Submitted by the experts from OICA

Informal document **GRPE-89-31**
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Agenda item 4.(a).

Proposal for a new Supplement to the 06 series of amendments to UN Regulation No. 49 (Emissions of compression ignition and positive ignition (LPG and CNG) engines)

This document aims at permitting the use of hydrogen (H2) as fuel for emissions type approval of heavy-duty vehicles. The modifications to the current text of the Regulation are marked in bold for new or strikethrough for deleted characters.

I. Proposal

Insert a new paragraph 3.5., to read:

"**3.5. Application for type approval of engines fuelled with hydrogen**

3.5.1. In case of an application for type approval of engines fuelled with hydrogen, hydrogen shall be the fuel the engine is designed to run on primarily. Requirements for dual-fuel hydrogen engines have not yet been established under this regulation."

Paragraph 4.6.2., amend to read:

"4.6.2. If the manufacturer permits the engine family to run on market fuels that do not comply neither with the reference fuels included in Annex 5 nor CEN standard EN 228 (in the case of unleaded petrol) **or grade D (type I or II) of ISO standard ISO 14687 (in the case of hydrogen)** or CEN standard EN 590 (in the case of diesel), such as running on FAME B100 (CEN standard EN14214), FAME diesel blends B20/B30 (CEN standard EN 16709), paraffinic fuel (CEN standard EN 15940) or others the manufacturer shall, in addition to the requirements in paragraph 4.6.1. comply with the following requirements:"

Insert a new paragraph 4.12.3.3.8., to read:

"**4.12.3.3.8. For hydrogen fuelled engines the approval mark shall contain a letter(s) after the national symbol, the purpose of which is to distinguish the fuel type and the working principal for which the approval has been granted. This letter(s) will be as follows:**

(a) T in case of a PI engine being approved and calibrated for gaseous hydrogen

(b) TD in case of a CI engine being approved and calibrated for gaseous hydrogen

(c) U in case of a PI engine being approved and calibrated for liquefied hydrogen

(d) UD in case of a CI engine being approved and calibrated for liquefied hydrogen"

Insert a new paragraph 5.1.6., to read:

"**5.1.6. Provisions for engines fuelled with hydrogen**

5.1.6.1. In case of an application for type approval of engines fuelled with hydrogen, the emission measurement system shall comply with the highest exhaust water content expected during emission testing. In particular it shall be ensured that the temperatures of all sample gas carrying components of the emission measurement system, except for sample dryers, remain at least 10 K above the dew point of the sample gas at the corresponding position."

Paragraph 5.3., amend to read:

"5.3. Emission limits

Table 1 provides the emissions limits that apply to this Regulation.

Table 1
Emission Limits

	Limit values							
	CO (mg/kWh)	*THC (mg/kWh)*	*NMHC***) (mg/kWh)*	*CH_4***) (mg/kWh)*	*NO_X *) (mg/kWh)*	*NH_3 (ppm)*	*PM mass (mg/kWh)*	*PM number (#/kWh)*
WHSC (CI)	1,500	130			400	10	10	8.0×10^{11}
WHTC (CI)	4,000	160			460	10	10	6.0×10^{11}**)
WHTC (PI)	4,000		160	500	460	10	10	6.0×10^{11}**)

Notes:

PI = Positive Ignition

CI = Compression Ignition

*) The admissible level of NO_2 component in the NO_X limit value may be defined at a later stage.

**) The limit shall apply as from the dates set out in row B of Table 1 in Appendix 9 to Annex 1 to this Regulation.

*****) For engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4, the measurement of CH_4 is not required and the manufacturer, technical service or Type Approval Authority may choose to measure the total hydrocarbon (THC) emissions instead of measuring the non-methane hydrocarbon emissions. In that case, the emission limit for the total hydrocarbon emissions is the same as shown in paragraph 5.3. of this Regulation for non-methane hydrocarbon emissions."**

Paragraph 8.3.3.3., amend to read:

"8.3.3.3. For diesel, ethanol (ED95), petrol, E85, **hydrogen,** LNG20, LNG and LPG fuelled, including dual-fuel, engines, all these tests may be conducted with the applicable market fuels. However, at the manufacturer's request, the reference fuels described in Annex 5 to this Regulation may be used. This implies tests, as described in paragraph 4. of this Regulation."

Annex 1, paragraph 3.2.2.2., amend to read:

"3.2.2.2. Heavy duty vehicles Diesel/Petrol/LPG/NG-H/NG-L/ NG-HL/Ethanol (ED95)/ Ethanol (E85) **/Hydrogen (T) /Hydrogen (TD) /Hydrogen (U) /Hydrogen (UD)** [1)]"

Annex 1, paragraph 3.2.17.1., amend to read:

"3.2.17.1. Fuel: LPG /NG-H/NG-L /NG-HL **/Hydrogen (T) /Hydrogen (TD) /Hydrogen (U) /Hydrogen (UD)** [1)]"

Addendum to Annex 2A, paragraph 1.1.5., amend to read:

