Euromot

US EPA

New Source Performance Standards for Stationary Gas Engines

The Euromot Position – March 2006

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EUROMOT
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Euromot is the **European Association of Internal Combustion Engine Manufacturers**.

We represent the leading manufacturers of internal combustion engines used in a broad range of nonroad and marine applications (construction, mining and material handling equipment, trucks and buses, agricultural and forestry equipment, commercial marine and seagoing vessels, workboats and pleasure boats, rail traction, lawn/garden and recreational equipment, power generation).

Euromot has been working for many years with international regulatory bodies, eg European Union, the UN Economic Commission for Europe (UNECE), the UN International Maritime Organizations (IMO) and the Central Commission for the Navigation on the Rhine (CCNR). In addition, we are seeking an open and fair dialogue with national governments to provide reliable know-how on advanced internal combustion engine technologies in general and, in particular, on the feasibility of environmental as well as cost-effective product regulations. To achieve a pro-active engagement of all stakeholders in international harmonisation of regulations affecting engines and equipment, we coordinate our activities worldwide with trade associations of the non-road and marine industry sector.

For further information about our Association please refer to our Annual Report 2002 or pay us a virtual visit at **http://www.euromot.org** – your bookmark for engine power worldwide.

US EPA:

Industry feedback on the New Source Performance Standards for Stationary Gas Engines

The Euromot Position

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1 Introduction

Under a proposed court settlement the US EPA has agreed to establish a New Source Performance Standards (NSPS) for new gas industrial engines (SI) used in stationary applications with the intent to finalize that rule by the end of 2006. This document is intended as a draft feedback to the questions raised by US EPA and shall serve as an input to the common meeting on 03. February 2006.

There are different types of SI engines in use worldwide. In todays´ market for bigger gas engines the lean burn type (equipped with spark plugs or without) dominates. In this document some aspects related to the lean burn gas fuelled engine are gathered.

For all following discussions a split in Natural Gas (NG) and Non Natural Gas (NNG) is recommended, NNG is mainly biogas or landfill gas. Emissions are for normal engine loading 90 … 100 % MCR and at steady load conditions. Part load operation may cause different numbers.

The gas diesel engine (high pressure gas) has not been considered, as according to the definition by US EPA it is not belonging to the SI "family".

2 Summary

Euromot welcomes the opportunity to provide input for the US EPA's proposed New Source Performance Standards for Stationary Gas Engines. Summarized our conclusions are as follows:

- Emissions standards for NOx, CO, PM, VOC,HC, etc. shall be based on current technology.
- Emissions of HC, CO, NMHC, VOC, PM, etc. vary with type and quality of gas. To note is that certain impurities of the exhaust gas such as some heavy metals and SO_2 will have a deactivating impact on the secondary abatement technology e.g. on the used oxidation catalyst reduction capacity.
- We do not see a need for useful life definitions or emission certification, only individual setting is useful.
- Formaldehyde limitations are critical because the measurement technologies for HCHO are not exactly defined. An industry research project related to this theme has been already started.
- Special operations like start-up, shut-down, peak shaving, emergency use and temporary limited island-operation should be neglected during emission measurement because during this operations emission limitations are not representative.
- Regulation of THC is difficult (no general commercial available secondary reduction technique existing).

3 Engine types & fuel options

Small gas engines have traditionally been of rich-burn type. Modern gas engines (> 300 kWe) are however usually of lean burn type. Lean burn engine technology is a response to the need for cleaner gas engines. The NOx formation in an engine is a function of both the flame temperature and the residence time. By using lean fuel/air mixtures the combustion temperature has been lowered in the lean burn compared to e.g. rich burn applications. Lean combustion decreases the fuel/air ratio in the zones where NOx is produced so the peak temperature is less than the stochiometric adiabatic temperature, thereby suppressing thermal NOx formation. This primary NOx reduction measure is analogous to the dry Low-NOx combustion used in gas turbines. An added performance advantage of the lean burn operation is the higher output and higher efficiency obtained.

The rich-burn engine type has a high NOx-emission up to 10 times the NOx emission compared to a lean burn gas engine. Therefore the rich-burn gas engine is often equipped with a catalytic three way catalyst unit in order to reduce the NOx emission and to comply with the legislation in force. The catalyst unit is besides NOx also reducing CO and VOC emissions. The three way catalyst (not applicable on lean burn engines, with flue gas O_2-% typically up to 11 vol-%) is only applicable to a rich burn engine due to the very low oxygen content in the flue gas (typically less than 0.5 %). The gas fired lean burn engine fulfils most current national legislation with primary methods only, sometimes an oxidation catalyst is needed for reducing unburned gaseous emissions (CO, etc.).

A SI (Spark Ignited) engine means a gasoline, natural gas, or liquefied petroleum gas fuelled engine or any other type of engine with a spark plug (or other sparking device) and with operating characteristics significantly similar to the theoretical Otto combustion cycle. Dual-fuel engines (DF) in which a liquid fuel (typically diesel fuel) is used for combustion ignition (CI) and gaseous fuel

(typically natural fuel) is used as the primary fuel at an annual average ratio of less than 2 parts diesel fuel to 100 parts total fuel of an energy equivalent basis are SI engines. /1/
Modern lean burn gas engines are typically divided into following main groups /13/:

- **Spark Ignited Gas Engines (SG) and Micro Pilot (MPG) Otto-type engines** (available up to about 8 MWe unit sizes) operating on (low pressure) natural gas, propane (with a derated engine output in order to avoid knocking) and depending on engine type sometimes on landfill, mining (coal bed), bio and even pyrolysis gases. The engine works according to the otto process principle.

