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Open gas markets, experience gained during gas import/export for gas fired CHP plants

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List of contents

0. Abstract

In 2010 a new situation occurred in Denmark/Sweden as gas imports via Germany started. Until then, solely gas with high calorific value from Denmark's North Sea fields had been supplied.

Prior to the imports, studies and discussions with suppliers had been taking place. Laboratory test of small household appliances were made. Gas was supplied from pressurized bottles. No such tests were possible to perform with medium-size and large-scale CHP plants.

In autumn 2010 the TSO ordered a test import of this new gas quality to a restricted area and some field experience with large and small scale appliances was gained. Later, import on commercial terms was opened and executed. During some periods low Wobbe gas close to the lower limit of acceptance was seen and further experience was gained.

The paper presents field-test results from series of measurements made at three gas engine based units and a gas turbine in CC configuration. The measurements were made during a period with imported low Wobbe gas and during a period where high Wobbe North Sea gas was supplied to the units. The same measuring equipment was used during both series of measurements to minimise measuring uncertainties.

This paper also presents lessons learned and operational problems/challenges reported by CHP customers. Gas company initiatives and prime mover suppliers' points of view and actions taken are presented as well.

1. The natural gas supply

Natural gas was introduced in Denmark in 1982. For a short time the gas was supplied from Germany, but from 1984 supplies from Denmark's fields in the North Sea fully took over the supply. Gas was supplied from the Tyra field (mainly gas), later on, other North Sea fields and wells were introduced most of them supplying associated gas in connection with oil exploration and production. The gas was used in Denmark and exported to Germany and Sweden.

Two gas storage facilities are now part of the system, one placed in northern Jutland (aquifer) and one at the island of Zealand (hydrofer). Gas chromatographs in the transmission grid are in continuous operation at five strategic locations.

The natural gas is supplied to households, the commercial and industrial sectors and for power/cogeneration production. The annual gas consumption is approx. 5 billion m_n^3/year. The power production and cogeneration sector consume some 25-30 % of this volume.

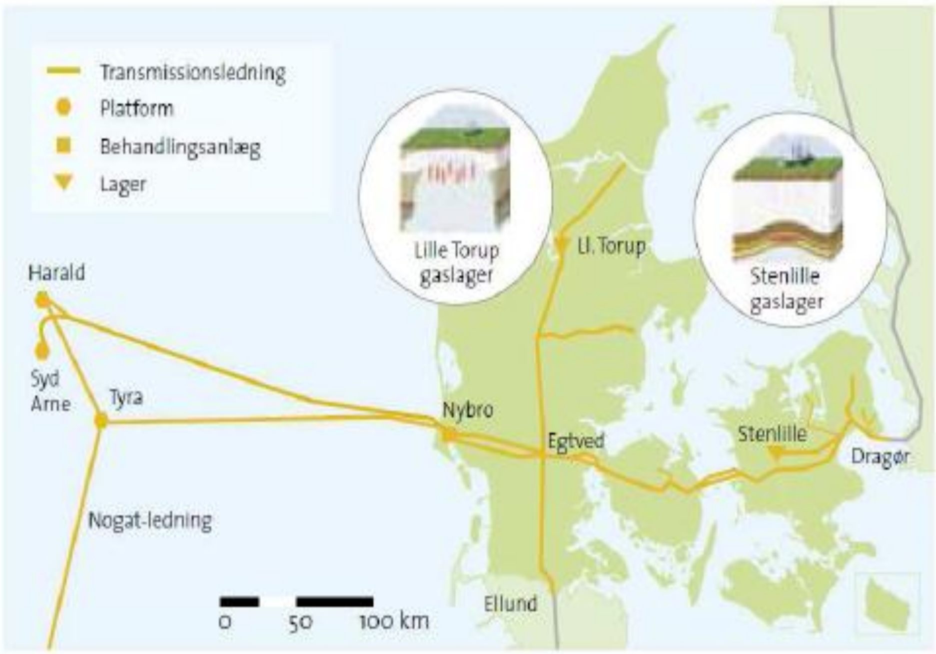


Figure 1 The natural gas transmission grid. The figure includes the two gas storages (shown as triangles), the major North Sea fields and entry/exit points.

In 2010 a new situation occurred as gas imports from Germany started. This was due to a deregulated gas market. This imported gas has a lower calorific value and thus a lower Wobbe index than the North Sea gas typically some 5-8 %.

2. Gas regulation requirements

The Danish natural gas requirements regarding gas quality are found in "Gasreglement A" (Danish Gas Regulations) /1/. The natural gas distributed must be Type 2, H series /4/.

The Wobbe index must be within the 51.9 – 55.8 MJ/m_n^3 (14.1 – 15.5 kWh/m_n^3) range during normal supply situations. For certain short and extraordinary situations supplies with higher Wobbe index might be allowed. Customers with sensible equipment must be warned prior to such extraordinary supply situations.

Mandatory components and their performance demands in the gas supply line to gas engines and gas turbines are stated in /2/ and /3/. The prime mover supplier must, for each specific installation, agree that this is suitable for operation of the specific appliance.

Up until import of natural gas via Germany started the gas quality was extremely stable and the supplied Wobbe range was predominantly 15.0 – 15.5 kWh/m_n^3.