"1.1.5. Category of engine: Diesel/Petrol/LPG/NG-H/NG-L/NG-HL/Ethanol (ED95)/ Ethanol (E85)/ LNG/LNG20 **/Hydrogen (T) /Hydrogen (TD) /Hydrogen (U) /Hydrogen (UD)** [1)]"

Addendum to Annex 2A, paragraph 1.4.1., amend to read:

"1.4.1. WHSC test

Table 4

WHSC test

WHSC test (if applicable) [*; **]							
DF Mult/add [1)]	CO	THC	NMHC [***,‡]	NO_X	PM Mass	NH_3	PM Number
Emissions	CO (mg/kWh)	THC (mg/kWh)	NMHC [***,‡] (mg/kWh)	NO_X (mg/kWh)	PM Mass (mg/kWh)	NH_3 ppm	PM Number (#/kWh)
Test result							
Calculated with DF							
CO_2 emissions mass emission [***]: ..... (g/kWh)							
Fuel consumption: ..... (g/kWh)							

Notes:

* In the case of engines considered in paragraphs 4.6.3. and 4.6.6. of this Regulation, repeat the information for all fuels tested, when applicable.

** In the case of dual-fuel engines of Type 1B, Type 2B, and Type 3B, types as defined in Annex 15 to this Regulation, repeat the information in both dual-fuel and diesel mode.

*** **For engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4, the measurement of CO_2 is not required and the manufacturer, technical service or Type Approval Authority may choose to measure the total hydrocarbon (THC) emissions instead of measuring the non-methane hydrocarbon emissions. In that case, the emission limit for the total hydrocarbon emissions is the same as shown in paragraph 5.3. of this Regulation for non-methane hydrocarbon emissions.**

‡ In the cases laid down in Table 1 of Annex 15 to this Regulation for dual-fuel engines, and for positive ignition engines."

Addendum to Annex 2A, paragraph 1.4.2., amend to read:

"1.4.2. WHTC test

Table 5
WHTC test

WHTC test [*; **]								
DF Mult/add [1)]	CO	THC	NMHC [***, ‡]	CH_4 [***, ‡‡]	NO_X	PM Mass	NH_3	PM Number

Emissions	CO (mg/kWh)	THC (mg/kWh)	NMHC ***, ‡ (mg/kWh)	CH_4 ***, ‡ (mg/kWh)	NO_X (mg/kWh)	PM Mass (mg/kWh)	NH_3 ppm	PM Number (#/kWh)
Cold start								
Hot start w/o regeneration								
Hot start with regeneration 1)								
kr,u (mult/add) 1) kr,d (mult/add) 1)								
Weighted test result								
Final test result with DF								
CO_2 emissions mass emission ***: ..... (g/kWh) Fuel consumption: ..... (g/kWh)								

Notes:

* In the case of engines considered in paragraphs 4.6.3. and 4.6.6. of this Regulation, repeat the information for all fuels tested, when applicable.

** In the case of dual-fuel engines of Type 1B, Type 2B, and Type 3B, types as defined in Annex 15 to this Regulation, repeat the information in both dual-fuel and diesel mode.

*** **For engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4, the measurement of CH_4 and CO_2 is not required and the manufacturer, technical service or Type Approval Authority may choose to measure the total hydrocarbon (THC) emissions instead of measuring the non-methane hydrocarbon emissions. In that case, the emission limit for the total hydrocarbon emissions is the same as shown in paragraph 5.3. of this Regulation for non-methane hydrocarbon emissions.**

‡ In the cases laid down in Table 1 of Annex 15 to this Regulation for dual-fuel engines, and for positive ignition engines."

Addendum to Annex 2B, paragraph 1.1.5., amend to read:

"1.1.5. Category of engine: Diesel/Petrol/LPG/NG-H/NG-L/NG-HL/Ethanol (ED95)/ Ethanol (E85)/~~dual fuel/~~ **LNG/LNG20 /Hydrogen (T) /Hydrogen (TD) /Hydrogen (U) /Hydrogen (UD)** ([1])"

[1] Delete where not applicable (there are cases where nothing needs to be deleted when more than one entry is applicable)

Addendum to Annex 2B, paragraph 1.4.1., amend to read:

"1.4.1. WHSC test

Table 4
WHSC test

	*WHSC test (if applicable) *,***						
DF Mult/add(1)	CO	THC	NMHC *** (†)	NO_X	PM Mass	NH_3	PM Number
Emissions	CO (mg/kWh)	THC (mg/kWh)	NMHC *** (†) (mg/kWh)	NO_X (mg/kWh)	PM Mass (mg/kWh)	NH_3 ppm	PM Number (#/kWh)
Test result							
Calculated with DF							
CO_2 emissions (mass emission ***……. g/kWh) Fuel consumption ([d]) ……..(g/kWh)							

* In the case of engines considered in paragraphs 4.6.3. and 4.6.6. of this Regulation, repeat the information for all fuels tested, when applicable.

** In the case of dual-fuel engines of Type 1B, Type 2B, and type 3B, types as defined in Annex 15 to this Regulation, repeat the information in both dual-fuel and diesel mode.