- **Dual fuel (DF) engines** (available up to about 17 MWe unit sizes) are fuel versatile, the primary fuel is (low pressure) natural gas, propane (with a derated engine output) and back-up fuel is such as diesel oil (back-up fuel, etc.), heavy fuel oil, etc. In gas mode the compression of the air/gas mixture with the piston does not heat the gas enough to start the combustion process, some additional energy needs to be added and this is arranged by injecting a small pilot fuel stream (for instance diesel oil). Diesel fuel has a lower self-ignition temperature than gas and the heat in the cylinder close to the top position is enough to ignite the diesel fuel which, in turn creates enough heat to cause the air/gas mixture to burn. The amount of pilot fuel is typically below one to two percent of the total fuel consumption at full load. The dual fuel engine can operate at full load in both fuel modes. The engine type is working according to the otto principle in gas mode and in liquid fuel operation according to the diesel principle.

4 US markets

The US market for stationary gas engines is appr. 20 – 25 % of the worldwide market. In US about 2/3 of the engines are used for mechanical drive applications and 1/3 for power generation. The power generation segment gas fuel use in US is 50:50 natural gas (NG) : other gases (NNG).

According to statistics /2/ between the years 2000 – 2003 about 10 – 34 gas (natural and liquefied gas) fired engine single units > 3 MW size were annually sold in the USA.

5 General aspects

In table 1 below are listed some aspects of medium-speed stationary SI engine plants. For information of availability of secondary flue gas abatement techniques (such as SCR, oxidation catalysts), please see table 2 in /3/.

Table 1:
Some different aspects of bigger stationary gas fired engine plants: applications, operation profiles, fuels and competition.

Typical sizes & application:

- Single engine units up to 8 MWe (SG) and 17 MWe (DF)
- Stationary power plants (typical size 1 – 150 MWe, consisting of single or multiple engine units).
- Continuous power generation
- Sometimes for peak load power generation

Typical operational profile:

- Continuously 85 – 100 % load
- Constant engine speed and steady load
- 4000 – 8000 hours/year
- Few transients

Fuels used:

- natural gas
- liquefied gas (natural gas or propane)
- (bio fuels, landfill gas, etc. are available in limited fuel amounts. On the market are some small size high speed stationary engines (size typically < 1 MWe) suitable for these gases.)

Competition:

- gas turbines
- steam boiler plants

In below table 2 measurement conditions and used emission standards world wide for bigger stationary plants are given. For more information about measurement standards and why regular measurements (e.g. on an annual basis) are recommended, see also CIMAC document /17/.

Table 2:
Existing emission legislation aspects for stationary engine plants

Emission units typically used:

- gaseous compounds: ppm or mg/Nm^3, dry at 15 vol-% O_2
- particulate compounds: mg/Nm^3, dry at 15 vol-% O_2

Compliance test procedure:

- *No* certification procedure

- Each engine (or selected engines at a multi engine plant) to be measured e.g. at regular intervals e.g. annually at real site conditions with the fuel in use. Emissions sometimes widely vary with the gas quality which cannot be influenced by the OEM or owner of the plant.
  - *No* test cycles to be used
  - Measurement at normal loading *typically 100 % engine load, steady load conditions* (see also paragraph 6 below*).*

This provides a better (emission) reliability than a certification !

Emission measurement methods:

- *Particulate (as dry dust):* ISO 9096 (2003), US EPA Methods 17 or 5B, JIS Z8808, EN 13284-1 or other principally similar methods

- *Sulphur dioxide*: US EPA Method 6C or principally similar other methods for liquid fired plants with FGD (Flue gas Desulphurization) unit or gas fired engines. ISO 8178-1 chapter 7.4.3.7 for liquid fired plants without FGD, (calculation based on fuel composition)

- *Nitrogen oxides*: US EPA Method 7E or principally similar other methods

- *Carbon monoxide*: US EPA Method 10 or principally similar other methods

- *Volatile Organic Compounds (VOC)* (methane/ethane excluded in USA /18/, in Europe methane):
  - *Gas engine without oxi-catalyst* :
    US EPA Method 25A, VOC = Total Hydrocarbons (THC) – methane – ethane. The ratio of methane and ethane concentrations in the exhaust gas are calculated based on the gaseous fuel analysis. The ratio of methane and ethane to THC in the flue gas is considered to remain constant in the flue gas. VOC is to be calculated and reported as methane or carbon.
  - *Gas engine with catalyst installed*:
    US EPA Method 18 or Method 320 or principally similar other methods.

- *Formaldehyde*: *****
  - *Gas engine without oxidation catalyst*: US EPA Method 320 or principally similar other methods.
  - *Gas engine equipped with oxidation catalyst:* US EPA Method 323 or principally similar other methods.

NO useful life nor certification approach usage, because the emission compliance test on a regular base is taking place under real conditions on each engine (or selected number of engines at a multi engine plant) at site.

** In Europe no standardized measuring technology is still defined for HCHO, it is under discussion and development. The existing methods are not specific for stationary engines. US EPA Methods should also be used with care, big variations in field measurement results have been observed. If acetaldehyde interference is suspected in context with EPA Method 323 use of CARB Method 430 is recommended.*

Field emission measurements in general:

If emissions are defined as mass related emission mass flow measurement is essential. As this is difficult to measure on site, field emission measurement results always contain a certain amount of insecurity and uncertainty. This is even more critical in cases of unknown and unstable gas qualities. This has to be taken into account with all emission regulation activities and should be covered by respective tolerance limits. It is essential to define suitable measurement equipment to be used however. As well calculations according to US EPA Method 19 have shown difficulties in cases of unknown and unstable gas qualities.

SI units should be followed to enable comparison of emission limits.

