production is able to ensure high product gas quality levels in the areas of both major compounds as well as minor and trace compounds. The methane losses via the stripper air varied without any preliminary technical improvement between 2 and 5.5 percent. After implementation of all required technical improvements like well-fitting water valves, applicable flash tank pressure level control and stripper air flow management devices the detected methane losses lowered to 2 percent, independently from the operating conditions. The produced biomethane quality is fulfilling the regulatory for both biofuel and natural gas grid injection (Table 1).

Table 7 shows the resulting parameters for the calculation of the energetic efficiency of the biogas upgrading plant, including the biomethane storing and fuelling equipment.

Table 7:

Energetic efficiency for 350 - 360 Nm$^3$/h biomethane flow (Ahrens report biological evaluation, 2006)

| Product gas flow 350 - 360 Nm$^3$/h | | |
|---|---|---|
| | winter period | summer period |
| Energy demand (biogas) per m$^3$ of biomethane *upgrading plant* | 1.46 kWh/m$^3$ | 1.56 kWh/m$^3$ |
| Energy demand (biogas) per m$^3$ of biomethane *Upgrading plant + filling station* | 2.19 kWh/m$^3$ | 2.29 kWh/m$^3$ |
| Flow of upgraded methane | 2 960 179 m$^3$/a | 3 006 432 m$^3$/a |
| | Efficiency rate of *upgrading plant:* 84.6 %:<br>Overall efficiency rate: 79.7 % | Efficiency rate of *upgrading plant:* 83.9 %:<br>Overall efficiency rate: 79.0 % |

Table 7 shows higher plant efficiency during wintertime operation. The coolers for water and gas cooling are not in operation and the methane concentration in the upgraded gas flow is high according to lower temperatures within the scrubbing process (Table 5). During summertime the efficiency rate is lowering because the coolers for water and gas are in operation. The gas flow has been higher during summertime which caused a higher energy demand at the filling station. A major influence on the energetic efficiency has also been caused by the lower methane concentration in the upgraded gas; the reason for this is the higher temperature within the absorption process in the scrubber tower (Table 5). The efficiency calculation is based on a full year operation with 365 days of non-stop plant operation. Biogas production and quality as well as the energy consumption have been scaled up to a whole year operation from single measurement periods between 2 and 12 hours; possibly occurring variations over the year weren't been considered.

## 3 Conclusions

A new strategy for covering the oncoming need of fuel is strictly necessary for the future of mobility. Not one single biofuel resource is able to cover the fuel need for nowadays yearly mileage and fuel consumption. Under that point of view it is strictly necessary to utilise all available sources for biofuel production and not only those which seem to be the most convenient ones, due to their comparable character to nowadays fossil fuels. Biomethane is nowadays the most efficient way for a reliable biofuel production; furthermore Germany is the leading nation in the technology field for biogas production. According to Germany's widespread natural gas grid the biomethane distribution and storing via the gas grid would be quite easy. If Germany shall keep its worldwide leading position in the field of biogas production in the future, it is strictly necessary to bring biomethane production and its utilisation as biofuel further ahead. Otherwise a golden opportunity for an oncoming field of technology export and an establishment of new jobs in Germany will pass by to other countries.

The Swedish strategy for biomethane production with a parallel integration of the local community and farming infrastructure is an imaginable role model for implementing biomethane into a reliable fuel concept. Besides to the production of a high efficient renewable fuel the closing of nutrient circles under requirements for organic farming has an exemplary character. The biogas production is highly efficient and only minor improvements are desirable, e.g. a higher efficiency in the supply of thermal and electrical energy for the biogas plant installations. From this point of view the implementation of well adapted and high efficient energy converters like special designed fuel cells is desirable in the near future. Water scrubbing is an adequate technology for biomethane production with only minor demands for improvement. These are mainly more effective solutions for treatment of by-products and furthermore reliable strategies for avoiding the forming of micro organisms in the fixed bed of the scrubber and the stripper tower.

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