Faster CHP gas engine start with less emission

Project summary.

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1 Introduction

This is the final report of the PSO Eltra project no. 5738 “Faster gas engine start with less emission“. During the project three reports and a number of notes have been published. This report gives summary of these publications. A list of the produced notes and reports can be found in Appendix B. The produced reports are

- Report 1. Faster Start-up of CHP gas engine with less emission. An analysis of emissions during start and stop of natural gas CHP engines, state of the art 2005/2006
- Report 2. Faster Start-up of CHP gas engine with less emission. Improvements obtained by engine modifications
- Rart report 3. Reviderede emissionsfaktorer for gasmotorer inklusiv emission under start/stop.

In this summarising report chapter 4 gives the background for the conducted work, Chapter 5 *Influence of start and stop on the overall emissions* is a summary of part report 1 [1], chapter 6 *Reduction of emissions during start and stop* is summary of part report 2 [2] and chapter 7 *Revised emission factors* is a summary of part report 3 [4]. For further details the reader is referred to the reports and notes published.

Measurements have been conducted by Steen D. Andersen, DGC in cooperation with engine manufactures/suppliers. Jan de Wit has made the main report Q/A works, Torben K. Jensen is responsible for Q/A works of the measuring reports. All persons involved are listed in Appendix A. Hanne Frederiksen, DGC, has been managing the project.

The work is financially supported by the Danish natural gas distribution companies, DONG Gas Distribution A/S, HNG I/S, Naturgas Midt-Nord I/S, KE Bygas, A/S Naturgas Fyn A/S and energinet.dk (former Eltra) as a part the PSO programme.

September 2007

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2 Summary

The liberalised energy market leads to new challenges. In countries like Denmark where a substantial part of the power is produced by wind turbines, there is a need for fast up- and downloading of electricity production. Gas engine based CHP units have excellent performance characteristics in that respect. From January 1st 2007 all units with an installed power larger than 5 MW_e will sell the electricity production at the open power market terms (Nord Pool). That might affect the operation pattern of these plants.

In order to assess the actual influence of starts and stops on the overall emissions of CO, NO_x and Unburned Hydro Carbons (UHC), measurements of these components were conducted during start up, shut down and steady full load operation on different engines installed at combined heat and power plants.

Gas engine based CHP units represent an installed capacity of some 900 MWe in Denmark. Twelve such engine CHP units were chosen for further analysis. The units were selected to be representative for the fuel consumption from natural gas engines in Denmark. From the conducted measurements the influence of start up and shut down on the emissions of CO, NO_x and UHC was determined. Both emissions at cold and warm starts were measured.

The measurements and analysis made show that the CO emissions was 6,9 % higher due to start and stop compared to steady full load operation for an operation period of eight hour consisting of one engine start, a period of steady full load operation and a shut down of the engine. However, one of the 12 engines was incorrectly adjusted during start and stop. If that one engine is omitted from the analysis the number would be 1,4 % instead. This investigation cannot tell whether one extreme unit out of 12 is representative. It might be more and it might be less. The overall NO_x emission hardly was affect by start and stop. The overall UHC emission was found to be 2,6 % higher than at steady full load operation due to start and stop of the engine.

From the 12 engines four were chosen for an investigation of the possibility of reducing the emissions during start and stop. However, for different rea-

sons it was only possible to modify two of the selected engines. The investigation showed that it was possible to reduce the emissions during start and stop significantly on the examined engines. However, these experiences cannot be extrapolated to other engine types directly, as it depends on e.g. the design of the air and fuelling system of the engine.

For describing an emission from a combustion process an *emission factor* can be applied. An emission factor is measure of the amount of a given component (or group of components) that is emitted per energy of fuel converted. The unit is g/MJ. The emission factors that DMU has applied until now for CHP gas engines are based on emission measurements carried out at full load.

From 1998 and until October 2006 new Danish environmental regulations came into force (bekendtgørelse 621) [5]. In order to comply with this regulation many plant owners installed a CO catalyst. Other modifications and adjustments were carried out as well at some plants. Therefore the emission factors generally needed to be updated.

The revised emission factors for CHP gas engines installed in Denmark including the effect start up and shut down are: CO 115 g/GJ, NO_x 148 g/GJ, UHC 434 g (C)/GJ, CH_4 465 g/GJ and NMVOC 105 g/GJ.

The cumulative emissions from CHP gas engines for 2005 are found to be 3642 tons CO, 4694 tons NO_x and 13792 tons (C) UHC of which CH4 makes out 14787 tons and NMVOC makes out 3327 tons. Compared to the total emissions from stationary combustion, the CHP gas engines contribute with 1 % of the CO emission, 7 % of the NO_x emissions, 14 % of the NMVOC emissions and 65 % of the CH_4 emission.

The most important factor affecting the emissions from gas engines due to operation on market conditions is not the change in emissions factor as these were found to be almost unchanged compared to earlier measurement series [6]. The number hours of operation per year were lower for the plants selling the production at market condition than plants selling to fixed prices. Variations in electricity prices will affect the number of operation hours significantly and thereby the environmental impact of CHP gas engine. High

electricity prices is not expected to increase the number of operation significantly compared the time before market condition were established. However low electricity prices is expected to reduce the numbers operation hours and thereby the environmental impact significantly.

