Upgraded biogas in the natural gas grid, operational challenges for power producing appliances

Jan de Wit, Leo van Gruijthuijsen and Steen D. Andersen

Danish Gas Technology Centre

Dr. Neergaards Vej 5B, 2970 Hoersholm, Denmark

Abstract

The gas supply situation becomes more and more complex in many countries: More import and export of gasses with different origins, compositions and related combustion properties. Also new internal gas sources, such as upgraded biogas (biomethane), are now entering the natural gas grids.

The paper will present examples of measured gas quality at a number of end-user sites. Significant changes of calorific value and methane number in a few minutes can be seen. Depending on the production/consumption issues and the actual end-user location, such changes can be seen many times a day.

This has shown to be a challenge for some connected appliances. Especially gas engines are put under pressure to cope with these changes without failures and downtime of these power producing units.

The paper will present operational end-user experience and point out issues that gas supply companies, plant owners and their operations staff as well as engine manufacturers should take into consideration in order to prepare and cope with this new situation.

New supply situations

The Danish natural gas grid (figure 1) was put into service in 1982, and up to 2010 the gas quality was pretty stable, as the supply was based on North Sea natural gas resources. This gas has a relatively high calorific value compared to the gas supplied in neighbouring countries. The high calorific value is due to some 6-8% (vol.) higher hydrocarbons than methane in the gas.

In 2010, a new supply situation occurred, as Denmark started to import gas from Germany. This import was not due to lack of supply, but due to commercial terms and in order to maintain security of supply in the long run. The gas imported can be of many origins. Typically, the gas has a high methane content leading to a significantly lower calorific value than North Sea gas, often in the low end of the accepted Wobbe range, examples can be seen in table 1.

Since 2011/2012, yet another gas of new origin has entered the gas grid, as biogas plants have started to inject upgraded biogas (bio-methane), see figure 2. Until now, this injection has primarily been done in the low-pressure 4 bar distribution grid. As more and more upgrading plants are being put into service, a number of these will inject to high-pressure parts of the grid in the near future.

Most often, the gas production from these plants is relatively stable over the year. This means that these plants will supply gas to a relatively larger area during summer than in the winter, as end-user gas consumption is larger during winter. The supply area will therefore depend on the actual gas production and gas consumption rates.

Table 1 Examples of composition of gasses supplied to the Danish natural gas grid (Source: /1/)

		Danish North Sea gas 2005-2009	**Example 1 Import gas**	**Example 2 Import gas**	**Expected North Sea gas after 2018**	**Upgraded biogas**
Methane	mole %	89.64	89.85	96.59	85.07	99.4
Ethane	mole %	5.87	5.01	2.46	8.2	0
Propane	mole %	2.32	1.01	0.13	3.81	0
I-Butane	mole %	0.38	0.1	0.042	0.27	0
N-Butane	mole %	0.53	0.12	0.023	0.7	0
I-Pentane	mole %	0.12	0.021	0.0046	0.074	0
N-Pentane	mole %	0.078	0.017	0.0029	0.084	0
Hexane +	mole %	0.056	0.016	0.0043	0.026	0
Nitrogen	mole %	0.29	2.53	0.41	0.38	0.25
Oxygen	mole %	0	0	0	0	0.18
Carbon dioxide	mole %	0.72	1.33	0.34	1.38	0.16
Calorific Value, Hs	kWh/Nm^3	12.14	11.30	11.23	12.50	11.00
Wobbe Index	kWh/Nm^3	15.26	14.38	14.82	15.32	14.72

The methane numbers (MN, definition to be found in /3/) for the North Sea gas is relatively low due to the content of some higher hydrocarbons. The MN for the North Sea gas has typically been in the range of 68-75. The MN for import gasses are higher, about 80-90. The upgraded biogas is almost pure methane, and, therefore, the MN is close to 100. It is in fact typically 101-103 due to a small residue of CO_2.

To ease injection and to avoid costly use of gas compressors, the grid pressure has been lowered in some areas. In the past, the gas pressure was 3½-4 bar(g) in a major part of the distribution grid. However, most gas consumers, including small- and medium-size gas engine based CHP plants, have gas contracts based on a minimum supply pressure of less than 1 bar.