Different standards small vs. large engines:

Displacement volume of the reciprocating engine is no proper indicator for different standards, if any we recommend a split according to the energy input (e.g. former German TA-Luft standard: Pin > 1 MW).

Conclusions:

- World wide praxis is that in stationary engine plants the emission guarantee test is done at handing over date. After this the owner takes over the responsibility of the plant. Emissions are measured regularly (e.g. on annual basis) at steady normal high load operation of the engine at site on the actual fuel used.
- In the light of the above market figures (see paragraph 4) and praxis world wide (table 2) *no* “useful life” *nor* certification approach is needed/possible as in the (liquid) non road engine sector. *Used fuel gas has a big impact on some of the gaseous emissions and therefore site measurements are preferred*.

6 Transient loading: start-up, shut-down, etc. conditions

Praxis worldwide is to measure emissions at steady normal load conditions and disregard the emissions occurring at start-up, shut-down and other transient periods (occurring in island mode, etc.) of a power plant, e.g. see /19/ (article 14). In /4/ on page 33478 is stated “… required to comply with the emission and operating limitations at all times, *except* during startup, shutdown and malfunction of your stationary RICE.”

During short transient conditions such as start-ups (typical duration times a "warm start" about 10 minutes to a "cold start" about 20 minutes) and shut-downs the flue gas parameters will vary greatly. As a consequence (e.g. at low flue gas temperatures) the performance efficiency of a secondary emission abatement technology will decrease radically (such as an oxidation catalyst or SCR) or it might even malfunction (e.g. control strategy) and the applicable emission limitation cannot be met.

It is important to conduct the emission measurements at isokinetic conditions (i.e. at steady state operation) in order to get meaningful comparable results. After a transient load change a sufficient time period is needed before measurements can be started.

Conclusions:

Emission standards should *not* be required to be met during:

a) Start-up and shut-down periods of the stationary engine/plant
b) The time period required for the engine(s) and the auxiliary system(s) to warm up
c) Ramp-up/ramp-down of the engine plant
d) The time period required for changing fuel mode in case of a dual-fuel application
e) Emission measurements should be done at steady normal high load conditions of the power plant (engine).
f) Sufficiently long measurement sampling periods and number of samples shall be taken in order to get statistically representative results. E.g. to ensure accurate particulate matter emission results of 3 samples are to be collected with a minimum sampling time of 1 hour per sample.
g) Emission obligation exclusions of engines for peak shaving up to 500 hours/year.
h) Emergency use of dual fuel engines in liquid fuel mode in gas delivery interruptions

7 Typical emission levels of the stationary SI engine and secondary methods

The following general text is shortly describing the emissions of spark ignited gas engines (SG) and dual fuel (DF) engines. At lower engine loads emissions are higher and below values are representative for the load span 90 .. .100 % MCR of the individual engine.

NOx (as NO_2):

Primary:
The modern *spark ignited* (SG) lean burn gas engine is designed to fulfil about 190 mg/Nm^3 (15 % O_2) NOx (as NO_2). Some *spark ignited engines* (SG) running on natural gas can also by engine tuning fulfil 95 mg/Nm^3 (15 % O2) NOx, *with following consequences a higher about 1.5 .. 3 % fuel consumption (and a higher specific CO_2 emission), higher unburned gaseous emissions (CO, HC) and particulate and with a lower flue gas temperature (detrimental for CHP applications).*

For biogas/landfill gas NOx max.190 mg/Nm^3 (15% O_2) is the common standard for SG engine types, lower levels are possible as well, but these gas types shows typically contaminations (e.g. volatile organic silica compounds => siloxanes, silanole, silanes…) which have a indirect impact on the combustion parameters by deposits in the combustion chamber and so on the related emissions

The dual fuel (DF) engine in gas mode engine is designed to fulfil about 190 mg/Nm^3 (15 % O_2) NOx. In oil mode the NOx emission is in the order of a liquid fired diesel engine.

Secondary:
A SCR (Selective Catalytic Reduction) is the only state of the art technology. NOx levels of about 20 mg/Nm^3 (15 % O_2) can be achieved by applying a SCR in **gas mode**. A SCR has a high investment cost and can therefore in most cases *not* be considered to represent BACT /14, 15, 16/. By applying a SCR additional secondary emissions (CO_2, NOx, NH_3, etc.) are also generated due to the transportation and manufacturing of the reagent (urea or ammonia).

CO:

Primary:
The CO emission after the gas fired lean-burn engine (SG, DF) is in the range 300 … 500 mg/Nm^3 (15 % O_2), but value tends to drift 20 .. 30 % due to engine deposits (due to used lubrication oil type, operating hours, engine tuning, etc.).

The dual fuel (DF) engine has in liquid fuel mode emissions in the range of a liquid fired diesel engine.

Secondary:
The secondary method is an oxidation catalyst widely in use when burning natural gas. In below paragraph 9 typical achievable figures are given.

In biogas and landfill applications use of an oxidation catalyst is not recommendable in many cases due to deactivating impurities present in the fuel.

Formaldehyde (HCHO):

Formaldehyde limitations in Germany are very critical and under review (a FVV[1]) project already has started) because

- Measurement technology is not defined properly thus creating a high level of insecurity and a wide spread of measurement results
- One and the same engine at site produces more or less HCHO at subsequent measurement sessions without any clear explanation for this behaviour. Occasionally cyclic combustion fluctuations, etc. may contribute to this.

Primary:
The formaldehyde emission from a natural gas lean burn (SG, DF) engine is in the order 30 … 70 mg/Nm^3 (15 % O_2) dependent on the engine tuning. **Note** comments in table 2 above regarding measurement methods.

The dual fuel (DF) engine has in liquid fuel mode an emission is in the range of a liquid fired diesel engine.