3 Resume (in Danish)

Det liberaliserede elmarked betyder nye udfordringer for dets aktører. I lande som Danmark, hvor en væsentlig del af elproduktionen kommer fra vindmøller, er der et behov for hurtig op- og nedregulering af elproduktionen. Gasmotorbaserede kraftvarmeværker har gode egenskaber til dette formål.
Fra 1. januar 2007 skal alle kraftværker med en installeret effekt større end 5 MW_e afsætte elproduktionen på markedsvilkår. Dette kan påvirke driftsmønstret på værker, der ændrer afsætningsform.

For at kunne vurdere indflydelsen af start og stop på den samlede emission af CO, NO_x, og UHC (uforbrændte kulbrinter) er koncentrationen af disse komponenter målt under opstart, kontinuert fuldlast drift og under nedlukning på gasmotorer installeret på kraftvarmeværker.

I projektet er der udvalgt 12 enheder, hvorfra indflydelsen af start og stop på den samlede emission skal vurderes. Anlæggene er udvalgt sådan, at de er repræsentative for den samlede gasforbrug for naturgasfyrede motorbaserede kraftvarmeværker.

For en driftsperiode på otte timer, der består af en motoropstart, en periode med kontinuert fuldlast drift og en nedlukning, var CO emissionen i gennemsnit 6,9 % højere pga. opstart og nedlukning i forhold kontinuert normal fuldlast drift. Af de 12 motorer var én forkert justeret under opstart og nedlukning. Hvis denne ene motor ikke medregnes er gennemsnittet 1,4 % i stedet for 6,9 %. Det er ikke muligt at vurdere, hvorvidt én motor ud af tolv er repræsentativ for andelen af motorer, der er uhensigtsmæssigt justeret under opstart. Den samlede emission af NO_x er praktisk taget upåvirket af start og stop. UHC emission var i gennemsnit 2,6 % højere pga. start og stop i forhold til kontinuert fuldlast drift.

Af de tolv motorer blev fire udvalgt til en undersøgelse af, i hvilken grad det er muligt at reducere emissionerne under opstart og nedlukning. Af forskellige grunde var det dog kun muligt, at udføre ændringer på to af de udvalgte motorer.

Forsøg med modificerede motorer viste, at det var muligt at reducere emissionen under start og stop betydeligt. Dette resultat kan dog ikke direkte overføres til andre motorer, da det afhænger af konstruktionsmæssige forhold som luft- og brændstofsystemet på de enkelte motortyper.

Emission fra en forbrændingsproces kan karakteriseres ved *emissionsfaktorer*. En emissionsfaktor er et mål for mængden af den angivne komponent (eller gruppe af komponenter), der emitteres pr. energimængde brændstof, der konverteres. Enheden for emissionsfaktorer er g/GJ. De emissionsfaktorer, som DMU har anvendt indtil nu for kraftvarmeværker, er baseret på emissionsmålinger, der er udført ved fuldlast drift.

I oktober 2006 trådte nye emissionskrav i kraft for danske gasmotor- og turbinebaserede kraftvarmeanlæg (bekendtgøre 621) [5]. For at kunne overholde de nye krav, er der på mange kraftvarmeværker blevet installeret en CO katalysator. Derudover er der udført andre ændringer og justeringer. Derfor er der behov for at revidere emissionsfaktorerne.

De reviderede emissionsfaktorer for gasmotorbaserede kraftvarmeværker i Danmark er; CO 115 g/GJ, NO_x 148 g/GJ, UHC 434 g (C)/GJ, CH_4 465 g/GJ og NMVOC 105 g/GJ. Effekten af start og stop er indregnet i de angivne værdier. Værdierne er gældende for otte timers drift pr. motorstart.

Det samlede emissionsbidrag fra gasmotorbaserede kraftvarmeværker er for 2005 beregnet til: 3642 ton CO, 4694 ton NO_x og 13792 ton (C) UHC (heraf 14787 ton CH_4 og 3327 ton NMVOC). Dermed udgør CH_4 emissionen fra motorerne 65 % af den samlede emission fra stationære forbrændingsanlæg, mens andelen for NMVOC er 14 %, NO_x andelen er 7 % og CO andelen er 1 %.

Den væsentligste miljømæssige ændring ved omlægning til markedstilpassede afregningsformer er ikke ændring i gasmotorernes generelle emissionsfaktorer idet driftstimetallet pr. motorstart har vist sig ganske konstant. Variation i det årlige driftstimetal som følge af prisudviklingen for el og gas vil kunne slå igennem sådan at der fremover kan forventes større udsving i gasmotorernes emissionsbidrag fra år til år. Ved en høj elpris forventes ikke større afvigelse i driftstimetal og emissionsbidrag i forhold til, hvad der har

været gældende hidtil. Derimod kan driftstimetallet og dermed årligt emissionsbidrag fra disse kraftvarme enheder forventes at falde væsentligt ved lave elpriser.

