ENGVA position paper on Euro-VI emission limits in relation to heavy-duty natural gas vehicles

European Natural Gas Vehicle Association
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Introduction

This is an update of the position paper developed by ENGVA (and provided to the European Commission in August 2004. The update consists of the renumbering of the original scenarios to the numbering used in the public consultation on Euro VI launched on July, 11th 2007.

The original position paper was the response of the European Natural Gas Vehicle Association (ENGVA) to the Euro-VI questionnaire sent out by the Euro V/VI subgroup of the Motor Vehicle Emissions Group (MVEG) in May 2004 as part of the preparatory work for development of Euro-VI emission standards for heavy-duty vehicles, buses and coaches. The questionnaire asked for data on technology and associated costs in a very high level of detail. ENGVA has considered it both undesirable and impossible to produce general answers that apply to the natural gas vehicle and component industry as a whole. As is probably also the case for the conventional vehicle industry, various manufacturers may wish to choose different technological pathways for reaching the proposed standards. Furthermore the aspect of costs is a sensitive issue. As ENGVA wishes to provide a constructive contribution to the development of Euro-VI standards for heavy-duty (HD) vehicles, writing a position paper was chosen as the best alternative to providing relevant information as a contribution to the debate on Euro VI emissions regulations.

This paper first presents some general considerations regarding the possibilities for the case of heavy-duty natural gas vehicles (NGVs) to reach the various proposed limit values (scenarios) for spark ignition engine vehicles as defined in the 2004 questionnaire. The main part of the document concerns a description of both general and specific technological measures considered necessary or optional for reaching the limits in the various scenarios are described.

General considerations regarding Euro-VI heavy-duty:

- From an engine construction point of view heavy-duty lean-burn gas engines are showing much similarity with HD diesel engines. For this reason many NG engine manufacturers used or are using the lean-burn concept, because of the relatively low diesel to NG conversion effort. However, even for scenarios with less stringent NO_x levels there is a general need for lean-burn closed loop λ-control to ensure emissions stability and to handle gas quality changes.
- There is broad consensus on the fact that the NO_x emission of lean-burn gas engines will not go below a certain level, unless new after-treatment concepts like selective catalytic reduction (SCR) (using urea) will be developed and applied for natural gas vehicles. This kind of new after-treatment, with yet unknown NO_x-reduction potential, would also include closed-loop control for λ and/or NO_x .
- Using closed-loop stoichiometric three-way catalyst technology, similar to (continuously improving) stoichiometric technology as applied in light-duty (natural

gas) vehicles, all of the proposed HD Euro-VI emission scenarios are expected to be feasible for HD natural gas vehicles, as already proven by production heavy-duty NGVs.

- From an emission point of view stoichiometric NG engines have many advantages, although there are also some disadvantages: Stoichiometric natural gas engines run with higher exhaust gas temperature compared to their lean-burn NG and diesel counterparts, and for that reason require(d) more engine developments when converting HD diesel engines in to gas engines. Furthermore stoichiometric engines are, generally speaking, slightly less efficient compared to lean-burn NG. Applying exhaust gas recirculation (EGR) might be a technique to improve fuel efficiency, reduce raw NO_x and to lower exhaust temperature of stoichiometric natural gas engines.
- For NG engines both single-point as well as multi-point fuel systems are feasible. Multi-point systems have certain advantages, however, accurate heavy-duty fuel injectors and usually dedicated intake manifolds are required when using multi-point fuel admission. If high quality of fuel distribution and homogeneity is required (lean burn) single point fuel admission might be in favour. Single-point fuel systems often are easier to package and also have advantages regarding mixture homogeneity. Single-point systems, however, are more sensitive to back-fire. E-gas and/or intake port flame arresters can be used to reduce the risk of back-fire.
- The hot start conditions of the heavy duty European test cycle (ETC) emission tests enable high conversion rates for any heavy-duty after-treatment system, which is a significant difference compared with light-duty applications.
- Low HC emissions can be achieved by means of a combination of lowered engine-out hydrocarbons, and/or with improved catalytic conversion technology. Improved and durable heavy duty CNG catalysts probably will lead to a cost increase of the power train. Depending on future European “in use compliance” legislation, the durability of after-treatment systems, especially regarding methane conversion, may need to be addressed by the industry.
- The CO-limitations of all scenarios are relatively easy to achieve by means of current or, if necessary, improved technology. The NO_x-limits and the long term HC limits are the emissions to focus on.
- PM emissions of future CNG engines can be improved compared to present systems with dedicated measures aimed at reducing oil consumption.
- Oxidation catalysts for lean-burn systems are sensitive to the sulphur content of natural gas. Europe-wide large scale application of lean-burn NGVs would thus require a Europe-wide standard for NG sulphur content, also in relation to the use of S-containing odorants. The issue of non-sulphur odorants is being addressed by the larger gas industry and will reflect positively upon low-sulphur requirements for vehicle-quality (pipeline-supplied) natural gas.
- Engineering targets for emission levels always are lower then the proposed limit levels for type approval. This engineering safety margin can vary per chosen concept (lean burn vs. stoichiometric) or per emission component, and will compensate for statistical scatter as well as long term effects.
- In this document the *most likely* technology solutions for HD Euro-VI natural gas vehicles are listed per scenario. However, other concepts or approaches might work well. Development costs, production costs and company philosophy will be of influence on the chosen concepts.