Secondary:
An oxidation catalyst for simultaneous reduction of CO and HCHO is commonly used in natural gas applications. In below paragraph 10 a typical achievable figure for HCHO in a natural gas application is given. Note ! Sufficient long term experience regarding life time of the oxidation catalyst is presently not available.

In biogas and landfill applications (small engine units) use of an oxidation catalyst is not recommendable in many cases due to deactivating impurities present in the fuel.

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[1] FVV: Forschungsvereinigung Verbrennungskraftmaschinen e.V. (Research Association for Internal Combustion Engines)

NMHC, VOC:

Primary:
The engine tuning and composition of the fuel gas are affecting the lean burn (SG, DF) engine emission and therefore no general emission range can be given.

The dual fuel (DF) engine liquid fuel mode emission is in the range of a liquid fired diesel engine.

Definitions of NMHC, NMOC and VOC are unclear.

Particulate:
The particulate (dry dust) emission in natural gas mode (SG, DF) is low typically < 7 mg/Nm^3 (15 % O_2) (US EPA Method 17 or principal similar other).
The PM10 emission is depending on many factors such as the purity of the natural gas. Aromatic hydrocarbons, silicon based compounds or impurities resulting from the operating and maintenance of the gas delivery systems might be present in the gas. With a *"clean natural gas"* typically PM10 < 20 mg/Nm^3 (15 % O_2) is achievable.

Contaminations in biogas/landfill respectively intake air can cause higher PM values.

The dual fuel (DF) engine in liquid fuel mode emission is in the range of a liquid fired diesel engine.

TotalHydroCarbons (THC):
THC depends on the engine tuning, engine type etc. THC typically consists of > 85 % methane (dependent on fuel gas composition). Organic compounds having a photochemical reactivity have so far been regulated. E.g. in USA /18/ organic compounds having a negligible photochemical reactivity such as methane; ethane have *not* been regulated. Engine industry has since mid of 90´s worked on decreasing the THC emission from the lean burn gas engines. On some lean burn gas engine types a reduction up to 50 % has been achieved with engine measures only compared to values of old engine types.

Industry has also been investigating secondary abatement equipment commercially available on the market and found that a lot of R&D work is still needed before a suitable abatement technology is commercially available. A lot of testing actions have therefore been done, below a short summary on some main findings:

Oxidation Catalysts:

Catalysts for methane abatement need to be palladium based. Industry has conducted numerous pilot tests and studies regarding the oxidation catalysts since many years, below some lessons learned:

- Palladium is very sensitive to impurities in the flue gas, in pilot tests the catalysts have been deactivated after *only* tens of hour duration operation. A regeneration system for the catalyst should be needed, in other words a concept including a good control system, etc. is to be developed.

- An other important issue is to maintain a high temperature of the inlet flue gas to the catalyst in order to enable the reactions and therefore e.g. a recuperative heat exchanger solution is needed.

A lot of testing (scale-up, etc.) is still needed, before an oxidation catalyst solution is ready. This technology is not yet demonstrated and commercially available.

Non catalyst based thermal reactors:

For some small size lean burn gas engines these have been applied. E.g. the same technology used in the painting industry to reduce HC emissions have been used.

The flue gas needs to contain a certain amount of THC in order to maintain the temperature in the reactor at such a level (about 800 degree C) that the methane destruction will occur. With modern gas engines with a much smaller THC slip compared to old engines this might lead to a need of natural gas injection into the flue gas into the inlet of the reactor. Therefore field tests are needed with modern gas engines before the suitability/availability of the technology can be properly judged. A thermal reactor is big (bulky) in size e.g. for a 8 MWe lean-burn gas engine: length* width*height 13*4.5*3 m and has a weight of 60 tonnes. In some applications a flue gas fan is also needed for compensating for the pressure drop, this (besides the possible gas injection need) will raise the running costs of the stationary engine power plant.
This technology is not yet demonstrated and commercially available for a broader use in the stationary engine market.

Regulation of HC around the world has in the past focused on VOC and in late years shifted towards formaldehyde (see chapter 8 below). There are very few legislations found where THC is regulated, below the Danish /20/ rule (corrected to 15 vol-% O_2):

- *UHC* max. 560 mg/Nm3 (15 % O2), calculated as C, at an 30 % electrical efficiency. At higher/lower electrical efficiencies of the engine the value is increased/decreased*. E.g. assuming an electrical efficiency of 42 % → 42/30*560=780 mg/Nm^3 (15 % O_2).

  ** UHC = Unburned Hydro Carbons*

8 Most regulated hydrocarbon emissions

In USA /4/ (for > 500 hp engines) formaldehyde, acrolein, methanol and acetaldehyde have been identified as the major sources of hazardous air pollutants from stationary reciprocating internal combustion engines (RICE). Dependent on engine type different emission limits and praxis have been stipulated in order to decrease these emissions. E.g. a 4SLB (4-stroke lean burn) stationary RICE has to reduce the CO emissions by 93 % or limit the formaldehyde emission to 14 ppm-v (15 % O_2). Engines burning landfill and digester do not have this obligation.
In the European Union Reference Document on Best Available Techniques for Large Combustion plants (BREF document) /11/ CO and formaldehyde BAT-limits are given. In UK /6, 7/ CO and non methane hydrocarbon (NMHC) emissions are regulated. In Germany /5/ CO and formaldehyde emissions are limited. In Finland /9/ unburned emissions are *not* regulated. In Turkey /10/ only a CO-limit is given for the unburned emissions. In Japan in some gas engine projects in *big city areas* (Tokyo and Yokohama) a formaldehyde limit has been seen.