3. The natural gas fired CHP units

A total of some 700 natural gas fired engines equal to a total of approx. 1,000 MW_e are installed for decentralised cogeneration. More than 25 different makes are represented, many of them with two, three or more engine series present. However, gas engines from Caterpillar, Jenbacher, Rolls Royce/Bergen and Wärtsilä account for more than 90 % of the power production or gas consumption in this segment.

Most engines were installed during the mid-90'ies. The pre-chamber engines account for approx. 50 % of the installed gas engine capacity.

A total of some 44 gas turbines (8 different makes) are installed with a total capacity of approx. 725 MW_e. A number of single-cycle gas turbines typically rated 4 - 10 MW_e each are installed for industrial cogeneration. Larger gas turbines, including aero-derivatives, are most often installed as combined-cycle units.

4. Field test measurements during import/export

In spring 2011, two series of measurements were made at CHP units located near the gas import entry point in southern Jutland. These measurement series were made during a supply situation with high-Wobbe North Sea gas and a supply situation with low-Wobbe import gas, respectively.

The measurement series were performed at three gas engine CHP units (one medium-size open-chamber and two pre-chamber units) and a combined-cycle gas turbine installation.

The measurements were made at full load during a 2-hour period. The same gas and heat meters were used during both series. For the emission tests high-quality laboratory equipment was used, calibrated before and controlled after the test.

The following key data was measured during each period:

- Gas consumption
- Electricity production
- Heat production (if heat meters were installed)
- Actual gas composition at site, three samples were taken during each test

- Ambient conditions (temperature, atmospheric pressure, gas supply pressure)
- Prime mover settings, such as ignition timing, intercooler temperature, temperature before first row of turbine blades (GT))
- Air excess (O_2 measurement)
- Emissions (CO, NO_x and UHC)
- Gas composition (three samples taken on site during each measurement)

The measurements were taken without prior extraordinary adjustments of the units.

The results can be presented in many ways. This paper focuses on possible differences between the two supply situations; therefore the differences between the two sets of measurements on each site are shown. By doing this, systematic measurement uncertainties/errors are eliminated.

The measurement uncertainties for the various parameters are shown in connection with possible measured differences. However, the uncertainty shown is as a rule the absolute accuracy of one measurement series only. The uncertainty of the difference is expected to be less. However, since the possible systematic error/uncertainty is not known, the most likely uncertainty of the differences cannot be shown.

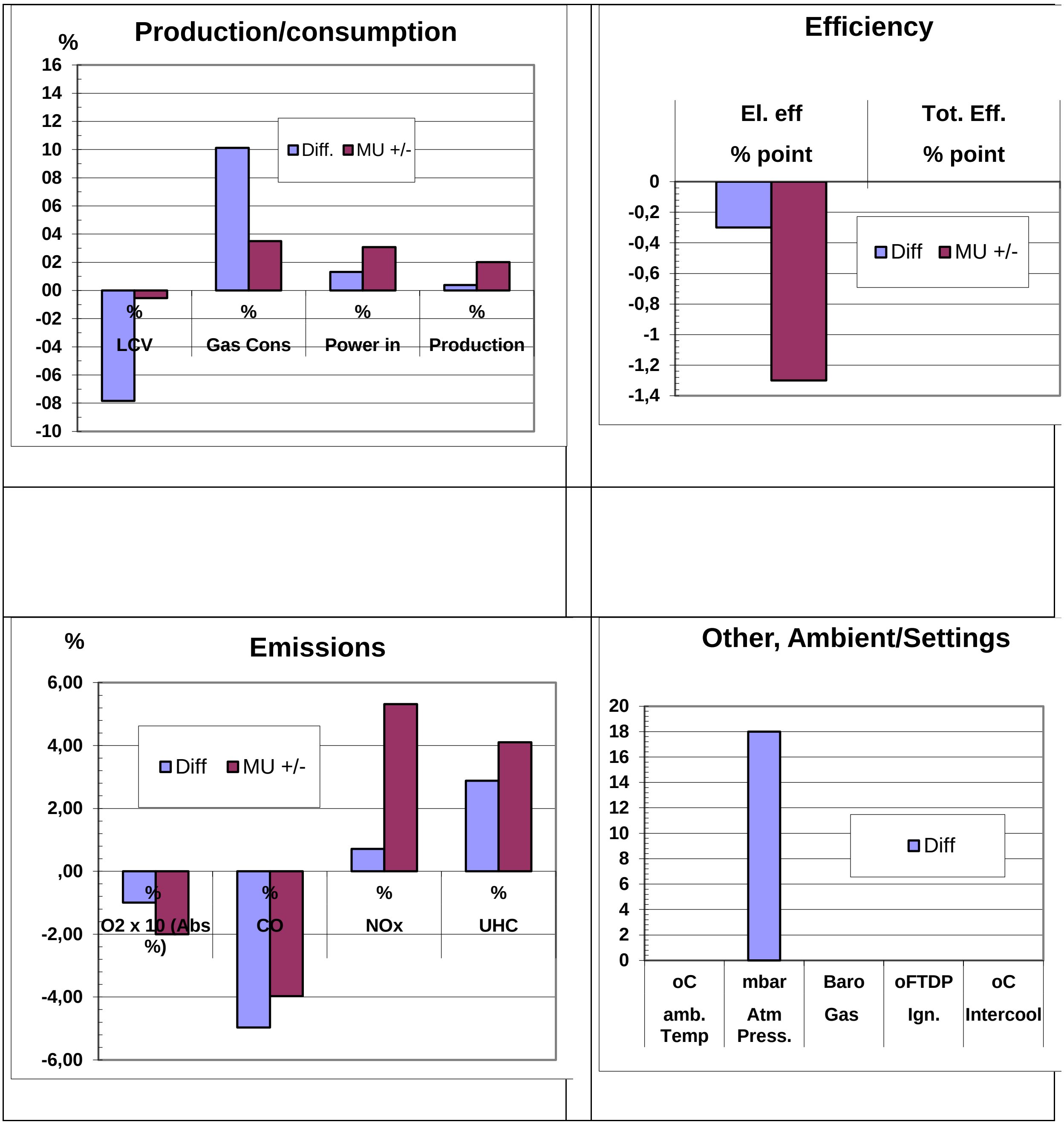
Based on experience gathered, new control system settings might have been introduced for a number of CHP plants. This may result in different efficiencies and emissions than shown here.