*** **For engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4, the measurement of CO_2 is not required and the manufacturer, technical service or Type Approval Authority may choose to measure the total hydrocarbon (THC) emissions instead of measuring the non-methane hydrocarbon emissions. In that case, the emission limit for the total hydrocarbon emissions is the same as shown in paragraph 5.3. of this Regulation for non-methane hydrocarbon emissions.**

† In the cases laid down in Table 1 of Annex 15 to this Regulation for dual-fuel engines, and for positive ignition engines"

[d] When required by this Regulation.

Addendum to Annex 2B, paragraph 1.4.2., amend to read:

"1.4.2. WHTC test

Table 5
WHTC Test

	WHTC test							
DF Mult/add[1]	CO	THC	NMHC* (‡)	CH_4 * (‡)	NO_x	PM Mass	NH_3	PM Number
Emissions	CO (mg/kWh)	THC (mg/kWh)	NMHC * (‡) (mg/kWh)	CH_4 * (‡) (mg/kWh)	NO_x (mg/kWh)	PM Mass (mg/kWh)	NH_3 ppm	PM Number
Cold start								
Hot start w/o regeneration								
Hot start with regeneration[1]								
$k_{r,u}$ (mult/add)[1] $k_{r,d}$ (mult/add)[1]								
Weighted test result								
Final test result with DF								
CO_2 emissions ([d]) mass emission * ……(g/kWh) Fuel consumption ([d]) (g/kWh)								

*** For engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4, the measurement of CH_4 and CO_2 is not required and the manufacturer, technical service or Type Approval Authority may choose to measure the total hydrocarbon (THC) emissions instead of measuring the non-methane hydrocarbon emissions. In that case, the emission limit for the total hydrocarbon emissions is the same as shown in paragraph 5.3. of this Regulation for non-methane hydrocarbon emissions.**

‡ In the cases laid down in Table 1 of Annex 15 to this Regulation for dual-fuel engines, and for positive ignition engines. "

Addendum to Annex 2C, paragraph 1.1.5., amend to read:

"1.1.5. Category of engine: Diesel/Petrol/LPG/NG-H/NG-L/NG-HL/Ethanol (ED95)/ Ethanol (E85)/ LNG/LNG20 **/Hydrogen (T) /Hydrogen (TD) /Hydrogen (U) /Hydrogen (UD)** [1)]"

Addendum to Annex 2C, paragraph 1.4.1., amend to read:

"1.4.1. WHSC test

Table 4
WHSC test

WHSC test (if applicable) *; **							
DF Mult/add [1)]	CO	THC	NMHC ***, ‡	NO_X	PM Mass	NH_3	PM Number
Emissions	CO (mg/kWh)	THC (mg/kWh)	NMHC ***, ‡ (mg/kWh)	NO_X (mg/kWh)	PM Mass (mg/kWh)	NH_3 ppm	PM Number (#/kWh)
Test result							
Calculated with DF							
CO_2 emissions mass emission ***: ..... (g/kWh)							
Fuel consumption: ..... (g/kWh)							

Notes:

* In the case of engines considered in paragraphs 4.6.3. and 4.6.6. of this Regulation, repeat the information for all fuels tested, when applicable.

** In the case of dual-fuel engines of Type 1B, Type 2B, and Type 3B, types as defined in Annex 15 to this Regulation, repeat the information in both dual-fuel and diesel mode.

*** **For engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4, the measurement of CO_2 is not required and the manufacturer, technical service or Type Approval Authority may choose to measure the total hydrocarbon (THC) emissions instead of measuring the non-methane hydrocarbon emissions. In that case, the emission limit for the total hydrocarbon emissions is the same as shown in paragraph 5.3. of this Regulation for non-methane hydrocarbon emissions.**

‡ In the cases laid down in Table 1 of Annex 15 to this Regulation for dual-fuel engines, and for positive ignition engines."

Addendum to Annex 2C, paragraph 1.4.2., amend to read:

"1.4.2. WHTC test

Table 5
WHTC test

WHTC test *; **								
DF Mult/add 1)	CO	THC	NMHC ***, ‡	CH_4 ***, ‡‡	NO_X	PM Mass	NH_3	PM Number
Emissions	CO (mg/kWh)	THC (mg/kWh)	NMHC ***, ‡ (mg/kWh)	CH_4 ***, ‡ (mg/kWh)	NO_X (mg/kWh)	PM Mass (mg/kWh)	NH_3 ppm	PM Number (#/kWh)
Cold start								
Hot start w/o regeneration								
Hot start with regeneration 1)								
kr,u (mult/add) 1) kr,d (mult/add) 1)								
Weighted test result								
Final test result with DF								
CO_2 emissions mass emission ***: ..... (g/kWh) Fuel consumption: ..... (g/kWh)								

Notes:

* In the case of engines considered in paragraphs 4.6.3. and 4.6.6. of this Regulation, repeat the information for all fuels tested, when applicable.

** In the case of dual-fuel engines of Type 1B, Type 2B, and Type 3B, types as defined in Annex 15 to this Regulation, repeat the information in both dual-fuel and diesel mode.

