BIOGAS AND NATURAL GAS
FUEL MIXTURE FOR THE FUTURE

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INTRODUCTION

The annual Danish biogas production is expected to keep growing and to increase tenfold during the next 25-year period with a reduction of greenhouse gas emissions as one of the important incentives.

When larger volumes of biogas are present, upgrading and distribution of biogas by the natural gas network and combined utilization of biogas and natural gas are realistic options for transport and use of renewable energy of the existing fossil fuel system.

During the last decade renewable energy, including biogas and natural gas, has expanded its market share to 30% of the total Danish energy consumption. Similarities of the fuels and the possibilities for combined utilization are described in this paper, supported by examples.

"ENERGY 21". BIOGAS AND NATURAL GAS

At the beginning of spring 1996, the Danish Government presented the fourth Danish energy plan "Energy 21", which adheres to the Danish aim of reducing national CO_2-emissions by 20% in 2005 and by 50% in 2030 in relation to 1988 level.

Increased energy efficiency in all aspects of energy conversion and expanded use of renewable energy and natural gas instead of coal and oil are the key elements in "Energy 21".
The consumption of renewable energy is expected to increase four times to 235 PJ per year, of which biogas stays on a minor part of 20 PJ per year. Nevertheless, this is 10 times today's production, which can only be met by using the potential feed stock volume from the agricultural sector.
Therefore, an increased biogas production will be based on animal manure from the agricultural sector.

Today's biogas production is based on approximately 20 centralized agricultural plans, approximately 15 landfill plants and approximately 65 sewage plants.

Since1984 natural gas has been distributed in Denmark. The natural gas network covers a large part of the country, and the present natural gas consumption is 165 PJ which is 20% of the total Danish energy consumption (1999).
Also production and consumption of renewable energy has developed during the same period, covering 10% of the energy supply (1999).
Centralized agricultural biogas plants are by nature placed in the countryside, and the natural gas network is developed from areas with high population density. During the build-up period of the natural gas network, priority has been given to this sector but focus has moved towards CO_2 neutral fuels and the waste treatment has taken place at biogas plants.
Expansion of both natural gas consumption and biogas production is expected, and the similarities between the fuels should open for further combined utilization of biogas and natural gas.

THE FUEL – GAS QUALITY

Since the beginning of the Danish natural gas project the natural gas distributed in Denmark has shown a quite stable gas quality.
The Danish Natural Gas has a high methane content, only a minor fraction of non-combustible components and a very low sulphur content.

The Danish legislation on gas quality reflects the present natural gas quality, which excludes biogas from the natural gas network.
Today's combined use of natural gas and biogas takes place only at single or at well-defined groups of users, where variations in gas quality can be handled.
Larger volumes of biogas will necessitate a more flexible view on gas quality, to ensure the market for biogas.

Table 1 shows the gas composition, physical properties, and combustion key numbers for natural gas and biogas. For both gases the main component is methane, and the main difference is the high content of CO_2 and H_2S in biogas. From a technical point of view the most important difference is that the Wobbe index for natural gas is twice the value of that of biogas. Only gases with a similar Wobbe index can substitute each other, and distribution of biogas by the natural gas network is limited by the difference in Wobbe index. Adjustment of the Wobbe index by removing the CO_2 can upgrade biogas close to natural gas quality.

Table 1. Key numbers for gas and flue gas, for natural gas and biogas. For calculation of flue gas data the gas composition CH_4 = 65% and CO_2 = 35% is used for biogas.

Key numbers		**Natural gas**	**Biogas**
CH_4 (methane)	[vol%]	91.0	55-70
C_2H_6 (ethane)	[vol%]	5.1	0
C_3H_8 (propane)	[vol%]	1.8	0
C_4H_{10} (butane)	[vol%]	0.9	0
C_5+ (pentane)	[vol%]	0.3	0
CO_2 (carbon dioxide)	[vol%]	0.61	30-45
N_2 (nitrogen)	[vol%]	0.32	0-2
H_2S (hydrogen sulphide)	ppm	~1	~500
NH_3 (ammoniac)	ppm	0	~100
Water dew point	[°C]	<-5	saturated
Net calorific value	[MJ/nm^3]	39.2	23.3
	[kWh/nm^3]	10.89	6.5
	[MJ/kg]	48.4	20.2
Density	[kg/nm^3]	0.809	1.16
Relative density	[-]	0.625	0.863
Wobbe index (W)	[MJ/nm^3]	54.8	27.3
Methane number	[-]	73	~135
Stoichiometric mixtures			
Air requirement	[nm^3/nm^3 gas]	10.4	6.22
Flame temperature*)	[°C]	2040	1911
Water dew point (flue gas)	[°C]	59.7	59.2
Water vapour (flue gas)	vol%	18.8	19.3