The measurement results from the 4 sites are presented as Figures 2-5 on the following pages.

As stated, the diagrams show the measured differences in per cent when operating on low-Wobbe import gas compared to high-Wobbe North Sea gas.

Figure 2 ***CHP Unit****: Open-chamber lean-burn gas engine output rated approx. 1000 kW$_e$.*

Diagrams showing the measured differences when operating on low-Wobbe import gas compared to high-Wobbe North Sea gas.



Abbreviations

Diff: Measured difference

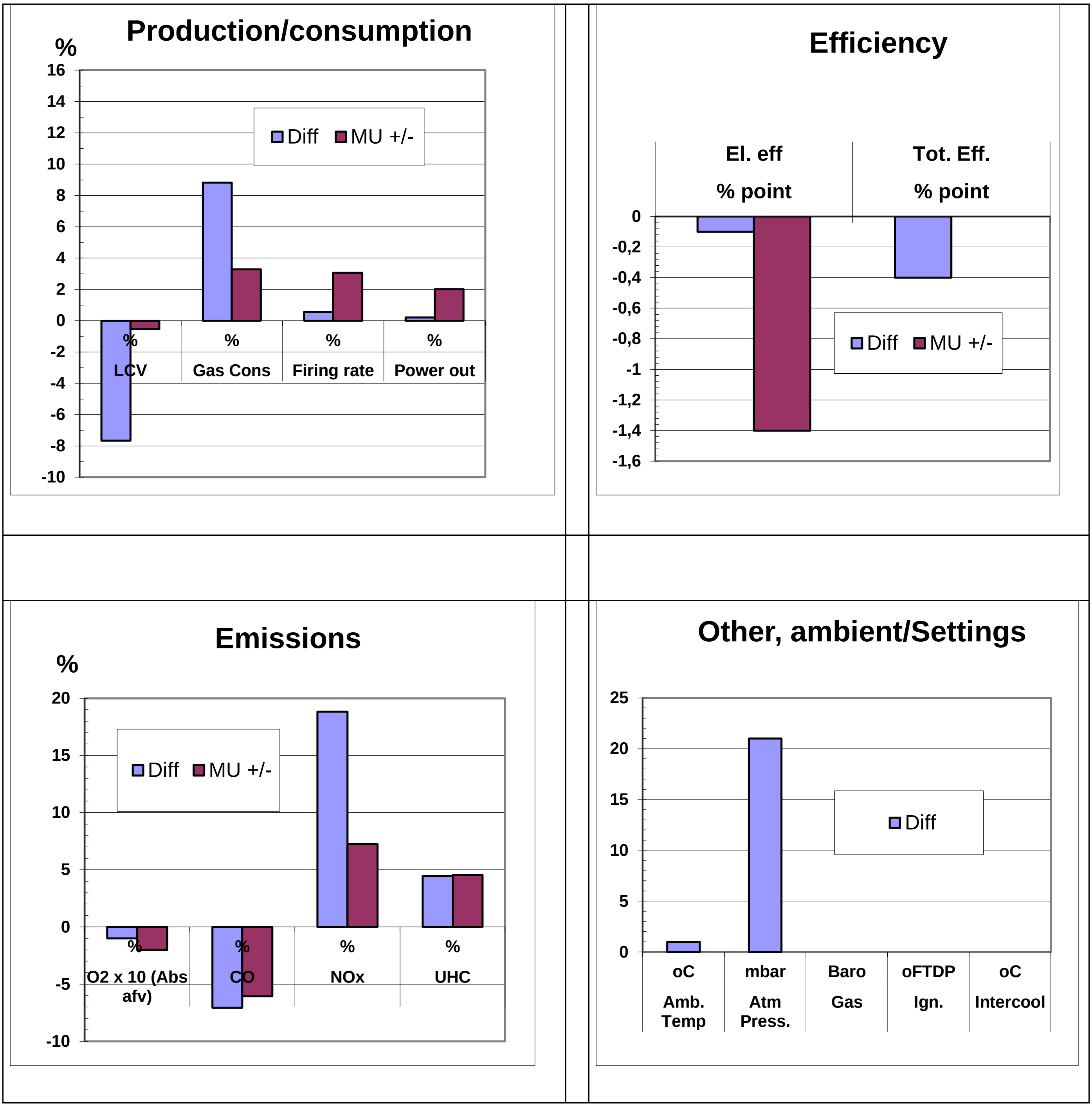
MU: Measuring uncertainty

LCV: Lower Calorific Value of gas

The O_2 difference shown is multiplied by 10 and shown in absolute numbers to make the difference, if any, visible. If 1 % is shown on the graph this means that 0.1 percentage point difference was measured.