Conclusion:
The NMHC/VOC emissions from spark ignited (SG) and dual fuel (DF) engines in gas mode depend largely on the composition of natural gas. Dependent on the regulation an oxidation catalyst for simultaneous CO and NMHC/VOC/formaldehyde reduction is sometimes applied. From above can be seen *an interesting trend:* in new standards (USA /4/ 2004 and Germany /5/ 2002) and in BREF /11/ only the formaldehyde part of the HC emission is regulated. E.g. in the old German TA-LUFT 1986 NMHC was regulated.

Oxidation catalysts are sensitive to impurities in the flue gas and fuel gas (such as digester, land fill gases) containing impurities such as siloxanes, etc. will deactivate the catalyst. In the US /4/

standard installations operating on such a fuel are therefore exempted from the above “gaseous unburned limits”.

9 Some existing emission regulation examples

Larger stationary gas fired reciprocating engine plants have own technique specific emission rules e.g. in Great Britain /6, 7/, Japan /8/, Germany /5/, Finland /9/ and Turkey /10/. Also in the EU BREF /11/ document for Large Combustion Plants BAT-values for stationary engine plants are proposed. Below these rules are briefly described.
In this chapter all emission limit concentration units are corrected to 15% O_2-content.

EU BREF:

In the EU BREF document for Large Combustion Plants /11/ BAT values for big gas engine power plants are proposed on pages 481 – 482. Values for NOx, CO and formaldehyde (only this NMVOC component is of interest) are given. The natural gas (“clean fuel”) fired stationary engine plant has negligible emissions of particulate and SO_2 and therefore no values for these are proposed. The formaldehyde value is equal to the one in German TA-LUFT 2002, i.e. 23 mg/Nm^3 (15 % O_2). Values for CO and NOx are given /11/ on page 482 in table 7.36, as can be seen from the footnotes of the table there is *a “split view*” about the proposed levels. *Industry considers proposed CO and NOx level spans as LAER (Lowest Achievable Emission Rate) far beyond the BACT –approach ! More information about this can be found from Euromot papers /15/ and /16/.*

Great Britain:

Great Britain do not have own specified rules for SG type engines. Below in tables 3 and 4 the emission limits for dual fuel engines (DF) in gas mode are given.

Table 3:
The Environmental protection Act 1990, Part 1 (1995 Revision) Engine 20 to 50 MWth. Emission limits in mg/Nm^3 (dry, 15 % O_2), Nm^3 defined at 273 K , 101.3 kPa. NMHC in wet gas. *See emission bonus calculation below.*

Fuel	NOx (as NO_2) (after 01.04.98)	SO_2*	Particulate***	CO	Non-Methane Hydrocarbons (as C)
Distillate Oil	1300		100**	150	150
Heavy fuel Oil	1400		100**	150	150
Gas (dual fuel)	500		50 (new plants)	450	200

* The sulphur of heavy fuel oil (residual oil) should not exceed 2 wt-%, with distillate oil the sulphur content should not exceed 0.2 wt-%. **Note** according to EU Directive /12/ the sulphur content of heavy fuel oil is restricted to max. 1.00 wt-% from 01.01 2003 and in gas oil to 0.1 wt-% from 01.01.2008.

** Consideration should be given for new process at the time of application to whether 50 mg/Nm3 is achievable.

*** Measurement method principal similar to US EPA 17.

For all emissions above in table 3: Corrected emission limit (“bonus”) = emission limit (in table above)*ISO Net Base Efficiency/40. ISO Net base Efficiency is calculated according to ISO 3046 Part 1.

Table 4: Achievable Releases to Air; HM Inspectorate of Pollution – Combustion Processes: Compression Ignition Engines 50 MWth*or Over, September 1995. Emission limits in mg/Nm^3 (dry, 15 % O_2), Nm^3 defined at 273 K , 101.3 kPa. NMHC in wet gas. * **Note !** Power plant thermal energy input.

Fuel	NOx (as NO_2) (after 01.04.98)	SO_2	Particulate****	CO	Non-Methane* Hydrocarbons (as C)
Distillate Oil	200** 300***	110	50	150	150
Heavy fuel Oil	200** 300***	570	50	150	150
Gas (dual fuel)	100	50	20 – 50	450	200

** Engines < 25 MWth
*** Engines ≥ 25 MWth
**** Measurement method principal similar to US EPA 17.

Germany:

The German limit values (HCHO, CO, NOx) are in the enclosed tables (see attachement 1[2] and 2[3]). Please note that in attachement 1 the original TA Luft emission limit values are given for an O2-content of 5% [mg/Nm3]. Euromot´s recommendation is to state the values for an O2-content of 15%. Therefore the TA Luft emission values were converted to an O2-content of 15%. Moreover the emission limit values for a typical engine with a mechanical efficiency of 40% were converted in g/bhphr (see attachement 2). The emission values depend on air consumption and mechanical efficiency. The limits vary depending on the engine type.

SO_2 limit (dependent on fuel used), e.g.:
- Natural gas : 4 mg/Nm^3 (15 % O_2)
- Bio, landfill gas : 130 mg/Nm^3 (15 % O_2)

In Germany discussions between industry and authorities is going on regarding the formaldehyde-limit problem (catalyst deactivation) when utilizing bio, land fill gases as fuel. Also the measurement method is under discussion, it is important to have it properly defined in order to avoid wide spread measurement results.

Japan:

An environmental quality need driven approach is used in Japan. Depending on the plant surrounding different stack limits are stipulated (stricter limits in big cities compared to “others” such as rural areas). Emissions below are corrected to dry, 15 vol-% O_2.