The lower gas supply pressure is a challenge for the pre-chamber gas engines, as the gas to the pre-chambers often requires around 3½ bar(g). If the supply gas pressure is too low, such gas engine installations must be equipped with a gas compressor. To avoid large investment and operational costs, it is an advantage if the gas compressor can operate solely on the pre-chamber gas supply.

Figure 1   The natural gas grid (Source: DGC et al., 2016)

Figure 2   Injection points for upgraded biogas as of March 2017. Total injected biomethane of March 2017 some 150 million m^3 (Source: HMN)

Variations in gas quality

Variations in gas quality resulting in changes in composition and the allocated combustion parameters may present a challenge with regard to:

- Safety issues
- Operational issues
- Correct billing issues

No safety related incidents have been seen, yet.

Operational challenges have been seen leading to dropouts of equipment (gas engine based CHP) and problems related to starting procedures of these.

The present Danish Gas Regulations on gas quality for gas in the national gas grid allow for a change in the Wobbe Index of ±4.5%. This is equal to a variation of almost ±6% in calorific value constituting a total span of some 12%. This has been in force for many years. However, until 2010 little variation in gas quality was seen for the grid supplied gas.

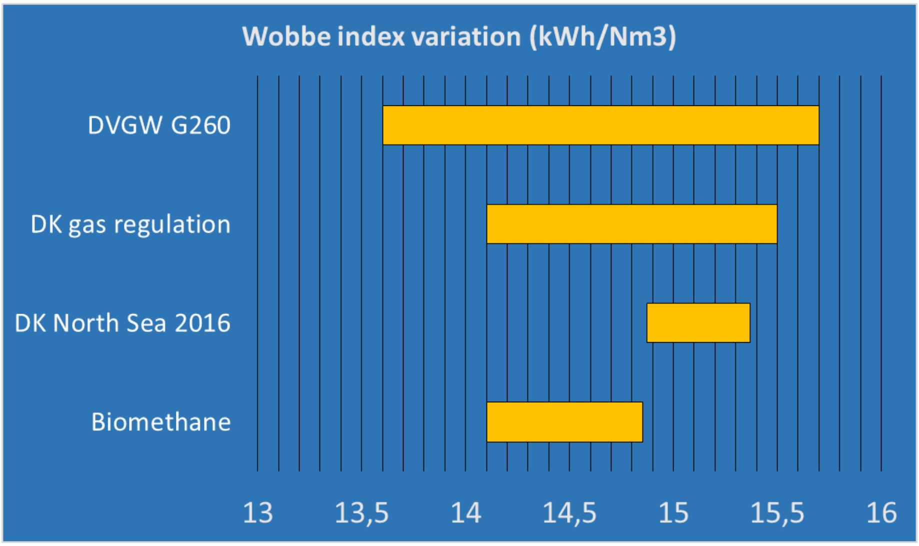

Figure 3 The Wobbe Index acceptance range (DVGW and Danish regulation). And the actual range for gas supplied from the North Sea in 2016 and for upgraded biogas (bio-methane).

The Danish TSO, Energinet.dk, monitors cross-border gas imports to make sure that all gas imported fulfils the Gas Regulations' requirements. The gas distribution companies monitor the upgraded biogas injected. A number of measurements are made continuously; others are made at regular intervals. If this gas does not fulfil the requirements, gas injection is immediately stopped by remote valve control.

There is no guaranteed value for the methane number (MN) in the regulations. During 2016, the MN ranged from approx. 68 to 80 with an average of 71.7 at the grid connection point Egtved in Jutland. At this point, natural gas (North Sea or imported natural gas) is predominant.

For correct energy based billing, the gas company must have a good knowledge of the gas supplied and consumed at each customer. Flow metering in the grid combined with advanced models for distribution-grid flow simulation is now being actively used to predict the gas available to the customers.

Gas fired cogeneration

Gas fired cogeneration population

Some 800 gas driven engines and some 33 natural gas fuelled gas turbines for power/CHP production are connected to the Danish natural gas grid. Most installations were built in the mid-90s. A number of plants have replaced their engines since then.

The gas engines are typically connected to the low-pressure plastic (PEX) grid, whereas the gas turbines are connected to the regional steel-pipe grid with pressures of 20 or 40 bar(g).