Figure 3 ***CHP unit****: Pre-chamber lean-burn gas engine output rated approx. 3½-4 MW$_e$.*

Diagrams showing the measured differences when operating on low-Wobbe import gas compared to high-Wobbe North Sea gas.



Abbreviations

Diff: Measured difference

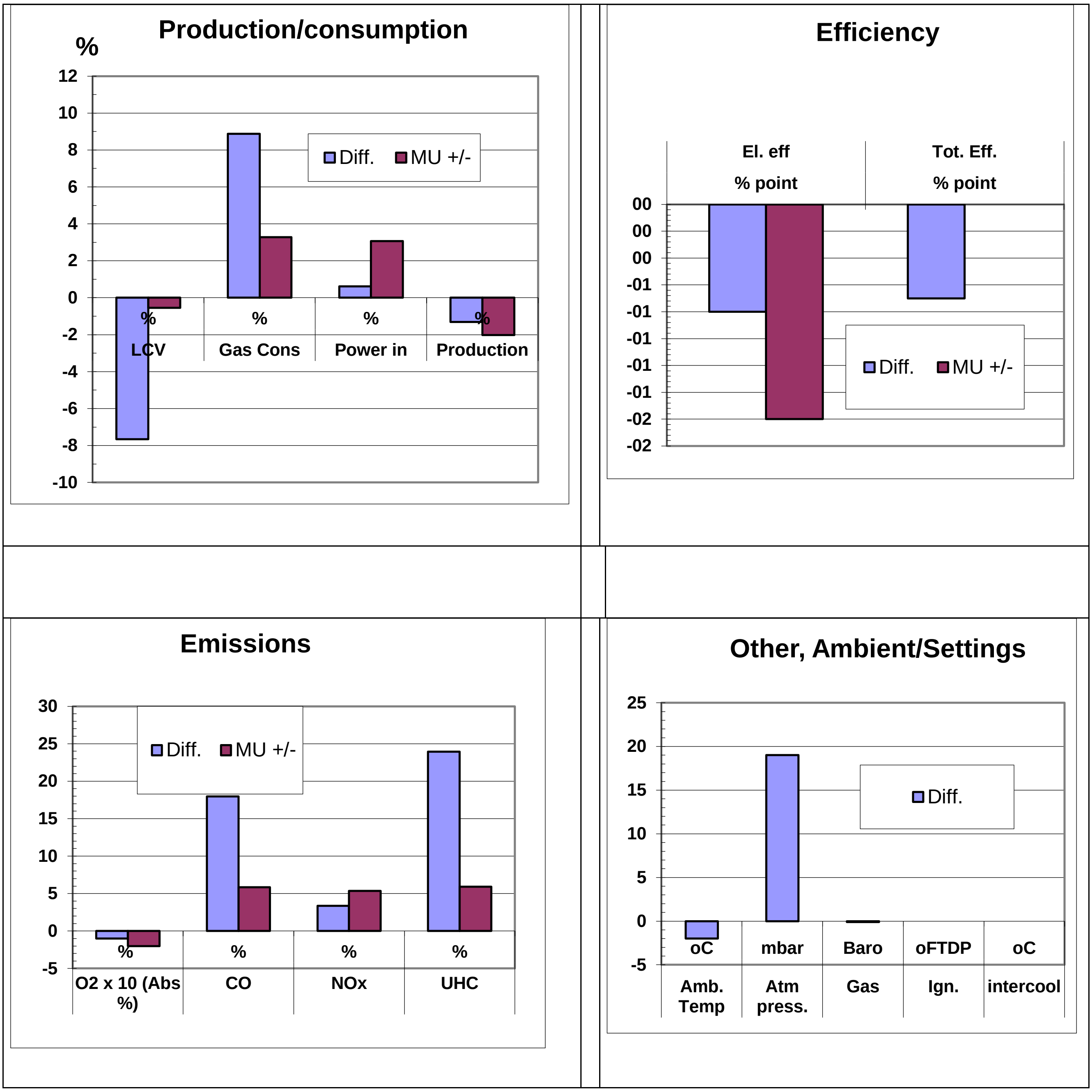
MU: Measuring uncertainty

LCV: Lower Calorific Value of gas

The O_2 difference shown is multiplied by 10 and shown in absolute numbers to make the difference, if any, visible. If 1 % is shown on the graph this means that 0.1 percentage point difference was measured.

Figure 4 ***CHP unit:*** *Pre-chamber lean-burn gas engine output rated approx. 6 MW_e.*

Diagrams showing the measured differences when operating on low-Wobbe import gas compared to high-Wobbe North Sea gas.