4 Background

The liberalised energy market results in new challenges. In countries like Denmark where a substantial part of the power is produced by wind turbines, there is often a need a for fast up- and downloading of electricity production [1]. Gas engine based CHP units have excellent performance characteristics in that respect [2]. From January 1st 2007 all unit with an installed power larger than 5 MW_e sell the electricity produced at market condition (Nord Pool). That might affect the operation pattern of these plants.

Previous investigations have shown that an increased number of starts and stops of gas engine based CHP units might lead to higher emission of UHC, NO_x and CO [3].

The objectives of the project is

- to evaluate the influence of start and stop on emission factors for stationary natural gas engines.
- to develop shorter start and stop procedures for gas engine sites facilitating the plants participation on the power market (regulation).
- to optimise the start/stop procedure in respect of achieving reduction of emissions.
- to determine the numbers of engine starts and to assess the future number of start in the free energy market
- to assess the effect engine start and stop on the overall emission factors

The participants in the project are

- PonPower (the Danish Caterpillar agent)
- GE Jenbacher
- Wärtsila Danmark A/S
- Rolls Royce Marine
- National Environmental Research Institute, DMU
- Danish Gas Technology Centre, DGC.

5 Influence of start and stop on the overall emissions

In order to assess the actual influence of starts and stops on the overall emissions of CO, NO_x and Unburned HydroCarbons (UHC), measurements of these emissions were conducted during start up, shut down and steady full load operation on different engines installed at combined heat and power plants. 12 engine units were chosen for further analysis. The units were selected to be representative for the fuel consumption natural gas engines in Denmark. For the 12 selected units, the concentration of CO_2, O_2, NO_x, CO and UHC were measured during start up and shut down. From the measured concentrations and a measurement fuel flow it is possible to calculate the relative influence of start and stop on the average emissions during a given period of operation. The developed method is described in details in [1]. Characteristics of the engines are given in Table 1.

Table 1. The examined engines.

Unit	Make	Type*	Size
#1	Wärtsilä 16V25SG	P	3140 MWe
#2	Wärtsilä 18V34SG	P	6060 MWe
#3	Rolls Royce KVGS-18G4	P	3110 MWe
#4	Rolls Royce KVGS16V-G4	P	2700 MWe
#5	Rolls Royce KVGS18V-G4	P	3470 MWe
#6	Jenbacher JMS 620 GS-N-LC	P	3047 MWe
#7	Jenbacher JMS 316 GS-N-LC	O	736 MWe
#8	Jenbacher JMS 320 GS-N-LC	O	922 MWe
#9	Caterpillar G3516	O	1047 MWe
#10	Caterpillar G3520	O	1900 MWe
#11	Caterpillar G3612	P	2875 MWe
#12	Caterpillar G3616	P	3750 MWe

* O: Open chamber
P: Pre-chamber

The influence of start and stop on the overall emissions varies significantly from engine to engine as shown on Figure 1. The values given in the figure are the overall emissions from an operation sequence consisting of one start up period, a period of steady full load operation and a shut down period compared to the emissions during steady full load operation. This means that the value 0 corresponds a case where there is no influence on start and stop on the overall emissions. The value +1 % corresponds to a case where the start and the stop sequence increases the overall emission by 1 % compared to steady full load operation for a certain given period of operation. The value for CO for unit #10 that exceeds the applied scale is 76 %.

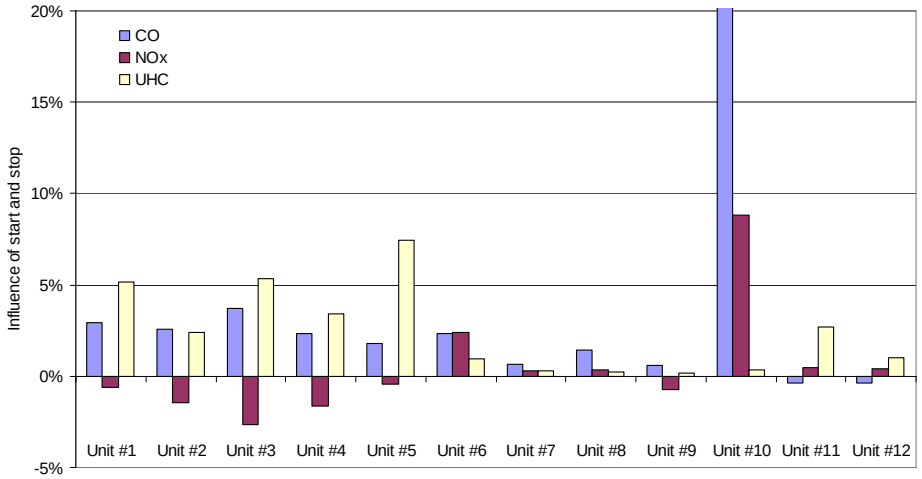

Figure 1. The relative influence of start and stop on the emissions from the examined units. One warm start per 8 hour of operation compared to steady state full load operation.

A small fraction of units that are poorly adjusted during start and stop as unit #10 might affect cumulative emissions from gas engines. The average influence of start and stop on the overall emissions for the examined engine is given in Table 2 with and without unit #10.

Table 2. The effect of a poorly adjusted unit on the average value of the influence of start and stop on emissions. Eight hours of operation per engine start compared to steady state full load operation.