**) Adiabatic flame temperature*

ADJUSTMENTS OF GAS QUALITY AND BIOGAS PURIFICATION

The natural gas network covers most of Denmark, and distribution of biogas by the existing network would ensure a stable market for biogas.
In general, distribution by the natural gas network will demand purification (H_2S) and upgrading (removal of CO_2) of the biogas to SNG (Substitute Natural Gas).
Common technologies for upgrading are: Pressure Swing Absorption (PSA), Membrane separation and Pressurized water absorption (water scrubber). Figure 1 shows the upgrading costs per m^3 SNG for full-scale upgrading plants operating in Europe and the US.

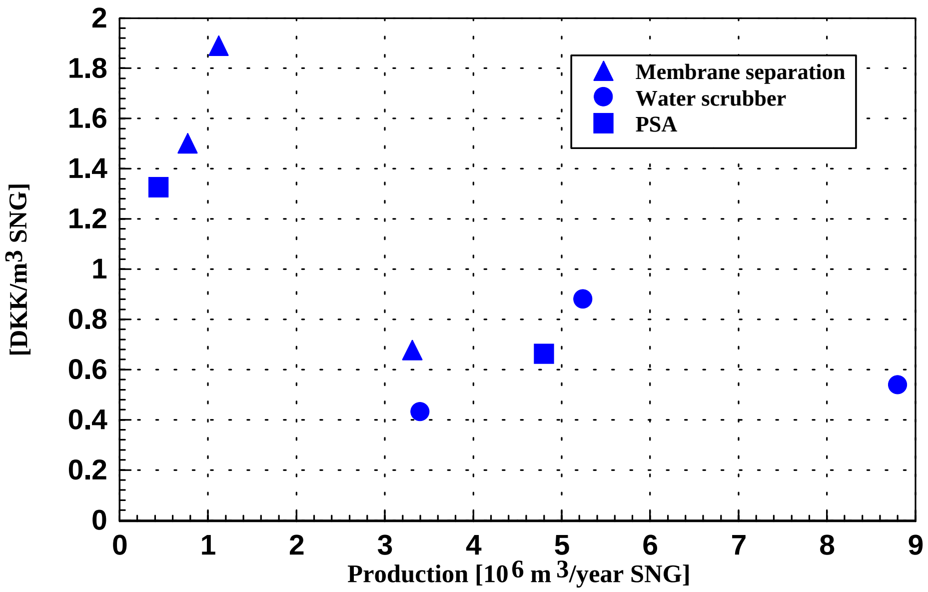

Figure 1. Total upgrading costs per m³ SNG as a function of upgrading technology and the plant capacity (1 DKK = 0.15 Euro)

The biogas production from a Danish centralized biogas plant is 1 - 3 · 10^6 m^3 per year which indicates an upgrading cost of approx. 0.15 Euro per m^3 SNG.
The Danish market situation does not allow an additional cost of 0.15 Euro per m^3 SNG, which is why low cost upgrading methods are investigated in pilot projects.

As biogas is mainly used in internal combustion engines for CHP production, the H_2S content is normally kept at a level of 700-1500 ppm or less. In the late 1980s it was experienced that the plants were generally able to meet these conditions without special purification due to the presence of iron in the feed stock.

This led, mistakenly as it turned out, to the establishment of new plants without any H_2S purification included. As, later on, the H_2S level turned out to be high, these new plants had to add ferric chloride to the feed stock for H_2S removal. This method of biogas “purification” is, however, quite expensive, especially when the H_2S concentration in the gas is high. For some of the plants the search for a suitable purification method became quite urgent.

In the light of this, H_2S purification with air addition was tested as a full scale experiment in the fall of 1993 at the Fangel plant. H_2S is biologically converted to sulphur (presumably predominately as S_8) The sulphur is retained in the liquid in the filter. Surplus liquid is returned to the buffer storage tanks, returning the sulphur to the field as fertilizer. The Fangel experiment was a great success. H_2S purification with air addition is now being implemented at nearly all new plants, as well as at some of the older plants.