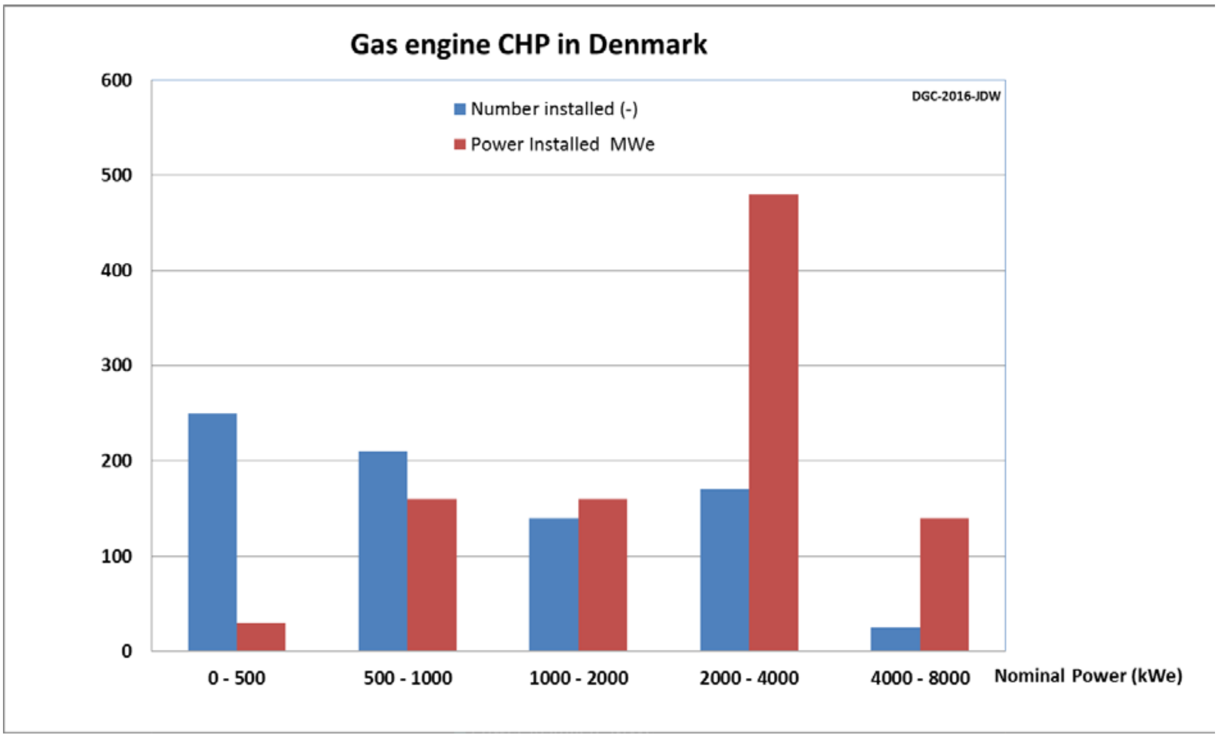

Figure 4 Overview of the gas engine population with regard to engine size, 2016 reference (nominal power, number of units and the total power for each power segments)

Gas quality at decentralised gas engine based CHP plant

During 2016 and 2017, Danish Gas Technology Centre (DGC) performed a number of gas quality measurements at medium-size end-users, including CHP plants. These measurements were performed with a mobile gas chromatograph.

Figures 5 and 6 show examples of results of the measurements made for CHP plants in the vicinity of injection points for upgraded biogas. It can be seen that relatively large changes of methane number (MN) and calorific value occur, sometimes several times a day for the periods of the measurements. As Danish gas of North Sea origin is in the high end of the Wobbe Index range and upgraded biogas is in the low end, this can be seen to cause a change of some 10%, relatively if going from biomethane to high Wobbe North Sea gas (figure 6).

As the methane number of North Sea gas is around 70-75 and the number for upgraded biogas is around 101-103, this is also a quite significant change. If the engine control system optimizes for a constant and relatively small margin for engine knocking, the change from predominantly upgraded biogas to North Sea-like gas may cause engine knocking and possible failures and downtime of the unit.

