Biogas as transportation fuel

O. Jönsson,
M. Persson
Swedish Gas Centre,
owe.jonsson@sgc.se
margareta.persson@sgc.se

Summary

Biogas is used as transportation fuel in a number of countries, but in Europe it has only reached a major breakthrough in Sweden. All of the biogas plants in Sweden that are in the planning or construction phase will be equipped with possibilities to deliver a biogas that is upgraded to natural gas quality, either for direct use as vehicle fuel or for injection into the natural gas grid.

The development of biogas as vehicle fuel in Sweden is a result of a combination of a surplus of gas from biogas plants, primarily at the sewage treatment plants, and a low electricity price that forces the biogas into markets other than electricity production.

Introduction

The supply of petroleum fuels will gradually decrease and these will have to be replaced by sustainable fuels. This has been addressed by the European Commission in the directive 2003/30/EG where the following targets are set:

- 2% biofuels by the end of 2005
- 5,75% biofuels by the end of 2010

In the short term this means that biofuels that already are present on the market where suitable vehicle technology is available (biogas, ethanol, biodiesel) must be used and development activities in order to develop long term alternatives (e.g. hydrogen) must be intensified.
Biogas is a biofuel that in Europe in general has mainly been regarded as a fuel suitable for electricity generation

Picture 1:
Biogas hybrid bus in Uppsala - Sweden

in gas engines. Biogas can just be used in vehicle engines as well, and there are more than 4.000 vehicles in Sweden running on biogas and natural gas today.

Sources of biogas

Biogas comes from four main sources:

- Sewage treatment plants: Many sewage treatment plants produce methane rich gases in the sludge fermentation stage. Utilisation of methane from sewage plants is used on a large scale in many countries. Optimised process conditions can enhance the production and collection of these gases.
- Landfills: All landfills produce methane rich gases. Collection and utilisation of the gases is applied quite widely. Improved collection, processing and utilisation of landfill gases will be an important tool to increase the importance of landfill gas.
- Cleaning of organic industrial waste streams: Anaerobic digestion processes are often successfully applied to clean the waste streams of agricultural processing industry.

The methane rich gases are mainly utilised to produce electricity and heat in local co-generation plants.

- Mesophilic and thermophilic digestion of organic waste: Compact installations convert organic waste to methane rich gases at higher temperatures. The main difference between the two methods is the digestion temperature (35 °C in the mesophilic process and 55 °C in the ther mophilic process).

Potential for biogas production in Europe

There are more than 3.000 biogas plants in Europe today and biogas is also used from a large number of landfill sites. The two countries that account for the largest biogas production in Europe are Germany and England. The total European biogas production was in 2002 estimated to 92 PJ/year and the total European potential is estimated to 770 PJ/year in 2020. The countries with the highest biogas production per capita are the UK, Sweden, Denmark, Switzerland and the Netherlands. In the short term the main potential for biogas production is the treatment of

Picture 2:
Mesophilic digesters in the city of Helsingborg for co-digestion of manure and animal waste

Picture 3:
Sulfatreat ® H_2S-removal

wet wastes like sewage water sludge, manure and waste from different kinds of food industries. In the long-term perspective the main source for biogas will be different kinds of agricultural products.

Upgrading of biogas to natural gas quality

Biogas has to be upgraded to natural gas quality in order to be used in normal vehicles designed to use natural gas. The most common technologies are the water scrubber technology and the PSA-technology. Gas upgrading is normally performed in two steps where the main step is the process that removes the CO_2 from the gas. Minor contaminants are normally removed before the CO_2-removal and the water dew point can be adjusted before or after the upgrading (depending on the process).

Water scrubber technology

Two types of water absorption processes are commonly used for upgrading of gas from anaerobic digestion, single pass absorption and regenerative absorption. The major difference between the two processes is that the water in the single pass process is used only once. A typical installation is at a sewage water treatment plant. Water can also be recycled and in this case a stripper column has to be integrated in the process (regenerative absorption).
The singel pass process is described below.