General technology solutions required for all proposed scenarios:

The following technical requirements are assumed to be part of the technology packages for all scenarios:

- (Development of) CNG catalysts with adequate conversion efficiency for the projected life time. Especially the long term methane conversion ability needs to be addressed. Also reduced engine-out HC/methane emission, by means of improved combustion system design (e.g. combustion chamber and piston design, in-cylinder charge dynamics, etc.) may be necessary.
- Development of accurate adaptive control algorithms or other methods that compensate for gas quality variation when switching from filling station to filling station.
- Especially in lean-burn concepts engine-out NO_x-emissions at a given load may vary substantially in response to gas quality and ambient conditions. If diesel-type SCR systems will be used on heavy-duty natural gas engines, developments are necessary to ensure accurate emission control on CNG, e.g. by means of closed loop NO_x control.

Scenario specific technologies are listed below.

Specific technologies for scenarios B and C (Scenario 2): current EEV limits

In the Euro VI HD questionnaire the following possible set of standards for HD engines was defined in scenario 2. These limit values are identical to the Environmentally Enhanced Vehicle (EEV) limits. A limit value for NH_3 is added to control the slip of ammonia in vehicles equipped with a selective catalytic reduction system on the basis of urea. This provision is added to all scenarios. In the public consultation scenarios B and C, the separate limit values for NMHC and CH_4 are added resulting in a 1.05 g/kWh THC limit value.

Scenario B,C	ETC test cycle
PM	0.02 g/kWh
NO_x	2.0 g/kWh
THC	1.05 g/kWh
CO	3.0 g/kWh
NH_3	10 ppm

Scenario 2:

NMHC	0.4 g/kWh
CH_4	0.65 g/kWh

Required technologies for stoichiometric engines in scenario B, C:

- Multi-point fuel system (preferably).
- One CNG-type switching type Heated Exhaust Gas Oxygen (HEGO) sensor.
- Alternatively a second downstream HEGO lambda sensor, which can be used to improve emission control. Another alternative is to use one upstream wide band Universal Exhaust Gas Oxygen (UEGO) sensor together with one down-stream HEGO lambda sensor
- One CNG-type heavy duty stoichiometric catalytic converter designed for 0.65 g/kWh CH_4 mounted in a location securing optimum working conditions.
- These stoichiometric technologies are more or less available today.

Required technologies for lean-burn engines in scenario B, C:

- Single-point or multi-point fuel system.
- Accurate and reliable lean-burn closed loop lambda control systems or even closed-loop using a NO_x-sensor and an oxidation catalyst might be sufficient to achieve EEV emission levels, although this is doubtful.
- After-treatment system like SCR with urea similar to heavy-duty diesel applications. Dedicated developments, especially on the control system, will be necessary to achieve scenario B, C emission limits.
- Advanced lean-burn systems as described above are not yet available today.

Specific technologies for scenario D (scenario 3): NO_x and PM 50% lower then EEV

In the Euro VI HD questionnaire the following possible set of limit values for HD engines was defined in scenario 3. Compared to scenario's B and C this scenario proposes a reduction by a factor of 2 of the limit values for NO_x and PM. In scenario D of the public consultation the separate limit values for NMHC and CH_4 are added resulting in a 1.05 g/kWh THC limit value.