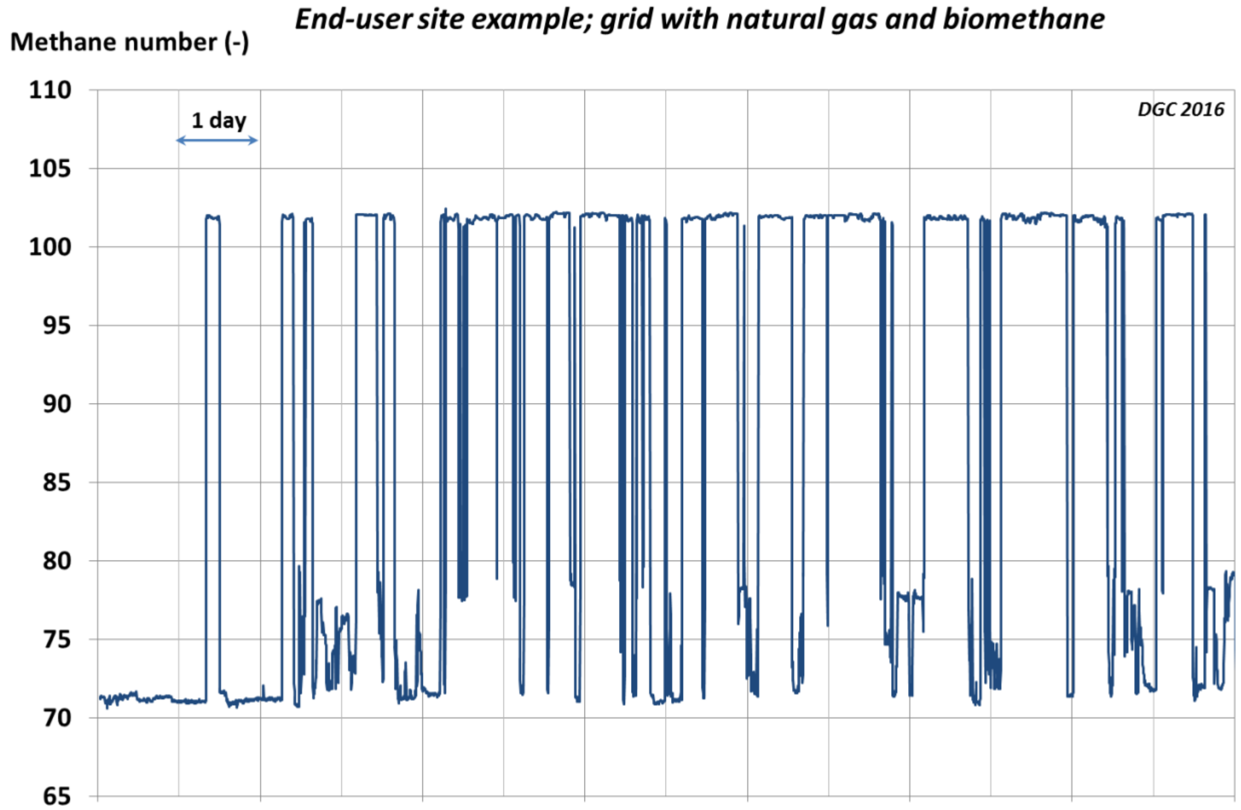

Figure 5 Example of gas quality (Methane Number) at a CHP plant in the central part of Denmark. The measurement was made early 2016.