	CO	Nox	UHC
Unit #10 included	6,9 %	0,4 %	2,6 %
Unit #10 excluded	1,4 %	-0,3 %	2,8 %

This investigation cannot tell whether one extreme unit out of 12 is representative. It might be more and it might be less.

The investigation has shown that the emissions from pre-chamber engines are more sensitive to start and stop than open chamber engines as shown in Table 3.

Table 3. The influence of engine type on the average value of the influence on start and stop on emissions. Unit #10 is excluded. Eight hours of operation per engine start compared to steady state full load operation.

	Pre-chamber (average)			Open chamber (average)		
	CO	NOx	UHC	CO	NOx	UHC
Cold start & stop	1,9%	-0,4%	3,5%	0,9%	0,0%	0,2%
Warm start &stop	1,4%	-0,5%	4,2%	0,9%	0,0%	0,1%

An increased number of engine starts will increased the influence of the emissions during stop up and shut down. If the engines are only running for

a few hours every time it will affect the overall emissions significantly. See Figure 2.

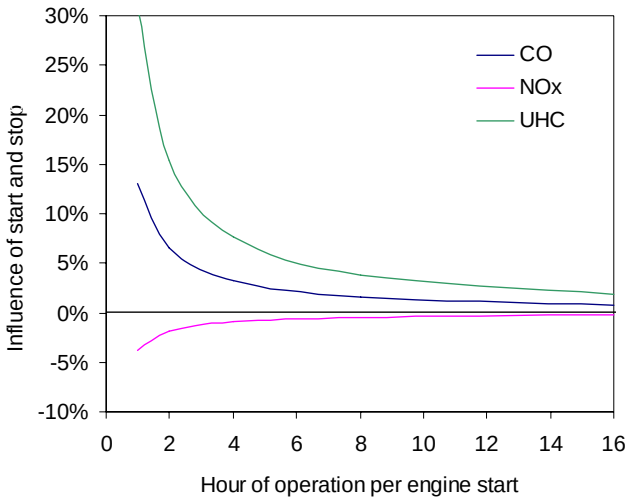

Figure 2. The relative influence of start and stop on the emissions depending the operation time per engine start. Emisions are compared to steady state full load operation. Average value of examined pre-chamber engines.

6 Reduction of emissions during start and stop

Two engines of different makes have subsequently been modified in different ways in order to reduce the emissions during start up and shut down of the engine. Another aim of the modification was to reduce the required start up period so the engine is on full load within 15 minutes as required in order to delivers system balance services. The examined engines are the ones denoted unit #2 and #4 in Table 1.
The modifications were chosen, designed and implemented by the individual engine manufactures or their representative. A brief description of the modifications is given in [2]. Details are known by the manufactures only.
Originally it was planned to optimise a Caterpillar G3500 engine as well. But as PonPower (the Danish Caterpillar agent) has chosen to leave the project it was necessary to omit that engine type from the analysis. An attempt was made for reducing the emission on an Jenbacher JMS 320-GS L.NC engine made. However, due both technical and administrative reasons it did not succeed. See [2] for further details.

6.1 Engine #2 Wärtsilä 18V34SG

The control system of this engine was modified so it was possible to choose different control strategies. Two different strategies for emission reduction were tested. The first strategy focused on reducing UHC emissions. The second modification was based on the first one but a further attempt to reduce the NO_x emissions was made.
One additional set of measurements were conducted in order to examine the possibility of reducing the start up and to examine the effect on the emissions.

6.1.1 Emissions

The engine settings were modified in order to reduce emissions of unburned fuel (UHC). The results are shown in Figure 3. The values given in the figure are the overall emissions from an operation sequence consisting of one start up period, a period of normal full load operation and a shut down period compared to the emissions during steady full load operation.

It was found that it was possible to reduce influence of start and stop on the total emission for both CO and UHC emission with around one third without negative influence on the NO_x emissions. The second attempt denoted *Modified 2 (NOx focus)* did reduce the NO_x emissions but that was obtained at the expense of higher UHC and CO emissions during warm start.
The bars value *Modified 3 (Short start up)* shows the results obtained was setting as *Modified 2* except the start up period is shortened. This shows that a shortened start up period reduces the negative influence on CO and UHC emissions during start and stop. This is a results of a shorter period of time where the engine is operated at non-optimal conditions. However, the overall NOx emissions were practically not affected by the shorter start up period.