In big cities the NOx-limits are stricter compared to rural areas e.g.:

In Tokyo:
- Gas engine (fuel consumption > 50 l/h heavy fuel oil eq.), Power > 200 kW
- Area 1 from 1. April 1992: 57 ppm-v (dry, 15 vol-% O_2)
- Area 2: 140 ppm-v (dry, 15 vol-% O_2)

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[2] TA Luft (oringinal version)
[3] TA Luft (converted to 15% O_2-content / [g/bhp_hr])

In Yokohama:

- Gas engine: Power > 7.5 kW:

85 ppm-v (dry, 15 vol-% O_2)

Note: In above *big cities* a formaldehyde limit of 5 ppm-v at 13 vol-% O2 has been applied for some gas fired engine projects. Note chapter 7 (above) statement about present insufficient information about long term lifetime experience of catalysts !

Table 5: “Nation wide general limits” (for “other” areas)

	NOx	Particulate*
Gas Engine (> 35 l/h fuel oil equivalent)	280 ppm-v** 170 ppm-v ***	14 mg/Nm3 (all areas) 11 mg/Nm3 (special areas)

* Measurement method principal similar to US EPA 17.
** Before 01.04.1994
*** New after 01.04.1994

Finland:

Table 6 : Emission limits for gas fired *SG/DF* engines. Emission limit in mg/Nm^3 (dry, 15 % O_2). BAT in small 5 -50 MW Combustion Plants. Nm^3 defined at 273 K , 101.3 kPa.

Component	Existing source	New source (August 2003)
NOx (as NO_2)	185	175

Note ! In Finland only NOx is regulated for gas fired stationary engines.

Turkey:

Table 7: Emission limits for gas fired SG/DF engines. Emission unit mg/Nm^3 corrected to dry, 15 % O_2. See emission *bonus* calc. below. Nm^3 defined at 273 K , 101.3 kPa.

Component	DF**	SG
Dust*	50	50
CO	560	240
NOx (as NO_2)	190	190
SO_2	22	22

*Measurement method principal similar to US EPA 17.
** In oil mode emission limits are similar to the liquid fired diesel engine values.

Emission bonus (A high overall yield is supported and values will be increased proportionally according to “K” coefficient):

SG:

- Single gas engine or combined cycle mechanical yield (%):
    - New emission limit = K * Existing emission limit (from table above)
      K = mechanical yield / 37
      Cogeneration yield (%):
    - New emission limit = K * Existing emission limit (from table above)
      K = Power plant cogeneration yield / 63

DF:

- Single gas engine or combined cycle mechanical yield (%):
    - New emission limit = K * Existing emission limit (from table above)
      K = mechanical yield / 45
      Cogeneration yield (%):
    - New emission limit = K * Existing emission limit (from table above)
      K = Power plant cogeneration yield / 63

Others:

When calculating the emission concentration unit of mg/Nm^3 (15 % O_2) into g/kWhe specific fuel and air consumptions of the engine will have impacts on the end result. Therefore value will vary from engine to engine and examples are valid (typical) for a bigger gas fired engine (90 .. 100 % load range): See attachement 2.

In the output emission limit approach (g/kWhe) the engine flue gas flow needs to be measured. It has been seen in measurements in field conditions that especially at low engine loads the mass rate emissions are varying, consequence has been that the emission limits at low loads get more stringent.

Conclusion:

Some aspects, which can be seen from the emission legislations world wide above are:

- Limits are emission concentration based at a certain oxygen reference point (in tables above correction to 15 % O_2 done).

- Bigger plant sizes has in some countries stricter rules than smaller ones

- Power plant location has an impact on the limit values in some standards ("environmental quality need driven approach"), e.g. in Japan.

- NOx seems to be most important (can be found in all standards). If hydrocarbons are regulated it is in some cases NMHC/VOC but in late years focus has started to *shift to formaldehyde only*. Natural gas is a clean fuel and therefore in some cases (negligible) SO_2 and particulate emissions are not regulated.

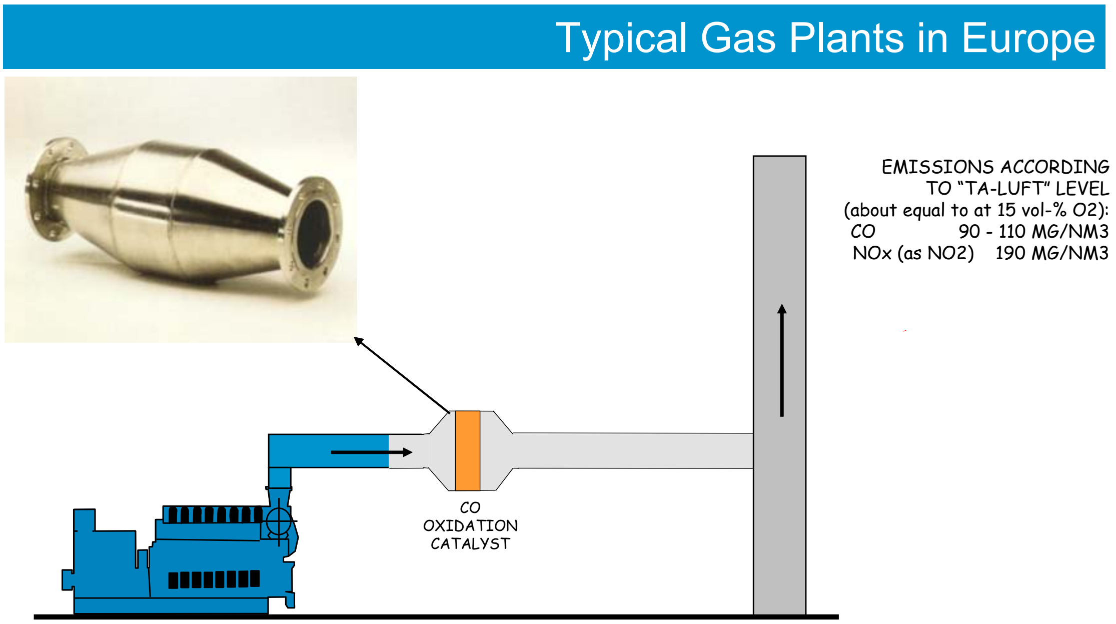
- In some regulations an efficiency bonus is granted (secondary emissions are also generated during the production and transportation of the fuel)

- Emissions are measured regularly (e.g. on annual basis) at steady high normal load operation of the engine at site on the fuel gas used.