Cleaned sewage water has a sufficient quality for use in the absorption column. After the flash tank the water is depressurised by a regulator valve and returned to the sewage water treatment system.

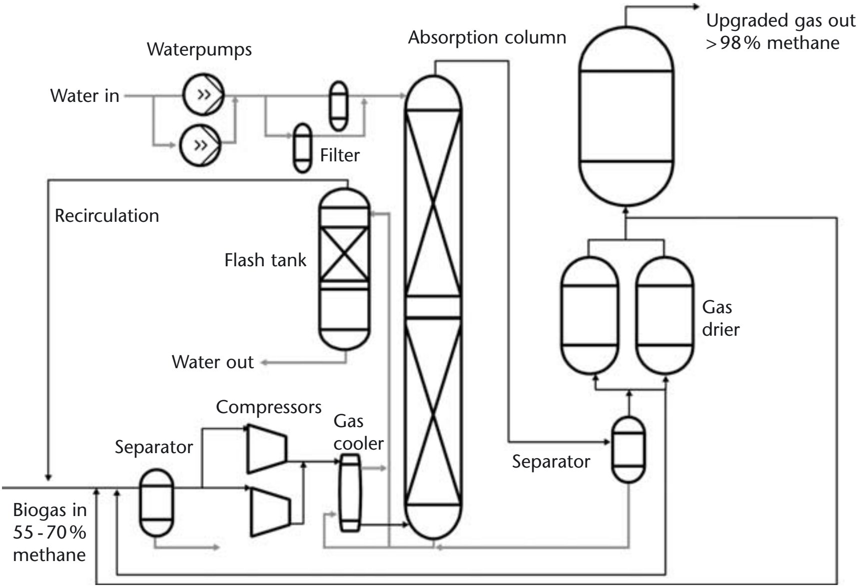


Figure 1:
Removal of carbon dioxide using water wash without regeneration

PSA (Pressure Swing Adsorption) technology

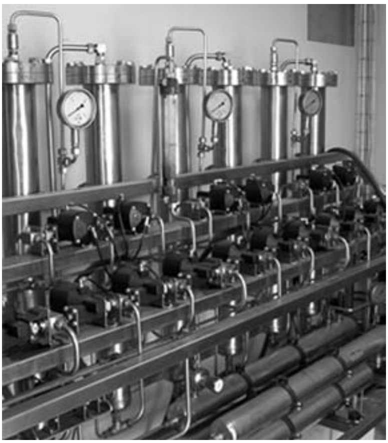
Pressure Swing Adsorption, or PSA, is a method for the separation of carbon dioxide from methane by adsorption/desorption of carbon dioxide on zeolites or activated carbon at different pressure levels. The adsorption material adsorbs hydrogen sulphide irreversibly and thus is poisoned by hydrogen sulphide. For this reason a hydrogen sulphide removing step is often included in the PSA process.

The upgrading system consists of four adsorber vessels filled with adsorption material. During normal operation each adsorber operates in an alternating cycle of adsorption, regeneration and pressure build-up. During the adsorption phase biogas enters from the bottom into one of the adsorbers. When passing the adsorber vessel, carbon dioxide, oxygen and nitrogen are adsorbed on the adsorbent material surface. The gas leaving the top of the adsorber vessel contains >97% methane.

Before the adsorbent material is completely saturated with the adsorbed feed gas components, the adsorption phase is stopped and another adsorber vessel that has been regenerated is switched into adsorption mode to achieve continuous operation.

Regeneration of the saturated adsorbent material is performed by a stepwise depressurisation of the adsorber vessel to atmospheric pressure and finally to near vacuum conditions. Initially the pressure is reduced by a pressure balance with an already regenerated adsorber vessel.

Picture 4:
Biogas upgrading with PSA technology – pilot system



This is followed by a second depressurisation step to almost atmospheric pressure. The gas leaving the vessel during this step contains significant amounts of methane and is recycled to the gas inlet.