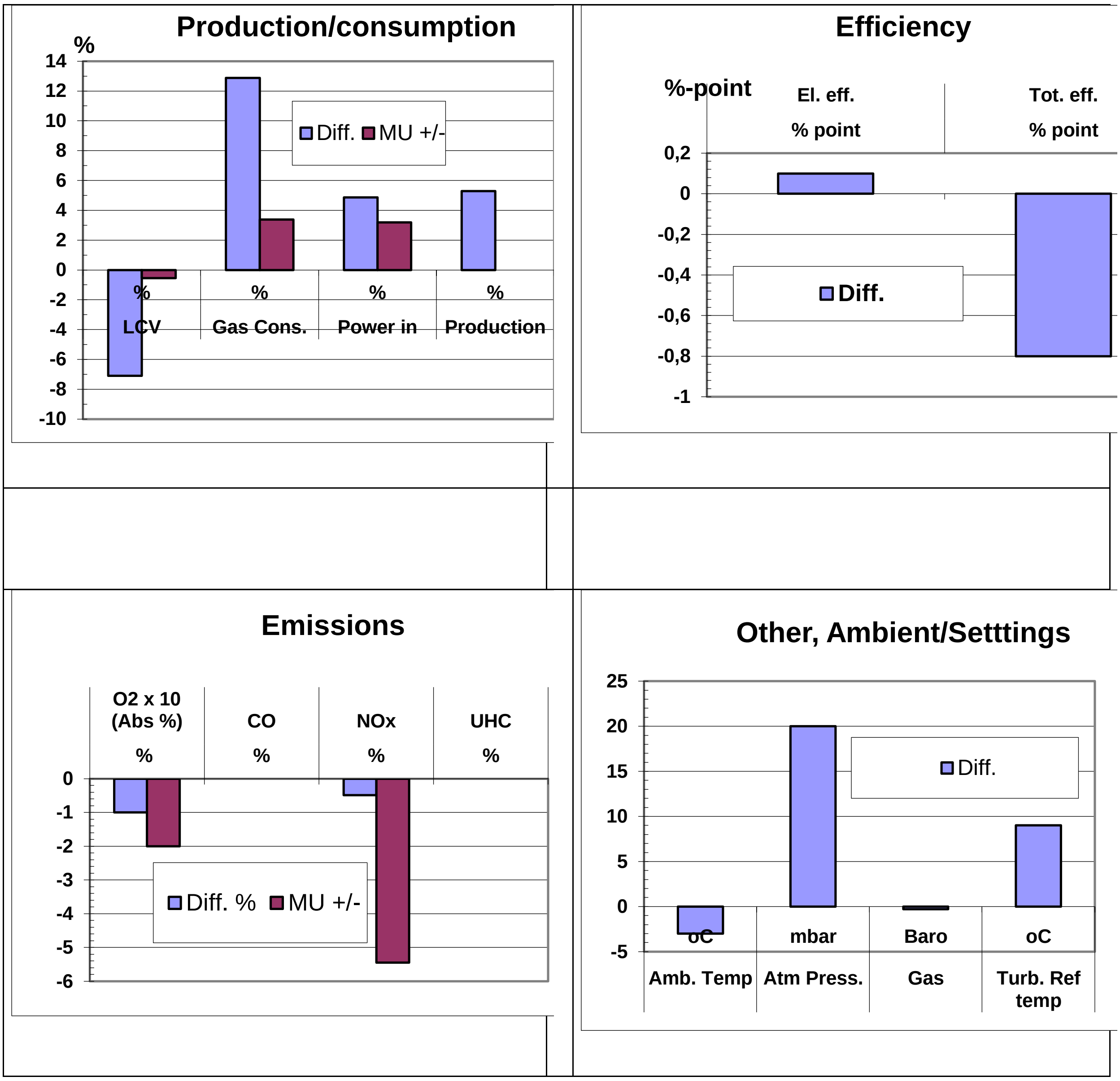


Abbreviations
Diff: Measured difference
MU: Measuring uncertainty
LCV: Lower Calorific Value of gas

The O_2 difference shown is multiplied by 10 and shown in absolute numbers to make the difference, if any, visible. If 1 % is shown on the graph this means that 0.1 percentage point difference was measured.

Figure 5 ***CHP unit:*** *Gas turbine, nominal output 40 MW_e.*

Diagrams showing the measured differences when operating on low-Wobbe import gas compared to high-Wobbe North Sea gas.



Abbreviations

Diff: Measured difference

MU: Measuring uncertainty

LCV: Lower Calorific Value of gas

The O_2 difference shown is multiplied by 10 and shown in absolute numbers to make the difference, if any, visible. If 1 % is shown on the graph this means that 0.1 percentage point difference was measured.

5. Comments on the measurement results

For two of the three gas engine units only very small and insignificant differences were measured regarding firing rate, power output and efficiency when using low-Wobbe import gas compared to high-Wobbe North Sea gas.

For all three gas engine units increased emission was found when operating on low-Wobbe import gas. In a number of cases this difference was below the uncertainty of the measuring equipment. However, also differences in atmospheric pressure and a slight decrease in air excess were seen between the two measurement series, which might be the reason for the rise in NO_x rather than the gas itself.

For gas engine #3 a decrease in electricity production efficiency of some 0.8 percentage point was measured when operating at low-Wobbe import gas. As also significant increased emissions of CO (+18 %) and unburned hydrocarbons (+24 %) were seen, this may indicate poor combustion and the need for new settings for this engine to achieve optimal operation on the import gas supplied.

At the gas turbine unit (#4) both a higher electrical output and also increased gas consumption were measured when operating on the low-Wobbe import gas. The electrical efficiency was improved by 0.1 percentage point (insignificant as measurement uncertainty was higher).