*** **For engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4, the measurement of CH_4 and CO_2 is not required and the manufacturer, technical service or Type Approval Authority may choose to measure the total hydrocarbon (THC) emissions instead of measuring the non-methane hydrocarbon emissions. In that case, the emission limit for the total hydrocarbon emissions is the same as shown in paragraph 5.3. of this Regulation for non-methane hydrocarbon emissions.**

‡ In the cases laid down in Table 1 of Annex 15 to this Regulation for dual-fuel engines, and for positive ignition engines."

Annex 3, Table 2, amend to read:

"

Engine type	*Code*
Diesel fuelled CI engine	D
Ethanol (ED95) fuelled CI engine	ED
Ethanol (E85) fuelled PI engine	E85
Petrol fuelled PI engine	P
LPG fuelled PI engine	Q
Natural gas fuelled PI engine	See paragraph 4.12.3.3.6. of this Regulation
Hydrogen fuelled engine	**See paragraph 4.12.3.3.8. of this Regulation**
Dual-fuel engines	See paragraph 4.12.3.3.7. of this Regulation

"

Annex 4, paragraph 3.3., amend to read:

"3.3. Symbols and abbreviations for the fuel composition

w_{ALF} Hydrogen content of fuel, per cent mass

w_{BET} Carbon content of fuel, per cent mass

w_{GAM} Sulphur content of fuel, per cent mass

w_{DEL} Nitrogen content of fuel, per cent mass

w_{EPS} Oxygen content of fuel, per cent mass

α Molar hydrogen ratio ~~(H/C)~~

β Molar carbon ratio

γ Molar sulphur ratio ~~(S/C)~~

δ Molar nitrogen ratio ~~(N/C)~~

ε Molar oxygen ratio ~~(O/C)~~

referring to a fuel $C_\beta H_\alpha O_\varepsilon N_\delta S_\gamma$**, with β=1 for fuels containing carbon and β=0 for fuels with a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of this annex**"

Annex 4, paragraph 3.4., amend to read:

"3.4. Symbols and abbreviations for the chemical components

C1 Carbon 1 equivalent hydrocarbon

CH_4 Methane

C_2H_6 Ethane

C_3H_8 Propane

CO Carbon monoxide

CO_2 Carbon dioxide

DOP Di-octylphtalate

HC Hydrocarbons

H_2	**Hydrogen**
H_2O	Water
NMHC	Non-methane hydrocarbons
NO_x	Oxides of nitrogen
NO	Nitric oxide
NO_2	Nitrogen dioxide
O_2	**Oxygen**
PM	Particulate matter"

Annex 4, paragraph 5.2.3.6., amend to read:

"5.2.3.6. Fuel type

(a) Diesel;

(b) Natural gas (NG);

(c) Liquefied petroleum gas (LPG);

(d) Ethanol~~.~~**;**

(e) Petrol;

(f) Hydrogen. "

Annex 4, paragraph 8., amend to read:

"8. Emission calculation

The final test result shall be rounded in one step to the number of places to the right of the decimal point indicated by the applicable emission standard plus one additional significant figure, in accordance with ASTM E 29-06B. No rounding of intermediate values leading to the final break-specific emission result is permitted.

Calculation of hydrocarbons and/or non-methane hydrocarbons is based on the following molar carbon/hydrogen/oxygen ratios (C/H/O) of the fuel:

$CH_{1.86}O_{0.006}$ for diesel (B7),

$CH_{2.92}O_{0.46}$ for ethanol for dedicated C.I. engines (ED95),

$CH_{1.93}O_{0.032}$ for petrol (E10),

$CH_{2.74}O_{0.385}$ for ethanol (E85),

$CH_{2.525}$ for LPG (liquefied petroleum gas),

CH_4 for NG (natural gas) and biomethane~~.~~**,**

H_2 for hydrogen.

Examples of the calculation procedures are given in Appendix 5 to this annex.

Emissions calculation on a molar basis, in accordance with Annex 7 of **UN GTR**~~gtr~~ No. 11 concerning the exhaust emission test protocol for Non-Road Mobile Machinery (NRMM), is permitted with the prior agreement of the Type Approval Authority."

Annex 4, paragraph 8.1.1. Equation (15), amend to read:

" $$\sout{k_{w,r} = \left(\frac{1}{1 + a \times 0{,}005 \times (c_{CO2} + c_{CO})} - k_{w1}\right) \times 1{,}008}$$

$$\mathbf{k_{w,r} = \left(\frac{1}{1 + \alpha \times 0{,}005 \times (c_{CO2} + c_{CO})} - k_{w1}\right) \times 1{,}008}$$ "

Annex 4, paragraph 8.1.1., amend to read:

"… Equations 13 and 14 are principally identical with the factor 1.008 in equations 13 and 15 being an approximation for the more accurate denominator in equation 14. **Equation 15 is not applicable, if one of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of this annex. Equations 13 to 17 are not applicable in the case that water injection is used.**"

Annex 4, paragraph 8.1.2., amend to read:

"8.1.2. Diluted exhaust gas

$$k_{w,e} = \left[\left(1 - \frac{\alpha \times c_{CO2w}}{200}\right) - k_{w2}\right] \times 1{,}008 \quad (18)$$

or

$$k_{w,e} = \left[\left(\frac{(1 - k_{w2})}{1 + \frac{\alpha \times c_{CO2d}}{200}}\right)\right] \times 1{,}008 \quad (19)$$