Scenario D	ETC test cycle
PM	0.01 g/kWh
NO_x	1.0 g/kWh
THC	1.05 g/kWh
CO	3.0 g/kWh
NH_3	10 ppm

Scenario 3:

NMHC	0.4 g/kWh
CH_4	0.65 g/kWh

Required technologies for stoichiometric engines in scenario D:

- Multi-point fuel system (preferably)
- One CNG-type HEGO (switching type) lambda sensor.
- Alternatively a second downstream HEGO lambda sensor, which can be used to improve emission control. Another alternative is to use one upstream wide-band UEGO lambda sensor together with one down-stream HEGO.
- One CNG-type heavy duty stoichiometric catalytic converter designed for 0.65 g/kWh CH_4 mounted in a location securing optimum working conditions.
- These stoichiometric technologies are more or less available today.

Required technologies for lean-burn engines in scenario D:

- Single-point or multi-point fuel system.
- Accurate and reliable lean-burn closed loop lambda control systems or even closed-loop using a NO_x-sensor and an oxidation catalyst are necessary, but not enough to achieve scenario 3 limits.
- After-treatment system like SCR with urea similar to heavy-duty diesel applications is necessary. Dedicated developments, especially on the control system, will be required to achieve scenario D limits.
- Advanced lean-burn systems as described above are not yet available today.

Specific technologies for scenario A (scenario 5)

In the Euro VI HD questionnaire the following possible set of limit values for HD engines was defined in scenario 5. This scenario is characterised by a very strong (factor 5) reduction of the NO_x limit value compared to Euro V and EEV and a strong reduction of the NMHC and CH_4 limit values. In scenario A of the public consultation the separate limit values for NMHC and CH_4 are added resulting in a 0.66 g/kWh THC limit value.

Scenario A	ETC test cycle
PM	0.01 g/kWh
NO_x	0.4 g/kWh
THC	0.66 g/kWh
CO	4.0 g/kWh
NH_3	10 ppm

Scenario 5:

NMHC	0.16 g/kWh
CH_4	0.5 g/kWh

The NO_x-limit of scenario A is quite ambitious, however, using proven light-duty SULEV-type stoichiometric concepts, this limit should be achievable. Regarding SCR, experiments and developments need to be carried out to see if these limits can be achieved by using lean-burn and SCR.

Required technologies for stoichiometric engines in scenario A:
- Multi-point fuel system (preferably).
- Two CNG-type HEGO (switching type) lambda sensor.
- Alternatively one upstream wide-band UEGO lambda sensor together with one down-stream HEGO should be used.
- One CNG-type heavy duty stoichiometric catalytic converter designed for 0.50 g/kWh CH_4 mounted in a location securing optimum working conditions. In order to achieve the required NO_x levels, it might be necessary to use a second catalyst after the second lambda sensor, together with a control algorithm that will ensure proper functioning of this advanced stoichiometric concept.
- These stoichiometric technologies are more or less available today.

Required technologies for lean-burn engines in scenario A:
- Single-point or multi-point fuel system.
- Accurate and reliable lean-burn closed loop lambda control systems or even closed-loop using a NO_x-sensor and an oxidation catalyst are necessary, but not enough to achieve scenario A limits.
- After-treatment system like SCR with urea similar to heavy-duty diesel applications is necessary. Dedicated developments, especially on the control system, will be required to achieve scenario A limits.
- Advanced lean-burn systems as described above are not yet available today, and the achievable NO_x-emission is unknown.

Other Considerations for NGV Technology & Euro VI

Dual Fuel Engines

Dual fuel technology for heavy duty engines maintains the compression ignition diesel cycle but adds a new twist to alternative fuel design. Unlike positive ignition bi-fuel engines that function on *either* natural gas *or* petrol dual fuel engines run on a combination of diesel and natural gas,. At idle the engine runs on 100% diesel. As the vehicle begins and moves up the power curve increasingly more natural gas is injected into the engine – up to 85% or more in some designs – but maintains diesel for 'pilot ignition' of the natural gas. This effectively reduces particulate and NOx emissions but overcomes efficiency losses associated with 100% dedicated natural gas HD engines. This technology is particularly effective with over-the-road operation (differentiated from stop-and-go operation associated with urban buses). This technology is recognized in the United Nations ECE Regulation 110, however, certification of these engines must be done on a country-by-country basis. European type approval is not yet possible because: 1) the technology is not defined as such within European regulations; and 2) this has been difficult to justify since there is no formal emissions test fuel since the amounts of diesel and natural gas mixture vary.