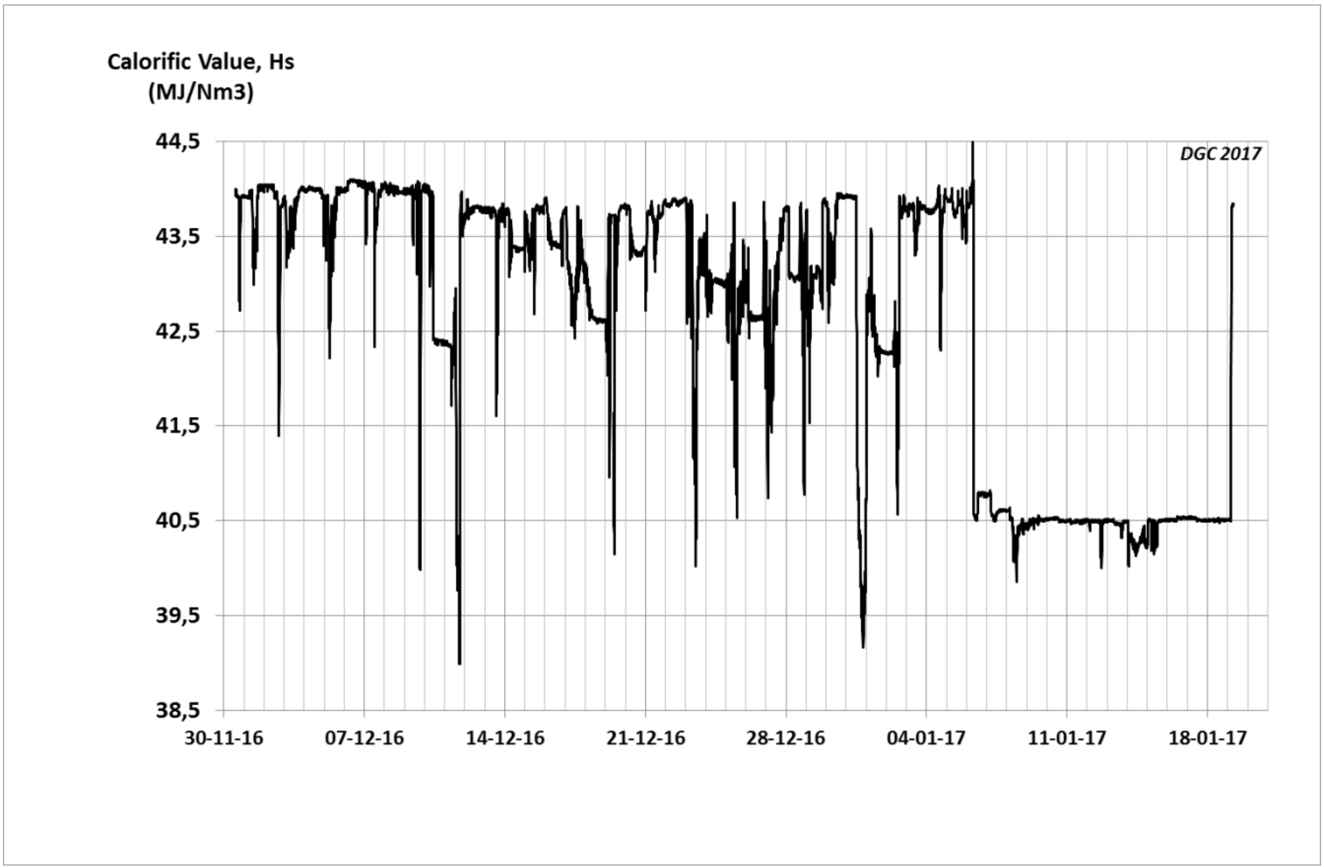

Figure 6 Example of measured gas quality at a CHP plant in the southern part of Jutland. The measurement was made during December/January 2016/2017.

From the rapid change of the calorific value of the gas supplied it seems that little gas mixing takes place in the gas distribution system; the measured results indicate more like a plug-flow situation.

The gas production from manure based biogas plants is to a large extent stable over the year. Depending on the size of the plant, costumers close to the plant can expect predominantly upgraded biogas most of the year. Customers far from the plant will possibly not receive upgraded gas from this injection point. Customers somewhere in between may experience many changes as a result of the supply/demand situation. Depending on fluctuations in gas consumption (or production), some consumers may be in a kind of "battle field" with many daily changes as in the examples shown.

Problems for CHP units and solutions so far

As mentioned previously, dropouts of gas-engine based CHP units have been seen at sites with large and sudden variations in the gas supplied. In general, the sudden change in the calorific value of the gas supplied is much faster than generally accepted by most engine manufacturers. More difficult or impossible start-ups have also been seen.

The dropouts are caused by the engine surveillance system as a result of the sudden change in heating value or due to knocking occurred when going from upgraded biogas to usual natural gas.

Discussions with leading gas engine suppliers have shown that most dropouts are in fact due to a sudden "mismatch" or "out of range" of gas air valve openings/positions etc. because of the change in heating value. Re-adjustment of valve position acceptance spans, turbocharger bypass (waste gate) or other settings have reduced the risk of dropouts for some engine makes/series.

In general, the more updated the control system the engine is fitted with, the better are the possibilities for operational adaption to the changing gas.