With

$$k_{w2} = \frac{1{,}608 \times \left[H_d \times \left(1 - \frac{1}{D}\right) + H_a \times \left(\frac{1}{D}\right)\right]}{1000 + \left\{1{,}608 \times \left[H_d \times \left(1 - \frac{1}{D}\right) + H_a \times \left(\frac{1}{D}\right)\right]\right\}} \quad (20)$$

Where:

α is the molar hydrogen ration of the fuel

c_{CO2w} is the wet CO2 concentration, per cent

c_{CO2d} is the dry CO2 concentration, per cent

H_d is the diluent humidity, g water per kg dry air

H_a is the intake air humidity, g water per kg dry air

D is the dilution factor (see paragraph 8.5.2.3.2.)

Equation (18) and (19) are not applicable if one of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of this annex."

Annex 4, paragraph 8.1.3. Equation (22), amend to read:

" ~~$k_{w2} = \frac{1{,}608 \times H_d}{1000 + (1{,}608 \times H_d)}$~~

$$\mathbf{k_{w3} = \frac{1{,}608 \times H_d}{1000 + (1{,}608 \times H_d)}}$$ "

Annex 4, paragraph 8.4.1.1., amend to read:

"8.4.1.1. Introduction

For calculation of the emissions in the raw exhaust gas and for controlling of a partial flow dilution system, it is necessary to know the exhaust gas mass flow rate. For the determination of the exhaust mass flow rate, one of the methods described in paragraphs 8.4.1.3. to 8.4.1.7. may be used. **In the case of the determination of exhaust gas mass flow for hydrogen engines the carbon balance method defined in paragraph 8.4.1.7. shall not be applied**.
"

Annex 4, paragraph 8.4.1.6., amend to read:

" ′…

With

~~$A/F_{st} = \frac{138{,}0 \times (1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma)}{12{,}011 + 1{,}00794 \times \alpha + 15{,}9994 \times \varepsilon + 14{,}0067 \times \delta + 32{,}065 \times \gamma}$~~

$$\mathbf{A/F_{st}} = \frac{\mathbf{138{,}0 \times (\beta + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma)}}{\mathbf{12{,}011 \times \beta + 1{,}00794 \times \alpha + 15{,}9994 \times \varepsilon + 14{,}0067 \times \delta + 32{,}065 \times \gamma}} \quad (31)$$

~~$\lambda_i = \frac{\left(100 - \frac{c_{COd} \times 10^{-4}}{2} - c_{HCw} \times 10^{-4}\right) + \left(\frac{\alpha}{4} \times \frac{1 - \frac{2 \times c_{COd} \times 10^{-4}}{3{,}5 \times c_{CO2d}}}{1 + \frac{c_{CO} \times 10^{-4}}{3{,}5 \times c_{CO2d}}} - \frac{\varepsilon}{2} \frac{\delta}{2}\right) \times (c_{CO2d} + c_{COd} \times 10^{-4})}{4{,}764 \times \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right) \times (c_{CO2d} + c_{COd} \times 10^{-4} + c_{HCw} \times 10^{-4})}$~~

$$\boldsymbol{\lambda_i} = \frac{\boldsymbol{\beta \times \left(100 - \frac{c_{COd} \times 10^{-4}}{2} - c_{HCw} \times 10^{-4}\right) + \left(\frac{\alpha}{4} \times \frac{1 - \frac{2 \times c_{COd} \times 10^{-4}}{3{,}5 \times c_{CO2d}}}{1 + \frac{c_{CO} \times 10^{-4}}{3{,}5 \times c_{CO2d}}} - \frac{\varepsilon}{2} - \frac{\delta}{2}\right) \times (c_{CO2d} + c_{COd} \times 10^{-4})}}{\mathbf{4{,}764 \times \left(\beta + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right) \times (c_{CO2d} + c_{COd} \times 10^{-4} + c_{HCw} \times 10^{-4})}} \quad (32)$$

Where:

$q_{maw,i}$ is the instantaneous intake air mass flow rate, kg/s

A/F_{st} is the stoichiometric air to fuel ratio, kg/kg

β is the molar carbon ratio of the fuel, with β=1 for fuels containing carbon and β=0 for fuels with a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of this annex.

λ_i is the instantaneous excess air ratio **calculated by equation 32 or measured by a lambda sensor**

c_{CO2d} is the dry CO_2 concentration, per cent

c_{COd} is the dry CO concentration, ppm

c_{HCw} is the wet HC concentration, ppm

Equation (32) is not applicable if one of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of this annex."