UTILIZATION OF BIOGAS

Sale of energy is by far the largest income for the biogas plants. In most cases the biogas is used for combined heat and power (CHP) generation. Around half of the space heating demand in Denmark is based on district heating why biogas sale for a district heating plant is an option in most cases.
If the biogas production multiplies CHP may not be an option. The options for biogas utilization are:

- District heating and CHP
- Biogas networks
- Distribution by natural gas networks
- Fuel for vehicles

District Heating and CHP

District heating covers most of the domestic heating demand in Denmark. The heat is produced by hundreds of small district heating plants and by condensing power plants. During the last 10 years more than 1000 MW_e gas engine based CHP have been installed at the decentralized district heating plants. By far the largest part is fuelled by natural gas but also most of the biogas plants are supplying a gas engine CHP-plant.

At the larger biogas plants the average gas engine power is 500-700 kW_e. The natural gas fuelled plants have an average engine power of approximately 1200 kW_e.

In most cases the CHP plant is an integrated part of the biogas plant. A low-pressure biogas pipeline a few kilometres long supplies some CHP plants.
Additional supply of natural gas to the biogas fuelled CHP plants takes place on four plants, of which three have combined use of biogas and natural gas, at the same engine generator set. The first plant (Thorsø) went on steam in 1994 and apart from some running-in problems this concept has been very promising.
The dual fuel engines can compensate for variations in gas quality (from 100% natural gas to 100% biogas) and no adjustment of gas quality is necessary.

Distribution by Biogas Network

The biogas plant at Revninge went on steam in 1990 and supplies 67 households in Revninge. For back up or for adjustment of the gas quality a mixture of natural gas and air can also supply the small network, which is isolated from the natural gas network.

An evaluation of the domestic boilers in Revninge in 1994 showed some minor corrosion problems, but the concept is, in general, promising.
Instead of biogas upgrading and supply of biogas to the natural gas network the Revninge concept could be a model for smaller parts of the natural gas network.
For safety reasons only minor variations of the Wobbe index can be accepted when supplying households. For separate biogas networks backup supply from natural gas or propane/butane is recommended.

Distribution by Natural Gas Network

The Danish natural gas network today distributes no biogas, but a Swedish plant (Laholm Biogas) has supplied upgraded biogas to the network from the beginning of 2000.

In case of upgrading there is no technical limitations of the biogas volume, which can be supplied to the network.

If biogas is cleaned and partly upgraded, the Wobbe index of the gas mixture is the limitation. In order to fulfil the Danish legislation on gas quality the Wobbe index should be 51,9 - 54,9 MJ/m^3n.

If biogas is upgraded to 90% methane a mixture of 25% biogas and 75% natural gas will have an acceptable Wobbe index. If no upgrading takes place a volume fraction of 8% biogas (65% methane) can be present in the mixture.

Today's upgrading technologies are costly and from an economic point of view distribution of non-upgraded biogas by the natural gas network is the most realistic option in Denmark.

Connection to the natural gas network has then to be at a location where the gas flow is rather constant over the day and the years.
This demand is best obtained at the high- and medium-pressure network, but from both a technical and economical point of view connections should be made at the low-pressure network (4 bar).

During ongoing experiments on low-pressure membrane separation the possibilities for low-cost upgrading techniques are examined.

Fuel for Vehicles

Use of upgraded pressurized biogas as fuel for vehicles is an option which has been widely demonstrated in Sweden. The technology does not differ from the use of CNG as fuel for vehicles.
Because of the limited tank storage volume, CO_2 must be removed from the biogas. Expanded use of this technology is basically a question of the fuel taxation.

CONCLUSION

The use of bio fuels including biogas is expected to increase significantly in Denmark. Apart from few exceptions biogas and natural gas have developed in different geographic areas, but in the future bio fuels will develop in areas supplied with natural gas.
The difference in gas quality between biogas and natural gas is in most cases of minor importance. If necessary, biogas can be upgraded to natural gas quality, but today's upgrading technology is too costly. Tests of a new low-cost upgrading method are ongoing and combined utilization of biogas and natural gas is expected to increase.

The technologies for combined utilization of biogas and natural gas are available and widely demonstrated at CHP plants, by supply of upgraded biogas to the natural gas network and by separate biogas networks. Furthermore, both natural gas and biogas can be used as fuel for vehicles.

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