The above findings for the gas turbine are most likely a result of lower outdoor temperature and higher atmospheric pressure during the import gas supply situation.

No significant difference in emissions from the gas turbine was found.

6. Observations during gas import periods

Based on feedback from plant operators, gas companies and others a number of other findings regarding CHP operation at the different supply situations were noted.

Little mixing seems to take place in the transmission pipes between the gasses. The flow is a kind of plug-flow. Some equipment suppliers have specifications regarding allowed change in energy content of fuel gas per minute while others have no such specification in the specification sheets.

A few gas engine based units have experienced problems during cold start if gas quality has changed compared to what the engine were initially adjusted for. A number of engine control systems are prepared to have different start settings for various gasses. A feed-forward signal regarding the actual gas quality at site is needed for efficient utilisation of these.

Knowledge about the actual gas composition is preferred/needed when doing tuning/setting of a CHP unit. An on-line gas chromatograph or a portable Wobbe index device is needed.

There are challenges for correct gas billing of plants with abnormal operation pattern (peak shaving, industrial plants etc.).

If the allowed Wobbe index (or gas calorific value) range and operation span is widened more than ±5 % this will exceed gas supply warranty specifications for a number of gas turbine makes and possible also for some engine makes.

7. Gas company initiatives before and after import started

The TSO and the gas distribution companies launched a series of initiatives before import was actually made. Supplementary initiatives based on experience gained during the first import periods were also made. A number of these initiatives are listed below:

7.1. Discussion with CHP-appliance suppliers

The possible influence of the import gas was informed to and discussed with the major CHP suppliers in 2008 and again in 2010/2011.

7.2. Limited test area

When the first import series was made it was geographically limited to a well-specified part of the distribution network close to an entry point by shutting valves in the main transmission grid.

7.3. Public information meetings with CHP and industrial users

Information meetings were held for end-users (CHP owners and operators), relevant organisations, equipment suppliers and service providers.

7.4. Website about the real time actual gas supply situation

The Danish TSO has established a publicly available website with information on the overall natural gas supply situation. Here a live diagram shows the current import/export situation at the various entry points and the related gas volumes and actual heating value. See examples in Figure 6.