Annex 4, paragraph 8.4.2.3. Table 5, amend to read:

"Table 5
Raw exhaust gas u values and component densities

Fuel	ρ_e	Gas					
		NO_x	CO	HC	CO_2	O_2	CH_4
		ρ_{gas} [kg/m^3]					
		2.053	1.250	[a]	1.9636	1.4277	0.716
		u_{gas}[b]					
Diesel (B7)	1.2943	0.001586	0.000966	0.000482	0.001517	0.001103	0.000553
Ethanol (ED95)	1.2768	0.001609	0.000980	0.000780	0.001539	0.001119	0.000561
CNG[c]	1.2661	0.001621	0.000987	0.000528[d]	0.001551	0.001128	0.000565
Propane	1.2805	0.001603	0.000976	0.000512	0.001533	0.001115	0.000559
Butane	1.2832	0.001600	0.000974	0.000505	0.001530	0.001113	0.000558
LPG[c]	1.2811	0.001602	0.000976	0.000510	0.001533	0.001115	0.000559
Petrol (E10)	1.2931	0.001587	0.000966	0.000499	0.001518	0.001104	0.000553
Ethanol (E85)	1.2797	0.001604	0.000977	0.000730	0.001534	0.001116	0.000559

Hydrogen	**1.1872**	**0.001729**	**0.001053**	**0.000075**	**0.001654**	**0.001203**	**0.000603**

[a] depending on fuel
[b] at λ = 2, dry air, 273 K, 101.3 kPa
[c] u accurate within 0.2 % for mass composition of: C=66 - 76 %; H=22 - 25 %; N=0 - 12 %
[d] NMHC on the basis of $CH_{2.93}$ (for total HC the u_{gas} coefficient of CH_4 shall be used)
[e] u accurate within 0.2 % for mass composition of: C3 = 70 - 90 %; C4 = 10 - 30 %"

Annex 4, paragraph 8.4.2.4., amend to read:

"…

The molar mass of the exhaust, M_e, shall be derived for a general fuel composition $C_\beta H_\alpha O_\varepsilon N_\delta S_\gamma$ under the assumption of complete combustion, as follows:

~~$$M_{e,i} = \frac{1+\frac{q_{mf,i}}{q_{maw,i}}}{\frac{q_{mf,i}}{q_{maw,i}} \times \frac{\frac{\alpha}{4}+\frac{\varepsilon}{2}+\frac{\delta}{2}}{12{,}011+1{,}00794\times\alpha+15{,}9994\times\varepsilon+14{,}0067\times\delta+32{,}065\times\gamma} + \frac{\frac{H_a\times10^{-2}}{2\times1{,}00794+15{,}9994+M_a}}{1+H_a\times10^{-2}}}$$~~

$$M_{e,i} = \frac{1+\frac{q_{mf,i}}{q_{maw,i}}}{\frac{q_{mf,i}}{q_{maw,i}} \times \frac{\frac{\alpha}{4}+\frac{\varepsilon}{2}+\frac{\delta}{2}}{12{,}011\times\beta+1{,}00794\times\alpha+15{,}9994\times\varepsilon+14{,}0067\times\delta+32{,}065\times\gamma} + \frac{\frac{H_a\times10^{-3}}{2\times1{,}00794+15{,}9994+\frac{1}{M_a}}}{1+H_a\times10^{-3}}} \quad (41)$$

"

Annex 4, paragraph 8.6.3., amend to read:

"8.6.3. Calculation of the specific emissions

The specific emissions e_{gas} or e_{PM} (g/kWh) shall be calculated for each individual component in the following ways depending on the type of test cycle.

For the WHSC, hot WHTC, or cold WHTC, the following equation shall be applied:

$$e = \frac{m}{W_{act}} \quad (69)$$

~~$$e = \frac{(0{,}14\times m_{cold})+(0{,}86\times m_{hot})}{(0{,}14\times W_{act,cold})+(0{,}86\times W_{act,hot})} \quad (70)$~~

Where:

m is the mass emission of the component, g/test

W_{act} is the actual cycle work as determined according to paragraph 7.8.6., kWh

For the WHTC, the final test result shall be a weighted average from cold start test and hot start test according to the following equation:

$$\boldsymbol{e = \frac{(0{,}14\times m_{cold})+(0{,}86\times m_{hot})}{(0{,}14\times W_{act,cold})+(0{,}86\times W_{act,hot})}} \quad \textbf{(70)}$$

Where:

m_{cold} is the mass emission of the component on the cold start test, g/test

m_{hot} is the mass emission of the component on the hot start test, g/test

$W_{act,cold}$ is the actual cycle work on the cold start test, kWh

$W_{act,hot}$ is the actual cycle work on the hot start test, kWh

If periodic regeneration in accordance with paragraph 6.6.2. applies, the regeneration adjustment factors $k_{r,u}$ or $k_{r,d}$ shall be multiplied with or be added to, respectively, the specific emissions result *e* as determined in equations 69 and 70."

Annex 4, paragraph 9.3.9.1., amend to read:

"9.3.9.1. CO analyser interference check

Water and CO_2 can interfere with the CO analyser performance. Therefore, a CO_2 span gas having a concentration of 80 to 100 per cent of full scale of the maximum operating range used during testing shall be bubbled through water at room temperature and the analyser response recorded. The analyser response shall not be more than 2 per cent of the mean CO concentration expected during testing **or 20 ppm, whichever is larger**.