10 General Conclusion

In Euromot document /14/ stationary engine manufacturers have given their view on the BAT emissions from lean burn gas engines: SG-type on page 7 and DF-type ("low pressure gas) on page 6.

Europe represents the biggest single market area for stationary gas fired engines. The German TA-LUFT regulations have been widely applied to gas engines in the European markets. The limits recommended by Euromot /14/ for *lean burn gas engines* are close to the German TA-LUFT 2002 limits. In picture 1 below is a typical configuration shown for a lean-burn gas engine for the European market.



Picture 1: Typical lean burn gas plant configuration in the European market.

As can be seen from the picture the gas engine plant is often equipped with a secondary oxidation catalyst for simultaneous CO and formaldehyde reduction. This concept should also fulfil the US hazardous pollutant /4/ requirement. *BAT limits for following emissions for natural gas fired SG and DF engines are thus:*

- *NOx (as NO_2): 190 mg/Nm^3 (15 % O_2)*
- *CO: 110 mg/Nm^3 (15 % O_2)*
- *Formaldehyde: 19* … 23 mg/Nm^3 (15 % O_2)*

** equals the US /4/ HAP limit.*

When burning natural gas (a clean fuel) the SO_2 and particulate emissions are negligible and therefore has been left out from above list.

For other fuel gases such as landfill, etc. it is reasonable only to stipulate a NOx-limit. For the other gaseous emissions such as CO, etc. a state-of-the-art principle of the available abatement technology should be followed, e.g. if an oxidation catalyst might be employed or not (deactivation due to flue gas impurities).

In the Euromot document /14/ emission corrections for a high efficiency stationary engine plant (single/combined cycle/CHP (Combined Heat and Power)) are proposed on page 8. Emission obligation exclusions of engines for peak shaving up to 500 hours/year and emergency use of dual fuel engines in liquid fuel mode in gas delivery interruptions are also mentioned.

11 Sources:

/1/ 40 CFR parts 60, 85, 89, et.al. Standards of Performance for Stationary Compression Ignition Internal Combustion Engines; Proposed Rule; Federal Register/Vol 70 No 131/ Monday, July 11, 2005/Proposed Rules US EPA

/2/ http://www.eia.doe.gov/cneaf/electricity/page/capacity/capacity.html

/3/ US EPA draft Concepts for NSPS Regulation Applicable to Stationary Diesel-fueled Engines, The Euromot position April 2005; see internet address: http://www.euromot.org/download/news/positions/stationary/US_EPA_NSPS_regulation_Euromot_Position_290405.pdf

/4/ 40 CFR Part 63 National Emission Standards for Hazardous Air Pollutants for Stationary reciprocating Internal Combustion Engines; Final Rule; Federal Register /Vol 69, no. 14/June 15 2004 US EPA

/5/ Technische Anleitung zur Reinhaltung der Luft – TA-Luft October 2002

/6/ The Environmental Protection Act 1990, part 1 (1995 revision), (PG1/5(95): Secretary of State´s Guidance-Compression Ignition Engines, 20-50 MW net rated Thermal input”

/7/ “Achievable Releases to air; HM Inspectorate of Pollution; Processes Subject to integrated Pollution Control; Chief Inspector´s Guidance Note, Series 2 (S2), S2 1.03 Combustion Processes: Compression ignition Engines 50 MWth and Over (September 1995)”

/8/ “Nationwide general limits”

/9/ “Best Available Techniques (BAT) in Small 5-50 MW Combustion Plants in Finland” 2003 , see http://www.ymparisto.fi/download.asp?contentid=3708 on page 102 in tables 29 and 30 you will find (in English) the guidance values for BAT in Finland for small stationary engine /gas turbine plants 3 .. 50 MWth.

/10/ Gazette number 25606, October 7, 2004.

/11/ Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Techniques for Large Combustion Plants, May 2005, European IPPC Bureau, see internet ftp://ftp.jrc.es/pub/eippcb/doc/lcp_final_0505.pdf

/12/ Council Directive 1999/32/EC relating to a reduction in the sulphur content of certain liquid fuels and amending Directive 93/12/EEC

/13/ CIMAC document "Prime Mover Technique Specific Emission Limits Need Stationary Reciprocating Plant", internet adress: http://www.cimac.com/workinggroups/Index1-working-groups-exhaustemission.htm (see link under "The subgroup of WG5 ...").