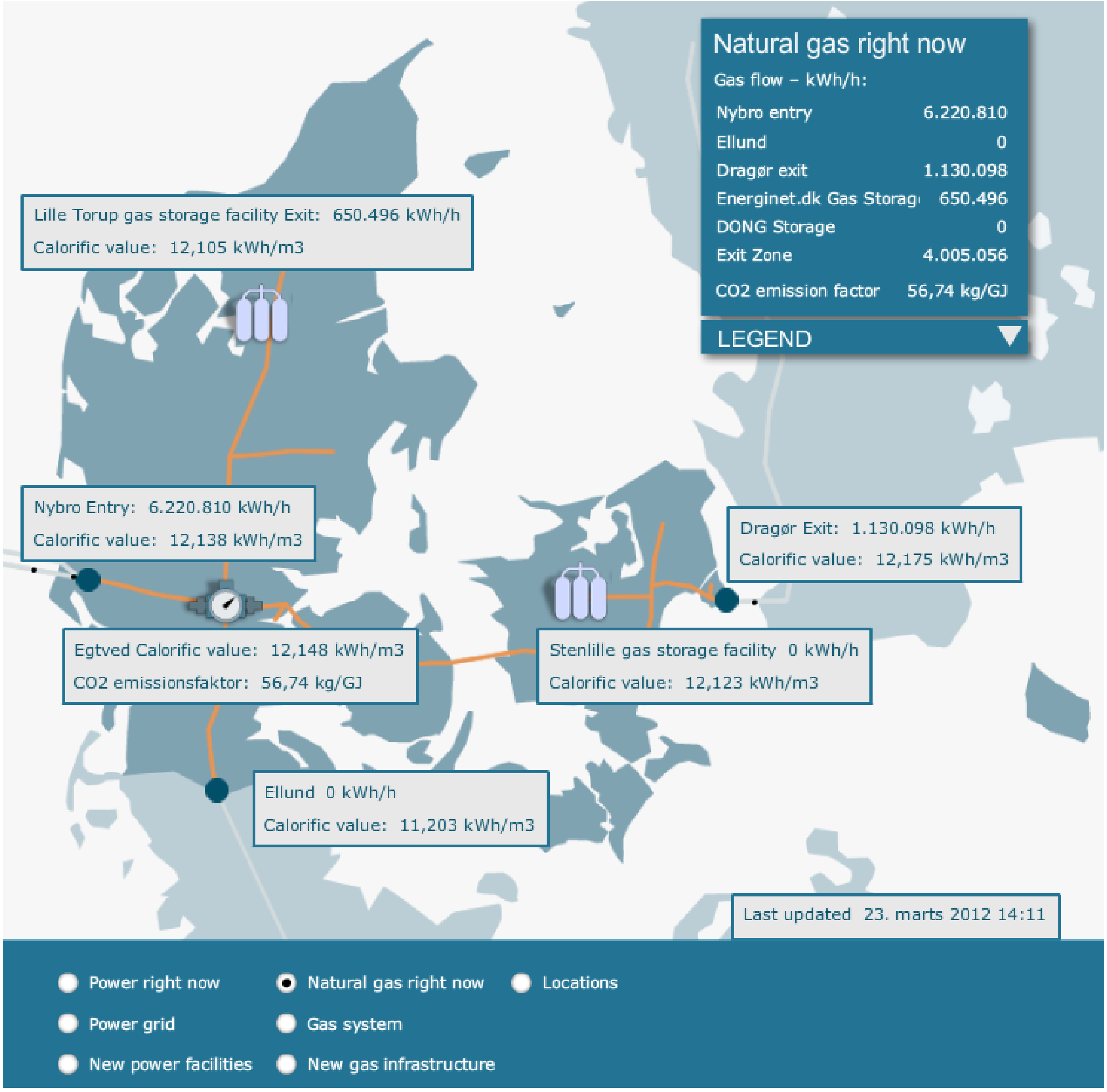


Figure 6 The Energinet.dk overall gas transmission system including information on actual supply situation. Published at www.energinet.dk.

7.5. Quality tracker

A quality tracker system based on knowledge on gas volumes and heating values in a number of points in the gas transmission system calculates/estimates the actual gas supply situation in a number of points (mostly pressure reduction stations) in the gas distribution network. This information is also published through the Energinet.dk website.

Figure 7 Detailed information points, from which data of measured or calculated actual gas composition can be found.

7.6. Text message service

A texting service (SMS service) is established to facilitate and service end-users, installers and others. A text message is transmitted when import starts and ends.

7.7. Analysis of influence on gas billing

Analyses were made for typical customers in the area closest to the entry point to find possible influence on the consumption weighted annual average heating value. Natural gas billing is (and has always been) corrected for the actual heating value of the gas supplied in a number of reference points in the system.

For consumers with a normal degree-day based gas consumption profile, these analyses have shown a possible uncertainty of < 0.55 % near the gas import entry point.

For consumers with abnormal consumption profile (industrial customers, peak load plants etc.) the billing uncertainty may possibly be larger; tests are now being made with small gas chromatographs installed at the end-user for onsite correction.

7.8. Courses for installers, service providers (other appliances than CHP)

Nationwide courses for installers and service providers for small appliances were held to ensure correct adjustment of household appliances. In less than a year, some 1400 persons have participated in these courses, which also included test of their measuring equipment.

A new code of practice has been developed to ensure uninterrupted and safe operation of such equipment. This has been introduced at the courses, via articles, QR codes, separate website etc.

Labelling of units adjusted to the new supply situation has been initiated.

8. CHP supplier activities

The suppliers have been invited and most of them participated in information meetings held.

The gas engine suppliers have followed the experience gained during the import periods with low Wobbe indexes. Within their own product programme new initial settings have been considered and for some engine series a change of control systems and/or settings has been initiated. A number of advanced control systems are prepared for operation and start on different gasses and two or more gasses can be stored in the memory of the system. However, exact knowledge of the gas delivered when starting up is preferred. Such information could be derived from the Energinet.dk home page or by direct measurements on the gas supplied.

A number of smaller gas engine based units have been operated for years with a fixed gas/air mixture rate. These controls are now being replaced with adjustable venturi systems based on a feedback signal.

9. Manufacturers experience and points of view

9.1. Gas engines

When import of low-Wobbe natural gas started, only a small number of engines experienced troubles. At a few installations the gas supply pressure (due to higher gas flow) came below usual settings of pressure gauges. This could be solved either by new settings or by slightly increasing gas pressure from the nearest pressure reduction station.

Other engines had start difficulties as the start settings were made for usual high-Wobbe gas.

In general, a number of engines need to be readjusted and settings for allowed pressures or gauges (valve movement etc.) must be reconsidered and possibly altered.

Older engines using venturies for gas/air mixing might need adjustable venturies to secure the exact air/fuel ratio for the gas supplied. The adjustment of the venturi setting can be made based on turbocharger pressure, temperatures etc.

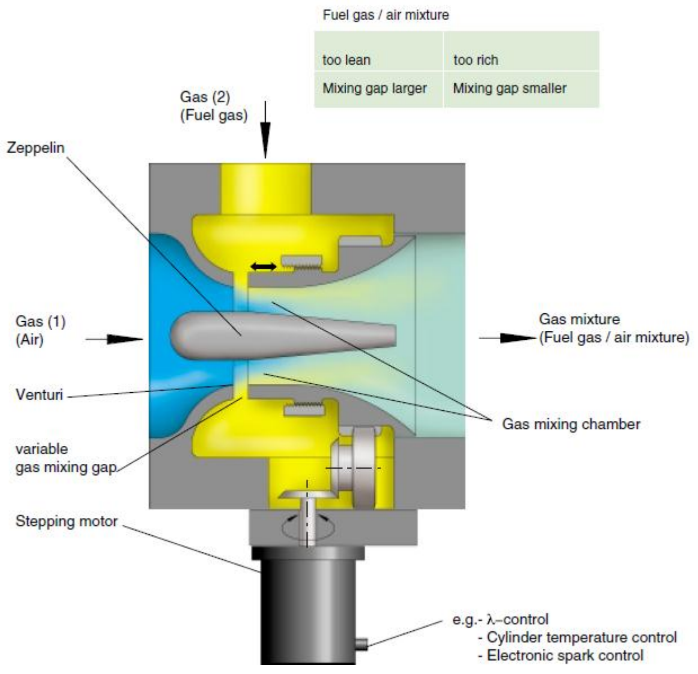


Figure 8 Adjustable venturi (from RMG Gas Carburator brochure)

A feed-forward signal on the actual gas quality when starting the engine would be beneficial.