Before the adsorption phase starts again, the adsorber vessel is repressurised stepwise to the final adsorption pressure. After a pressure balance with an adsorber that has been in adsorption mode before, the final pressure build-up is achieved with feed gas.

Other technologies

In some cases membrane technologies have been used for gas upgrading. The membrane technology has a potential to be energy efficient but for the moment there is very limited experience in Sweden of this technology.

Chemical adsorption technologies seem to be an attractive solution due to low methane losses and high selectivity. The process requires a rather high input of thermal energy for the regeneration of the chemical but can on the other hand be operated at low pressure that reduces the electrical energy demand of the process.

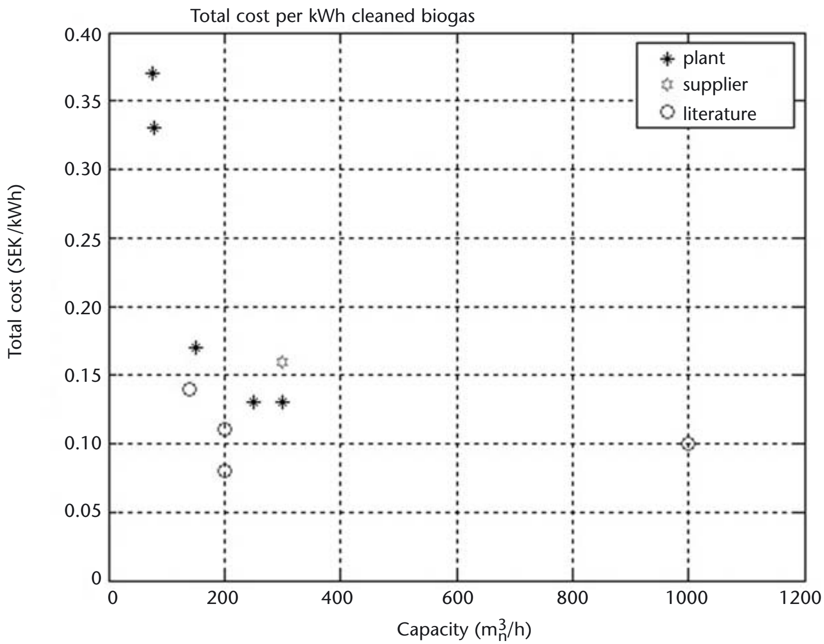
Economic and technical experience of gas upgrading

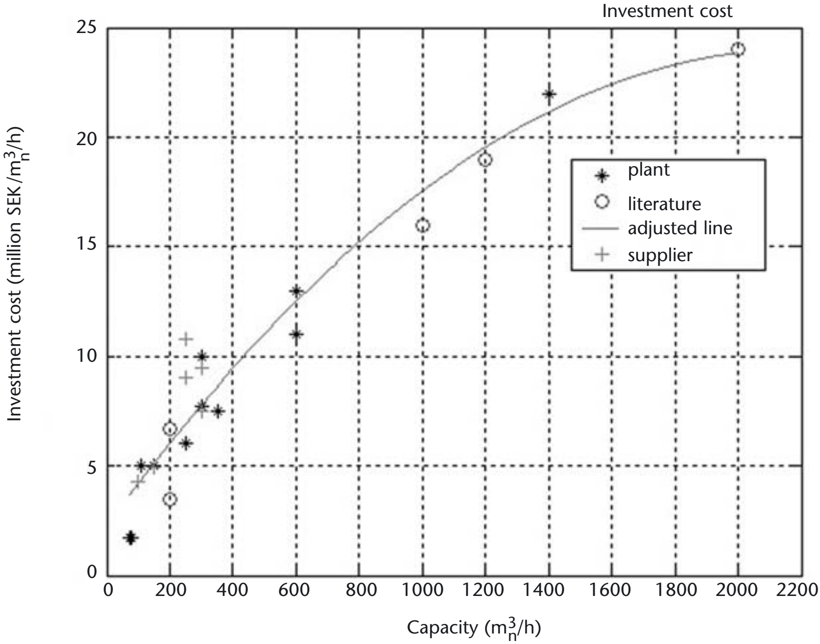
The economical and technical performance of the Swedish upgrading plants has been studied during 2003. 11 of the Swedish upgrading plants with longest operation experience have participated in the study. Some of the main conclusions from this study are:

Picture 5:
Trailer for transport of biogas to filling stations in Stockholm

- The upgrading cost depends very much on the plant size. Small plants for <100 $m^3/h_{raw\ gas}$ have upgrading costs between 3 and 4 € ct/$kWh_{upgraded\ gas}$ whereas upgrading plants in the range 200 - 300 $m^3/h_{raw\ gas}$ have upgrading costs around 1-1,5 € ct/$kWh_{upgraded\ gas}$
- The electricity demand for upgrading corresponds to 3 - 6 % of the energy content in the upgraded gas.
- The function of the upgrading plant is generally acceptable after the commissioning period. Common problems at the plants are malfunctions in valves (PSA-plants) and deteriorating adsorption rates due to clogging (water adsorption systems).

Investment costs and total upgrading costs for a selected number of upgrading plants are shown in the diagrams below.


Total cost per kWh cleaned biogas
Total cost (SEK/kWh)
Capacity (m$_n^3$/h)
plant
supplier
literature
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
0
200
400
600
800
1000
1200


Investment cost
Investment cost (million SEK/m$_n^3$/h)
Capacity (m$_n^3$/h)
plant
literature
adjusted line
supplier
25
20
15
10
5
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200

Biogas vehicles

Biogas can be used in both heavy duty and light duty vehicles. Light duty vehicles can normally run both on natural gas and biogas without any modifications, whereas heavy duty vehicles without closed loop control may have to be adjusted, if they run alternately on biogas and natural gas.

Sweden is the only country in the world with a national standard for biogas as vehicle fuel today. This standard essentially states that the methane content must be higher than 95% and also sets limits for dew point, sulphur content and some other minor constituents.

Today there are more than 4.000 vehicles in Sweden running on natural gas and biogas and several local fleets (e.g. Linköping, Uppsala, Kristianstad) where the major part of the urban public transports are operated on biogas.

Biogas the pathway to hydrogen

Biogas can be regarded as one possible way to gradually change over to hydrogen as energy carrier. There are many similarities:

- Hydrogen (if produced from sustainable sources) and biogas are both renewable fuels.
- Hydrogen and biogas can both be distributed on the natural gas grid.
- Hydrogen and biogas can be used in natural gas vehicles. The first European tests with hydrogen / natural gas mixtures in buses are now carried out in Malmö, Sweden.

Picture 8:
Hydrogen car and natural gas bus at hydrogen filling station in Malmö

The introduction of biogas as a vehicle fuel in Sweden has been based on a solid co-operation between the natural gas utilities and the biogas producers. This has resulted in an understanding for gas quality aspects and other technical issues that have to be dealt with when introducing both biogas and hydrogen as vehicle fuels.

Conclusions

Natural gas is a fossil fuel that has many advantages (high security of supply, low emissions, established distribution grid etc.) compared to liquid fuels like diesel and gasoline and has also been pointed out as a major alternative in the changeover to sustainable fuels. Upgraded biogas has the same advantages as natural gas, but additionally is a sustainable fuel that can be manufactured from local waste streams thereby also solving local waste problems.

Production of biogas is a mature technology that is well established in many European countries and the biogas potential is considerable, especially when taking into account the possibilities to use set aside land for production of crops for biogas.

Upgrading of biogas is a relatively new technology but experience from Sweden and other countries shows that it is possible now to upgrade biogas with high reliability and at reasonable costs.

The Swedish experience shows that biogas can be an economical sustainable fuel with a potential to drastically reduce emissions in urban transport.

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