All the leading gas engine suppliers would like a feed-forward signal on the actual sites on what to expect on a short-term basis.

Until now, upgraded biogas has primarily been supplied to the low-pressure gas grid. No gas turbines have yet been supplied with such gas. But more upgrading plants are under construction and will be fitted with compressors for injection of upgraded biogas in the high-pressure part of the system, and challenges for gas turbine units may be seen.

Gas company activities

The gas companies (including the TSO "Energinet") have also been active in adapting to the challenges seen. The gas distribution companies have put many efforts into achieving correct billing (heating value correction) for the costumers. This is done via further measurements, flow prediction tools etc.

Improved customer information on gas quality in the natural gas grid has been made available on-line on the web for many sites in Denmark.

Meetings have been held to inform CHP end-users and equipment suppliers on this topic seen from a gas supply company and from equipment manufacturer's point of view.

The allowance range for the gas in the gas grid is not new; the new thing is that a wider range is now operational compared to the past.

What to expect … and what can be done?

This paper shows that various gasses with different origin, compositions and related combustion characteristics are present in the natural gas grids and limited mixing seems to take place. This will occur even more in the future, as more interconnectors are being built, more import/export will take place, and more gasses of other origin (as the upgraded biogas) will enter the grid.

Gas flows will depend on market conditions, and gas storage facilities are expected to take a more active part in this flow regime as well. The Danish TSO, Energinet.dk, has prepared a table about what <u>might be expected</u> for the Danish situation, see table 2.

Table 2 Possible future extreme maximum and minimum values for each gas component and related properties based on historical data (Source: Energinet.dk, 2017)

Component/property	Unit	Minimum	Maximum
Methane	mole %	83	100
Ethane	mole %	0	10
Propane	mole %	0	5
I-Butane	mole %	0	0,5
N-Butane	mole %	0	1
I-Pentane	mole %	0	0,2
N-Pentane	mole %	0	0,2
Hexane +	mole %	0	0,2
Nitrogen	mole %	0	5
Oxygen	mole %	0	0,5
Carbondioxide	mole %	0	2,5
Calorific Value, Hs	kWh/Nm^3	10,69	12,79
Wobbe Number	kWh/Nm^3	13,91	15,46

As shown in the measurements presented in this paper, little gas mixing seems to take place in the system. These sudden changes in gas composition will challenge the connected appliances, such as gas engines and possibly gas turbines as well.

Gas companies constantly monitor the system and ensure that the gas entering the system fulfils the actual standards agreed. The gas distribution companies should make real-time information on actual gas supply situation (key parameters) available in a number of points in the distribution grids. Such data can be based on measurements, wherever possible, and predictions in other points based on the measured values combined with flow simulation software.

Gas distribution companies can use the above knowledge/predictions in combination with customer gas meters with e.g. hourly automatic reading to obtain correct (energy basis) billing of the specific customer.

The customers should make themselves familiar with the information available on gas quality. During contract negotiations and contact with the gas distributor, the customer should also address possible contractual issues on gas pressure in relation to their appliances installed. Customers might install measuring equipment (Wobbe meters, methane number sensors etc.) on their own premises for feed forward signals and/or registration on gas quality available at site.

Gas engine and gas turbine manufacturers must address the possible rapidly changing gas properties of the fuel supplied. The flow has shown to be very plug-flow-like causing rapid change of calorific value, methane number etc. Inclusion of feed-forward signals on the gas quality to come should be considered for prime movers optimized for the highest efficiencies and relatively little margin for engine knocking etc. Wider acceptance range during start up and possible restrictions, alarms and/or adjustments during prime mover operation might also be relevant.

References

/1/ The Danish Safety Technology Authority (www.sik.dk): Danish Gas Regulations, Section C-12

/2/ The Danish TSO on Power and Gas, www.energinet.dk

/3/ "Die Bewertung der Klopffestigkeit von Kraftgassen mittels der Methanzahl und deren praktische Anwendung bei Gasmotoren", Christoff, Cartellieri & Pfeifer 1972

/4/ DGC algorithm for methane number calculations; www.dgc.dk

/5/ "Open Gas Markets, Experience gained during gas import/export for gas fired CHP Plants", PowerGen Europe, Cologne 2012