…"

Annex 4, paragraph 9.4.6.4., amend to read:

"9.4.6.4. Carbon Flow Check

A carbon flow check using actual exhaust is strongly recommended for detecting measurement and control problems and verifying the proper operation of the partial flow system. The carbon flow check should be run at least each time a new engine is installed, or something significant is changed in the test cell configuration.

The engine shall be operated at peak torque load and speed or any other steady state mode that produces 5 per cent or more of CO_2. The partial flow sampling system shall be operated with a dilution factor of about 15 to 1.

If a carbon flow check is conducted, the procedure given in Appendix 4 shall be applied. The carbon flow rates shall be calculated according to Equations 112 to 114 in Appendix 4 to this Annex. All carbon flow rates should agree to within 3 per cent.

In the case that a hydrogen fuelled engine is to be tested, the carbon flow check should be performed on a diesel fuelled engine prior to the installation of the hydrogen fuelled engine. "

Annex 4, Appendix 7, paragraph A.7.2.1., amend to read:

"A.7.2.1. ~~Laser Diode Spectrometer (LDS)~~ **Laser Infrared Analyser**

A.7.2.1.1. ~~Measurement principle~~

~~The LDS employs the single line spectroscopy principle. The NH_3 absorption line is chosen in the near infrared spectral range and scanned by a single mode diode laser.~~

Measurement Principles

An infrared laser such as a tunable diode laser (TDL) (e.g. those used in a Laser Diode Spectrometer (LDS)), or a quantum cascade laser (QCL) can emit coherent light in the near-infrared region or in the mid-infrared region respectively, where nitrogen compounds including NH_3 have strong absorption. These laser optics give a pulsed-mode high resolution narrow band near-infrared or mid-infrared spectrum. Therefore, laser infrared analysers can reduce interference caused by the spectral overlap of co-existing components in engine exhaust gas.

A.7.2.1.2. Installation

The analyser shall be installed either directly in the exhaust pipe (in-situ) or within an analyser cabinet using extractive sampling in accordance with the instrument manufacturers instructions. If installed in an analyser cabinet, the sample path (sampling line, pre-filter(s) and valves) shall be made of stainless steel or PTFE and shall be heated to ~~463 ± 10 K (190 ± 10 °C)~~ **between 383**

and 464 K (110 – 191 °C) in order to minimize NH_3 losses and sampling artefacts. In addition, the sampling line shall be as short as ~~practically~~ **practicably** possible.

Influence from exhaust temperature and pressure, installation environment and vibrations on the measurement shall be minimized, or compensation techniques be used.

If applicable, sheath air used in conjunction with in-situ measurement for protection of the instrument, shall not affect the concentration of any exhaust component measured downstream of the device, or sampling of other exhaust components shall be made upstream of the device.

A.7.2.1.3. Cross interference

The spectral resolution of the laser shall be within 0.5 cm^{-1} in order to minimize cross interference from other gases present in the exhaust gas. "

Annex 4, Appendix 7, paragraph A.7.2.2.2., amend to read:

"A.7.2.2.2. Installation and sampling

The FTIR shall be installed in accordance with the instrument manufacturer's instructions. The NH_3 wavelength shall be selected for evaluation. The sample path (sampling line, pre-filter(s) and valves) shall be made of stainless steel or PTFE and shall be heated to ~~463 ± 10 K (190 ± 10 °C)~~ **between 383 and 464 K (110 – 191 °C)** in order to minimize NH_3 losses and sampling artefacts. In addition, the sampling line shall be as short as ~~practically~~ **practicably** possible."

Annex 5, add new fuel type to read:

"… **Technical data on fuels for testing compression-ignition or positive ignition and dual-fuel engines**

Type: Hydrogen

Characteristics	*Units*	*Limits*		*Test Method*
		Minimum	*Maximum*	
Hydrogen fuel index	% mole fraction	99.97		(a)
Total non-hydrogen gases	µmol/mol		300	
Lists of non-hydrogen gases and the specification of each contaminant (f)				
Water (H_2O)	µmol/mol		5	(e)
Total hydrocarbons(b) except methane (C1 equivalent)	µmol/mol		2	(e)
Methane (CH_4)	µmol/mol		100	(e)
Oxygen (O_2)	µmol/mol		5	(e)
Helium (He)	µmol/mol		300	(e)
Total Nitrogen (N_2) and Argon (Ar) (b)	µmol/mol		300	(e)
Carbon dioxide (CO_2)	µmol/mol		2	(e)
Carbon monoxide (CO) (c)	µmol/mol		0.2	(e)
Total sulfur compounds (d) (H_2S basis)	µmol/mol		0.004	(e)

Formaldehyde (HCHO)	µmol/mol		0.2	(e)
Formic acid (HCOOH)	µmol/mol		0.2	(e)
Ammonia (NH_3)	µmol/mol		0.1	(e)
Total halogenated compounds (e) (Halogenate ion basis)	µmol/mol		0.05	(e)

(a) The hydrogen fuel index is determined by subtracting the "total non-hydrogen gases" in this table, expressed in mole per cent, from 100 mole per cent.

(b) Total hydrocarbons except methane include oxygenated organic species.