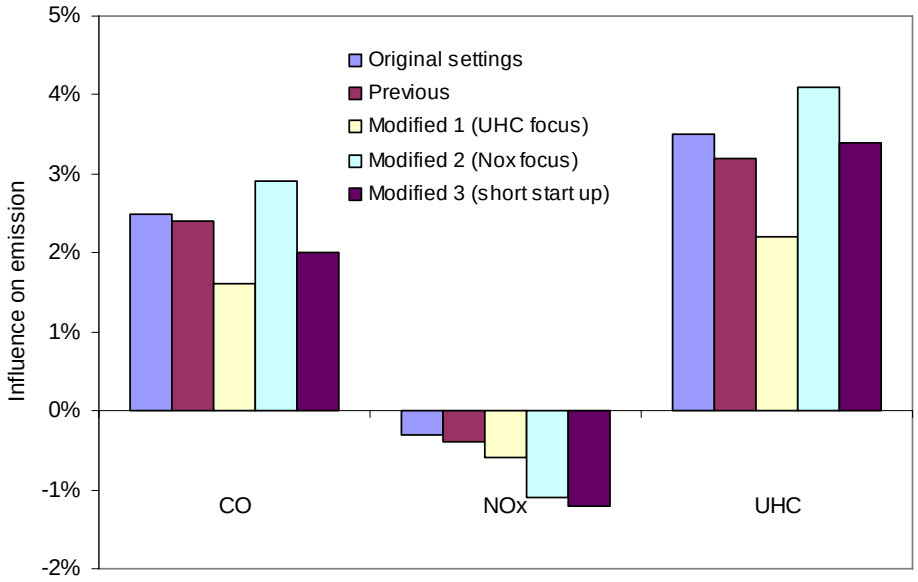

Figure 3. The influence of start and stop on the overall emissions for engine unit #2. One warm start per 8 hour of operation compared to steady state full load operation.

6.1.2 Start up duration

The attempt of reducing the start-up time was successful. The rate of increasing the engine load was increased so the time from receiving the start signal and till the engine was at full load operation was reduced to 11 minutes. The shorter start up time reduced the negative effect of start and stop.

6.2 Engine #4. Rolls Royce KVGS16V-G4

The fuel supply systems and the control system were modified by Rolls Royce in order to reduce the emissions of CO and unburned fuel during start up and shut down.
The nature of the modifications allows the control system to switch the effect of the modifications on or off. Since the first set of measurements the unit was equipped with a CO catalyst. Measurements have been conducted with modified engine where the modifications activated and deactivated.

6.2.1 Emissions

The results of the measurements are compared with results of previously conducted measurements (Original settings (no cat.)) [1], see Figure 4 and Figure 5.
The influence of start and stop on the CO emission was almost eliminated by the installation of the CO catalyst. This is true except for one case, namely during cold start with the original settings. However even in that case the influence of start and stop on the overall emission was reduced significantly. During the warm start-stop sequence the UHC emission was reduced to around one third compared to the original settings without affecting the NO_x emissions. In all warm start cases NO_x emissions are lower than during steady full load operation. During the cold start sequence the influence on the UHC emission was reduced to around the half applying the installed modifications. The NOx emissions are lower than steady state full load operation. During cold start the influence of NO_x emissions are the same as during steady operation.

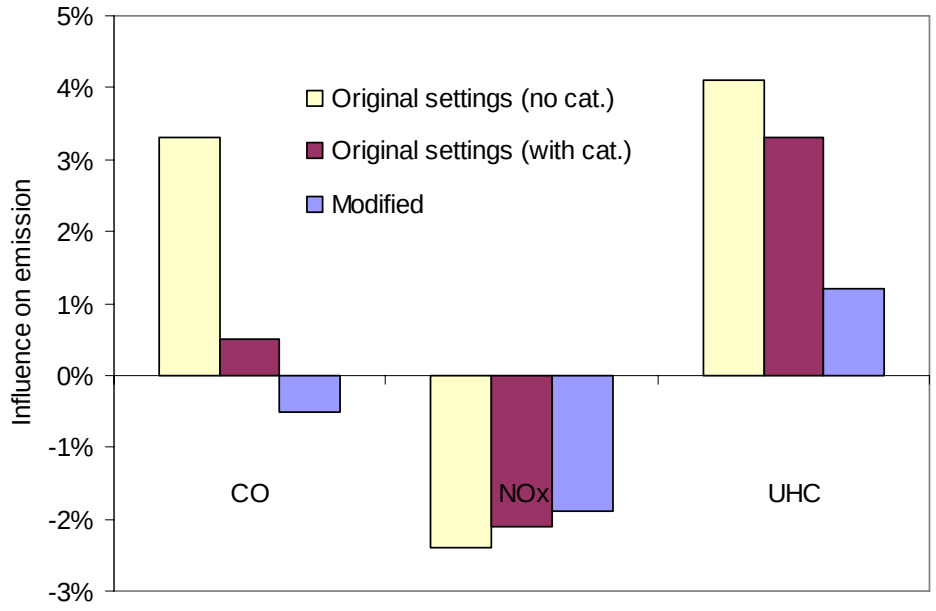

Figure 4. The influence of start and stop on the overall emissions for engine unit #4 . One warm start per 8 hour of operation compared to steady state full load operation.