In /5/ the engine manufacturer association has stated their point of view in the light of increased cross border gas trading covering a Wobbe range broader than what has been experienced in Denmark so far. In the light of technical challenges and to achieve the best possible fuel efficiency the “Euromot” association advocates for gas treatment at gas entry points so methane will be the only hydrocarbon in the gas grid.

9.2. Gas turbines

No technical problems have been reported from gas turbine based CHP plants during gas import periods. Only two to three sites are installed in the region where most unmixed import gas was supplied.

Based on discussions with suppliers and specification sheets for the gas turbines, the gas turbines are often able to cope with Wobbe index variations up to approx. ±5 % from the base adjustment point.

Gas turbine suppliers also foresee possible larger gas quality and Wobbe index variations in the future gas supplies in Europe. Therefore, development of sensors and retrofit appliances has been given a high priority.

10. Conclusion

During the gas import periods no safety critical issues with the natural gas fired CHP units have been reported. During one of these periods, import gas with a Wobbe number very close to the national minimum requirement was supplied.

A measurement program carried out during high- and low-Wobbe supply situation showed for some of the gas engine units differences in performance or emissions that might be gas quality related. However, the CHP units might not necessarily be fully tuned/adjusted or equipped for this new supply situation.

Re-adjustment, change of setting or modification of gas/air mixture systems at some engines may be needed.

If the appliance is adjusted in the middle of the allowed Wobbe span for normal supply situation in the national requirements the possible Wobbe variation will be a little less than ± 5 % as given as the limit in the specification sheets for a number of gas turbine makes. If the national Wobbe acceptance band is further widened, this limit might be exceeded.

The gas engine and gas turbine suppliers have very different permissions for the accepted rate of change (per minute/hour) of the Wobbe number.

So far, only little mixing in the transmission and distribution system has been reported; the flow pattern is much like plug-flow giving abrupt changes in gas composition.

A number of service initiatives on the part of the gas companies have been developed and initiated to help customers find information of the supply situation, even down to distribution system level.

11. References

1. Gas Reglementet (Danish Gas Regulations), GR-A enclosure 1A: Gas Quality; published by The Danish Safety Authority (www.sik.dk)

2. Gas Reglementet (Danish Gas Regulations), GR-B40 Supplement for Gas Turbines; published by The Danish Safety Authority (www.sik.dk)

3. Gas Reglementet (Danish Gas Regulations), GR-B41 Supplement for Gas Engines; published by The Danish Safety Authority (www.sik.dk)

4. EN 437 European Standard: Test gasses, Test pressures, Appliance Categories, May 2003

5. Gas Quality Aspects for Reciprocating Gas Engines, Euromot Position Paper, May 30th 2011

6. The Impact of Natural Gas Quality on Gas Turbine Performance, Position Paper, European Turbine Network, Feb. 2009

7. Energinet.dk, the Danish TSO (Natural gas and Power transmission)

Enclosure

1. Gas composition and related properties for import/North Sea gas during the measurements

Enclosure 1

Gas analysis of low-Wobbe import gas and high-Wobbe North Sea gas

Samples taken on site, week 12 and 15, 2011, respectively

Unit #4 is a gas turbine (GT), others are gas engines (GE)

		Low-Wobbe import gas			**High-Wobbe North Sea gas**			
Gas		**Unit #1 (GE)**	**Unit #2&3 (GE)**	**Unit #4 (GT)**	**Unit #1 (GE)**	**Unit #2&3 (GE)**	**Unit #4 (GT)**	**Uncertainty**
Methane	Mol. %	92,2	92,1	92,2	89,6	89,7	89,3	+/- 0,32
Ethane	Mol. %	3,6	3,7	3,9	5,9	5,8	5,9	+/- 0,06
Propane	Mol. %	0,71	0,74	0,8	2,3	2,2	2,4	+/- 0,012
i-Butane	Mol. %	0,11	0,11	0,12	0,37	0,37	0,37	+/- 0,003
n-Butane	Mol. %	0,11	0,11	0,12	0,56	0,55	0,58	+/- 0,003
Neo-Pentane	Mol. %	0,002	0,002	0,002	0,002	0,002	0,002	+/- 0,0001
i-Pentane	Mol. %	0,03	0,03	0,03	0,13	0,13	0,13	+/- 0,001
n-Pentane	Mol. %	0,02	0,02	0,03	0,09	0,08	0.09	+/- 0,000
Hexan +	Mol. %	0,03	0,03	0,03	0,06	0,05	0,05	+/- 0,002
Nitrogen	Mol. %	2,4	2,3	1,8	0,31	0,32	0,33	+/- 0,03
Carbon Dioxide	Mol. %	0,84	0,92	1,0	0,75	0,73	0,80	+/- 0,015
Calculated values								
Calorific value, lower [1]	*kWh/m^3_n*	10,12	10,13	10,22	10,98	10,97	11,00	+/- 0,04
Wobbe index[1]	*kWh/m^3_n*	14,44	14,45	14,56	15,3	15,2	15,3	+/- 0,07
Density[1]	*kg/m^3_n*	0,78	0,78	0,78	0,820	0,818	0,822	+/- 0,002

1) *ISO 6976*