/14/"Stationary Engine Emission Legislation - Diesel and Gas" November 2004 Position paper by Euromot showing the forecasted stationary engine development in year 2007, see internet address:
http://www.euromot.org/download/news/positions/stationary/Future_stationary_engine_emission_legislation_Nov04.pdf

/15/ EIPPCB LCP BREF, European Integrated Pollution Prevention and Control Bureau: BAT Reference Documents; Industry feedback on the proposed NOx/CO BAT level spans for stationary gas-fired engines; The Euromot Position – December 2003, see internet at:
http://www.euromot.org/download/news/positions/stationary/EIPPCB_BREF_BAT_gas_engines_comment_euromot_dec03.pdf

/16/ EIPPCB LCP BREF, European Integrated Pollution Prevention and Control Bureau: BAT Reference Documents; Industry feedback on the proposed NOx/CO BAT level spans for stationary gas-fired engines; The Euromot Position – August 2004, see internet at:
http://www.euromot.org/download/news/positions/stationary/EIPPCB_BREF_BAT_gas_engines_comment_euromot_aug04.pdf

/17/ "CIMAC Recommendation - Standards and Methods for Sampling and Analysing Emission Components in Non-automotive Diesel and Gas Engine Exhaust Gases - Marine and Land Based Power Plant Sources". The Document can be ordered from:
http://www.cimac.com/services/Index1-publications.htm

/18/ VOC is defined in 51.100(s), see link: http://www.epa.gov/ttnatw01/voc/vocpg.html

/19/ EU Directive 2001/80/EC, October 2001. “On the limitation of emissions of certain pollutants into the air from large combustion plants”

/20/ Miljö- og Energiministeriets lovbekendtgörelse nr. 625 af 15. juli 1997.

2006-03-14

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Attachment 1[4]: TA Luft (oringinal version)

Emission limit values for stationary reciprocating internal combustion engines ≥ 1 MW_{th} (for landfill gas no power limit applies)

Values in mg/m^3, O_2-content 5 %

Dust	20 1)		
SO_2	Depending from the fuel used e.g. 350 with biogas or sewage gas		
Formaldehydes	60		
C	-		
Chlorine, Fluorine, Halogens	3 %		
CO 2) 3)	a) Compression ignition engines and spark ignition engines with liquid fuel, compression ignition (pilot injection) engines and spark ignition engines with gaseous fuels (except biogas, sewage gas or mine gas)	300	
	b) Spark ignition engines with biogas or sewage gas	< 3 MW_{th} 1000 3)	≥ 3 MW_{th} 650
	c) Spark ignition engines with mine gas 4)	650	
	d) Pilot injection engines with biogas or , sewage gas	< 3 MW_{th} 2000 3)	≥ 3 MW_{th} 650
NO_x 3)	a) Compression ignition engines with liquid fuel	< 3 MW_{th} 1000	≥ 3 MW_{th} 500
	b) Gas-fired compression ignition (pilot injection) engines and spark ignition engines		
	– Pilot injection engines with biogas or sewage gas	< 3 MW_{th} 1000	≥ 3 MW_{th} 500
	– Lean-mix engines and other four stroke spark ignition engines with biogas or sewage gas	500	
	– Pilot injection engines and lean-mix engines with other gaseous fuels	500	
	c) Other four stroke spark ignition engines (□=1)	250	
	d) Two-stroke engines	800	

1) 80 mg/m^3 for emergency use or for up to 300 h peak shaving at power generation. Measurement method principally similar to US EPA Method 17. Gas fired engines do not have particulate limits.
2) Landfill gas at present generally 650 mg/m^3
3) Emission values not applicable for emergency use or for up to 300 h peak shaving at power generation
4) For spark ignition engines with mine gas 650 mg/m^3 (independent of power)

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[4] Source: VDMA, Engines and Systems, 2006

Attachment 2[5]: TA Luft (converted to 15% O_2-content / [g/bhp_hr])

Emission limit values for stationary reciprocating internal combustion engines ≥ 1 MW$_{th}$ (for landfill gas no power limit applies)

Values in mg/m^3, emission concentrations are corrected to O_2-content 15 % (at 0° C and 101,3 kPa).
Values in brackets are typical g/bhp_hr-emissions based on a 40% mech. efficiency gas fired engine.

Dust	7,5[1] (0,042)		
SO_2	Depending from the fuel used e.g. 131 (0,738) with biogas or sewage gas		
Formaldehydes	23 (0,126)		
C	-		
Chlorine, Fluorine, Halogens	3 %		
CO[2,3]	a) Compression ignition engines and spark ignition engines with liquid fuel, compression ignition (pilot injection) engines and spark ignition engines with gaseous fuels (except biogas, sewage gas or mine gas)	113 (0,63)	
	b) Spark ignition engines with biogas or sewage gas	< 3 MW$_{th}$ 375[3] (2,1)	≥ 3 MW$_{th}$ 244 (1,37)
	c) Spark ignition engines with mine gas[4]	244 (1,37)	
	d) Pilot injection engines with biogas or , sewage gas	< 3 MW$_{th}$ 750[3] (4,2)	≥ 3 MW$_{th}$ 244 (1,37)
NO_x[3]	a) Compression ignition engines with liquid fuel	< 3 MW$_{th}$ 375 (2,1)	≥ 3 MW$_{th}$ 188 (1,05)
	b) Gas-fired compression ignition (pilot injection) engines and spark ignition engines		
	– Pilot injection engines with biogas or sewage gas	< 3 MW$_{th}$ 375 (2,1)	≥ 3 MW$_{th}$ 188 (1,05)
	– Lean-mix engines and other four stroke spark ignition engines with biogas or sewage gas	188 (1,05)	
	– Pilot injection engines and lean-mix engines with other gaseous fuels	188 (1,05)	
	c) Other four stroke spark ignition engines (□=1)	94 (0,525)	
	d) Two-stroke engines	300 (1,68)	

[1] 30 mg/m^3 (0,169 g/bhp_hr) for emergency use or for up to 300 h peak shaving at power generation. Measurement method principally similar to US EPA Method 17. Gas fired engines do not have particulate limits.
[2] Landfill gas at present generally 244 mg/m^3 (1,37 g/bhp_hr)
[3] Emission values not applicable for emergency use or for up to 300 h peak shaving at power generation
[4] For spark ignition engines with mine gas 244 mg/m^3 (1,37 g/bhp_hr) (independent of power)

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[5] Source: VDMA, Engines and Systems, 2006