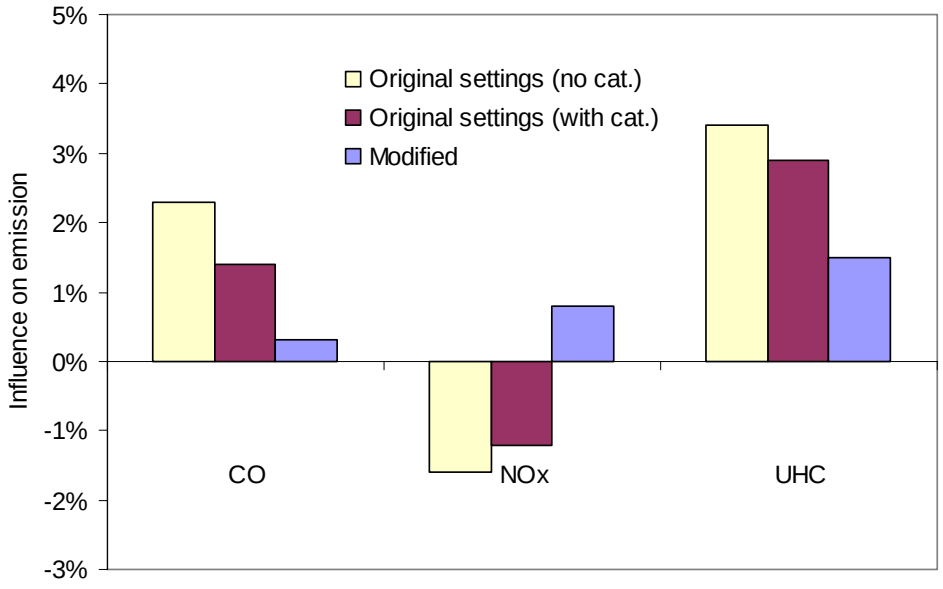

Figure 5. The influence of start and stop on the overall emissions for engine unit #4. One cold start per 8 hour of operation compared to steady state full load operation

6.2.2 Start up duration

This unit can just meet meet the demand of maximum 15 minutes from start signal to full load operation for delivering balance service with little time

margin. Prior to start up, this unit is venting the exhaust gas system. The venting event can be changed from prior to start up to just after shut down. This will reduce the total period of the start up sequence so the 15 minutes demand is met. If a change of venting from before start till after stop is planned the gas supplier should on behalf of the Safety Body be informed, and one should await acceptance [3].

6.3 Incineration of unburned fuel in exhaust gas

A brief investigation was made on the possibility of incineration of unburned fuel and CO by installing burners in the exhaust duct in order to raise the temperature so oxidation can take place. It was found that complete oxidation can be obtained with a temperature of around 750 °C and a residence time of around 1 second. At an excess air ratio of λ=2,0, an exhaust temperature of 450 °C and an electrical efficiency of 0,38 this require a liberation of heat corresponding to around 65 % of the produced electrical power or an additional fuel consumption of 25 %. However, the energy might be recovered and used for district heating. For further information see [7].

7 Revised emission factors

The emission factors that DMU has applied until now for CHP gas engines are based on emission measurement carried out at full load. These full load emission factors have been revised.

7.1.1 Revised full load emission factors

October 2006 new emission regulations came into force for Danish gas engine and gas turbine based CHP plants [5]. In order to comply with these regulations many plant owners installed a CO catalyst. Other modifications and adjustments were carried out as well. Therefore the emission factors have been updated. The update is based on

- Data from the Danish Environmental Protection Agency (EPA)
- A database containing data of type of installed gas engines in Denmark
- Emission factors applied until now
- Emission limits given by the regulation
- Emission data provided by engine manufacturer/suppliers Wärtsila and Rolls Royce

For selected engine types values of the updated emission factors for CO, NO_x and UHC are given in **Fejl! Henvisningskilde ikke fundet.** together with the electrical efficiency. Data for the other engine types and further details are given in [4].

Engines with a fuel consumption smaller than 120kW are not covered by the new regulations (bekendtgørelse 621) [5]. For some of these smaller engines the emissions are significantly higher than stated by regulations.

For the engines larger than 120 kW (thermal input, LCV reference) the CO emission factor for the different engine types varies from 20-163 g/GJ, the NO_x emission factors varies from 74-172 g/GJ and for UHC the emission factors varies from 76-619 g/GJ, however, 239-619 g/GJ for the most dominating engine types.

Aggregated full load emission factors for gas engines for CHP production in Denmark are shown in Table 5 together with emission factors including the

effect of start and stop. The updated emission factor for CO is reduced by 35 % and 11-12 % for NOx and UHC when the effect of start and stop is included. This is valid for eight hours of operation per engine start.
Since last time the emission factors were updated the overall electrical efficiency has increased from 38,3 to 39,2 %.

Table 4. Fuel consumption, electrical efficiency and revised full load emission factors for different engine types. Previous values are given as [ ] .

Engine type	Fuel consumption 2005 [TJ]	Electrical efficiency [%]	CO [g/GJ]	NO_x [g/GJ]	UHC (C) [g/GJ]
Rolls Royce[1)2)]	7686	[39,4] 41,7	[225] 68	[232] 156	[648] 483
Jenbacher 300	4881	[n.r.[3]] 38,4	[129] 129	[169] 169	[235] 235
Caterpillar 3500	4256	[n.r.[3]] 36,3	[110] 110	[137] 137	[434] 434
Caterpillar 3600	3364	[n.r.[3]] 39,2	[145] 145	[91] 91	[611] 611
Wärtsilä 25SG[1)]	1877	[37,2] 39,9	[248] 65	[157] 127	[479] 475
Wärtsilä 34SG[1)]	2032	[41,2] 41,5	[163] 108	[121] 137	[413] 402
Jenbacher 600	1777	[nr[3]] 38,8	[222] 156	[169] 169	[516] 516
Wärtsilä Øvrige	957	[n.r.[3]] 40,2	[135] 135	[200] 172	[92] 92
Niigata 26	419	[n.r.[3]] 38,0	[122] 122	[93] 93	[891] 593

1. Based on emission measurements made available for the project by the plant owners.
2. Previous Ulstein Bergen
3. n.r.: no recalculation

Table 5. Full load emission factors.