Engine manufacturers such as Cummins and Caterpillar have developed high quality, computer controlled conversion systems that today are marketed internationally. Other smaller manufacturers also have developed dual fuel natural gas/diesel engines based upon these technologies. Most recently Volvo AB has announced that they are developing dual fuel technology for HDVs. Although the current population of dual fuel natural gas engines is relatively small, it is essential that dual fuel HD engines be formally recognized by definition within the body of Euro VI regulations. Such regulatory legitimacy by definition would allow further progress for natural gas dual fuel technology to make a substantial contribution to reduced emissions and higher efficiencies than most other alternative fuels can achieve in HDVs.

Hybrid Natural Gas/ElectricTechnology

Only a decade ago hybrid vehicles with two drive-trains were considered by many vehicle manufacturers as too complicated and too expensive. With growing concerns about climate control and air quality, hybrid vehicles are today making their way into the open market. Natural gas hybrid vehicles, while superior in reducing emissions than traditional petroleum fuelled hybrids, are not yet as popular as petrol or diesel hybrid technologies. HDV manufacturers worldwide are interested in developing natural gas hybrid truck engines so the landscape for alternative fuel hybrids is about to change dramatically with the entry of natural gas engines running in concert with electric engine systems. This too needs to be recognized within the body of the Euro VI regulations.

Hydrogen and Natural Gas Blended

The advent of hydrogen fuel cells has brought increased interest in developments associated with supplying sufficient quantities of market-based hydrogen. Nearly all the hydrogen currently used is made from natural gas (methane being the main constituent, with one part carbon and four parts hydrogen. One company has branded the Hythane name to reflect the potential to supply natural gas with as much as 10% hydrogen blended into the gas. This has proven potential to further reduce NOx emissions over diesel HDVs and presents an opportunity to transition into a more robust hydrogen future.

Conclusions

From the above scenarios and analysis it can be concluded that all proposed sets of heavy-duty Euro-VI emissions limit values can be reached with natural gas vehicles using already available stoichiometric technologies. Alternatively, new-to-be-developed technology based on diesel SCR might be considered by individual CNG vehicle manufacturers. Although concrete cost data cannot be provided, the proposed technology packages do not appear to involve costs that differ very much from those involved in making heavy-duty diesel vehicles meet the respective emissions limit values for CO, HC and NO_x. An uncertainty here is the costs and durability of methane sensitive catalytic equipment. With respect to PM-limits, CNG engines will have a cost benefit as they will not require particulate filters to meet stringent PM emissions limits.

For lean-burn engines technological directions have been indicated that may help to achieve the various proposed limits. It is, however, not yet certain whether or at what costs these limits can actually be achieved using lean-burn technology. Experimental research is necessary to provide more insight into this matter.

With regard to the omission in the proposed scenarios of a separate NMHC limit value, ENGVA believes the 're-creation' of a single THC limit value is a step backward in the Euro VI emissions regulations from previous HDV regulations. Manufacturers of HD natural gas engines and vehicles have been broadly supportive of keeping a separate regulation for non-methane hydrocarbons (NMHC). If future regulations with only a total hydrocarbon (THC) limit value were to continue to drop significantly, this could threaten future natural gas HDV development unnecessarily by adding additional costs to the engines and vehicles.

Furthermore, ENGVA believes that the omission of an Environmentally Enhanced Vehicle (EEV) target standard is a mistake. The non-binding EEV target standard advocated successfully by ENGVA, culminating in the 1999 standard had a very positive effect on the HD engine and vehicle industry, with several manufacturers of natural gas engines/vehicles touting their ability to achieve this ultra-low level of emissions. As intended, manufacturers advertised their ability to achieve the target standard with natural gas. Diesel engine manufacturers also strove to achieve EEV levels and made public pronouncements about their 'clean', EEV diesel engines using various emissions control strategies and after-treatment technologies. The EEV, as initially conceived, can be used by European and national policy makers to identify what is a 'clean' (or ultra clean) engine or vehicle, which can be used to provide incentives to manufacturers and consumers to motivate the development and use of engines and vehicles with emissions levels lower than anticipated by EURO VI regulations.

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