	Full load emission factor mg/m^3_n (ref. 5% O_2)	Previous full load emission factor g/GJ	Full load emission factor g/GJ	Emission factor. Effect of start-stop is included g/GJ
CO	351	175	109	115
NO_x	473	168	148	148
UHC (C)	1347	485	420	434
- CH_4	1444	520	450	465
- NMVOC	325	117	101	105

7.1.2 Operation pattern

In order to quantify the influence of start and stop on the total emissions from gas engines it is necessary to know the yearly number operation hours, the number of start-stop and the distribution between cold starts and warm starts.

Hours of operation were deduced from data from the Danish EPA, but the number of engine starts was not available.

Instead an interview study was carried out by DGC. 30 different plants were selected in a way that the different forms of accounting were represented. The results of the analysis only give indications as they are relatively uncertain. This is partly due to the low number of interviewed, partly due to year to year variations in electricity prices and the fact that a number of the interviewed has only selling at marked conditions for one year or less.
The plant operators were asked whether they have changed from the fixed time dependent tariff (peak, high and low load) to market dependent pricing and if so, how it affected the operation pattern of the engine. If was found that for plants that are selling the electricity production on the spot market the yearly number of operations hours was reduced by 35% and for plants on the balance power market the number operation hours was reduced by 86%. See Table 6. The operation duration per engine start has not changed significantly for any of the examined pricing systems. That means that the relative influence of start and stop has not changed either.

Table 6. Influence of accounting form on operation pattern.

	Number of engines	Hours of operation per year [h]	Hours of operation per start [h]	Decrease in number of hour of opartion[1)]	Decrease in number of starts[1)]
Fixed time dependent tariff	13	3792	10,5	6 %	4 %
Spot market	12	2633	10,8	35 %	17 %
System balance market	5	500	9,6	86 %	78 %

1 Relative to previous operation at fixed time dependent tariff (peak, high and low load).

The group of engines that as of the January 1st 2007 must sell the electricity production at market conditions contribute with around 50 % of the total installed electricity power from stationary gas engines in Denmark. For this group of engines the emissions factor for CO and NO_x is around 10 % lower than the other stationary gas engines. For UHC the number is 23 % higher than the other stationary gas engines. The actual overall emission factor for gas engines depends on the total production from units selling at market conditions. This sensitivity is illustrated in Figure 6 that shows the overall

emission factors depending on the gas consumption of engines selling the electricity production at market conditions.

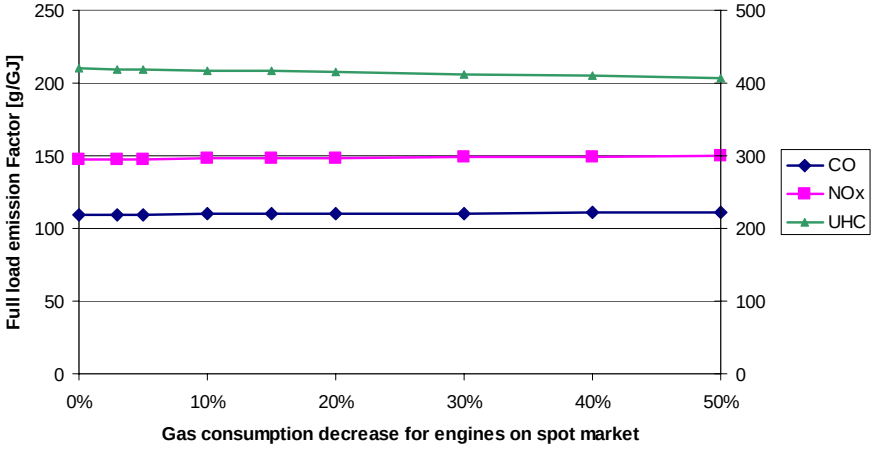

Figure 6. Sensitivity of reduced numbers of operation on full load emission factors for plants operating on the spot market.

The fraction of the different emissions from stationary combustion plants coming from stationary gas engines are shown in Table 7. Here it is seen that the emission from gas engines makes up as much as 65 % of the total CH_4 emissions from stationary combustion plants.

Table 7. Emissions from stationary combustion plants in Denmark.

	CO	NO_x	CH_4	NMVOC
Emissions from gas engine 2005 (tons)	3642	4694	14787	3327
- of this additional due to start-stop (tons)	161	2	466	105
Gas engines share of total from stationary combustion units	1 %	7 %	65 %	14 %

This means that despite transition to market conditions hardly affects the relative influence of start and stop on the total emissions the change in the number of operation hours caused by the new markets conditions might affect the environmental impact from gas engines significantly.

Variations in electricity prices will affect the number of operation hours significantly and thereby the environmental impact of CHP gas engine. High electricity prices is not expected to increase the number of operation significantly compared the time before market condition were established. Low

electricity will, however, is expected to reduce the numbers operation hours and thereby the environmental impact significantly.

8 References

[1] Faster CHP gas engine start with less emission. An analysis of emissions during start and stop of natural gas engines, state of art 2005/2006. Report 1 of this project.

[2] Faster CHP gas engine start with less emission. Improvements obtained by modifications. Report 2 of this project.

[3] Gasmotoranlæg. Skylning af udstødssystem. In Danish language, english summary included, Project note July 2006.

[4] Reviderede emissionsfaktorer for gasmotorer inklusiv emission under start/stop (in Danish). Report 3 of this project.

[5] Bekendtgørelse om begrænsning af emission of nitrogenoxider, forbrændte carbonhydrider og carbonmonooxid mv. fra motorer og turbiner. Bekendtgørelse 621. 23/06/2005. The Danish Environmental Protection Agency

[6] Kortlægning af emissioner fra decentrale kraftvarmeværker (Mapping of emissions from decentral combined heat and power plants. In Danish) . Delrapport 4. ISBN 87-7795-237-5. DGC-rapport April 2003.

[7] Gas burner UHC incineration in gas engines exhaust during start and stop. Project note November 2006

Appendix A. List of participants

- Danish Gas technology Centre, DGC
  - Hanne Frederiksen. Project manager
  - Per G. Kristensen
  - Steen D. Andersen
  - Jan de Wit
  - Henrik Andersen
  - Mikael Näslund
  - Torben Kvist Jensen
- Pon Power (Danish Caterpillar agent)
  - Jens M. Jakobsen
  - Flemming Hjøllund
- GE Jenbacher
  - Jesper Greve Jensen
  - Jens Hylling Kristensen
- Wärtsila Danmark
  - Bent Iversen
  - Kent Jensen
- Rolls Royce Marine
  - Keld Skærbæk Nielsen
  - Kim Larsen
  - René Hansen
- National Environmental Research Institute, DMU
  - Malene Nielsen
  - Jytte Boll Illerup

- Sikkerhedsstyrelsen (Danish Safety Technology Authority). Not a project partner.
  - Anders Knak-Nielsen. Safety aspects.

Appendix B. List of produced notes and reports

Beside this summary report, a number of part reports and notes are produced. These are listed below.

Reports

Faster CHP gas engine start with less emission. An analysis of emissions during start and stop of natural gas engines, state of art 2005/2006. Report 1 of this project.

Faster CHP gas engine start with less emission. Improvements obtained by modifications. Report 2 of this project.

Reviderede emissionsfaktorer for gasmotorer inklusiv emission under start/stop (in Danish). Report 3 of this project.

Measurement reports

Faster CHP gas engine start with less emissions. Test Report – original settings. Plant #1 Wärtsilä 16V25SG. June 2006.

Faster CHP gas engine start with less emissions. Test Report – original settings. Plant #2 Wärtsilä 18V34SG. May 2006.

Faster CHP gas engine start with less emissions. Test Report – original settings. Plant #3 Rolls Royce KVGS-18G4. June 2006.

Faster CHP gas engine start with less emissions. Test Report – original settings. Plant #4 Rolls Royce KVGS-16G4. June 2006.

Faster CHP gas engine start with less emissions. Test Report – original settings. Plant #5 Rolls Royce KVGS-18G4. June 2006.

Faster CHP gas engine start with less emissions. Test Report – original settings. Plant #6 Jenbacher J620. May 2006.

Faster CHP gas engine start with less emissions. Test Report – original settings. Plant #7 Jenbacher JMS316. June 2006.

Faster CHP gas engine start with less emissions. Test Report – original settings. Plant #8 Jenbacher JMS320. June 2006.

Faster CHP gas engine start with less emissions. Test Report – original settings. Plant #9 Caterpillar G3516. June 2006.

Faster CHP gas engine start with less emissions. Test Report – original settings. Plant #10 Caterpillar G3520. June 2006.

Faster CHP gas engine start with less emissions. Test Report – original settings. Plant #11 Caterpillar G3612. June 2006.

Faster CHP gas engine start with less emissions. Test Report – original settings. Plant #12 Caterpillar G3616. June 2006.

Faster CHP gas engine start with less emissions. Test Report – complementary measurements. Plant #2 Wärtsilä 18V34SG. January 2007.

Faster CHP gas engine start with less emissions. Test Report – complementary measurements. Plant #4 Rolls Royce KVGS-16G4. January 2007.

Faster CHP gas engine start with less emissions. Test Report – complementary measurements. Plant #2 Wärtsilä 18V34SG. January 2007.

Notes

Gas burner UHC incineration in gas engines exhaust during start and stop. Project note November 2006

Anvendelsen af miljøøkonomiske beregningspriser for skadesomkostninger fra luftemissioner i teknilogivurderinger. Project note. In Danish. 2006.

Gasmotoranlæg. Skylning af udstødssystem. In Danish language, english summary included, Project note July 2006.

Operation pattern, Project note March 2007.