(c) The sum of measured CO, HCHO and HCOOH shall not exceed 0.2 µmol/mol

(d) As a minimum, total sulphur compounds include H2S, COS, CS2 and mercaptans, which are typically found in natural gas.

(e) Test method shall be documented. Test methods defined in ISO21087 are preferable.

(f) The analysis of specific contaminants depending on the production process shall be exempted. A vehicle manufacturer shall provide the responsible authority reasons for exempting specific contaminants."

Annex 6, paragraph 1.2., amend to read:

"1.2. This annex does not apply to dual-fuel engines and vehicles or engines and vehicles **where all of the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.**"

Annex 8, paragraph 6.2., amend to read:

"6.2. The conformity factors shall be calculated and presented for both the CO_2 mass based method and the work based method. The pass/fail decision shall be made on the basis of the results of the work based method. **The CO_2 mass based method may be omitted, if the molar carbon to hydrogen ratio of at least one of the fuels used is 0 as defined in paragraph 8. of Annex 4**."

Annex 8, paragraph 10.1.1.11., amend to read:

"10.1.1.11. Type of engine: petrol, ethanol (E85), diesel/NG /LPG /ethanol (ED95) **/hydrogen** (Delete as appropriate)"

Annex 8, paragraph 10.1.5.1., amend to read:

"10.1.5.1. Engine fuel type (e.g. diesel, ethanol ED95, NG, LPG, petrol, E85**, hydrogen**)"

Annex 8, paragraph 10.1.8.4., amend to read:

"10.1.8.4. CO_2 concentration [ppm] **for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4.**"

Annex 8, paragraph 10.1.9.4., amend to read:

"10.1.9.4. CO_2 mass [g/s] **for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4.**"

Annex 8, paragraph 10.1.9.5., amend to read:

"10.1.9.5. CH_4 mass [g/s] for ~~P.I.~~ **natural gas** fuelled engines only"

Annex 8, paragraph 10.1.9.9., amend to read:

"10.1.9.9. CO_2 cumulated mass [g] **for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4.**"

Annex 8, paragraph 10.1.9.20., amend to read:

"10.1.9.20. CO_2 mass window duration [s] **for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.**"

Annex 8, paragraph 10.1.9.21., amend to read:

"10.1.9.21. CO_2 mass window THC conformity factor [-] **for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.**"

Annex 8, paragraph 10.1.9.22., amend to read:

"10.1.9.22. CO_2 mass window CO conformity factor [-] **for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.**"

Annex 8, paragraph 10.1.9.23., amend to read:

"10.1.9.23. CO_2 mass window NO_x conformity factor [-] **for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.**"

Annex 8, paragraph 10.1.9.24a., amend to read:

"10.1.9.24a. CO_2 mass window PM number conformity factor [-] **for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.**"

Annex 8, paragraph 10.1.10.11., amend to read:

"10.1.10.11. CO_2 emissions [g] **for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4.**"

Annex 8, paragraph 10.1.11.6., amend to read:

"10.1.11.6. CO_2 mass window THC conformity factor [-] **for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.**"

Annex 8, paragraph 10.1.11.7., amend to read:

"10.1.11.7. CO_2 mass window NO_x conformity factor [-] **for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.**"

Annex 8, paragraph 10.1.11.8., amend to read:

"10.1.11.8. CO_2 mass window CO conformity factor [-] **for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.**"

Annex 8, paragraph 10.1.11.9bis., amend to read:

"10.1.11.9bis. CO_2 mass window PM number conformity factor [-] **for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.**"

Annex 8, paragraph 10.1.11.11., amend to read:

"10.1.11.11. CO_2 mass window: Minimum and maximum window duration [s] **for engines for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.**"

Annex 8, paragraph 10.1.11.13., amend to read:

"10.1.11.13. CO_2 mass window: Percentage of valid windows **for engines for engines where none of the fuels used has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.**"

Annex 8, paragraph 10.1.12.4., amend to read:

"10.1.12.4. CO_2 analyser zero, span and audit results, pre and post test **for engines where one of the fuels used has a molar carbon to hydrogen ratio greater than 0 as defined in paragraph 8. of Annex 4.**"

Annex 8, Appendix 1, paragraph A.1.1., amend to read:

"A.1.1. Introduction

This Appendix describes the procedure to determine pollutant emissions from on-vehicle on-road measurements using Portable Emissions Measurement Systems (hereinafter "PEMS"). The pollutant emissions to be measured from the exhaust of the engine include the following components: carbon monoxide, total hydrocarbons, nitrogen oxides and PM number for compression ignition engines and carbon monoxide, non- methane hydrocarbons, methane, nitrogen oxides and PM number for positive ignition engines. Additionally, carbon dioxide shall be measured to enable the calculation procedures described in paragraph A.1.4.

For engines fuelled with natural gas, the manufacturer, technical service or Type Approval Authority may choose to measure the total hydrocarbon (THC) emissions only instead of measuring the methane and non-methane hydrocarbon emissions. In that case, the emission limit for the total hydrocarbon emissions is the same as the one shown in paragraph 5.3. of this Regulation for methane emissions. For the purposes of the calculation of the conformity factors pursuant to paragraphs A.1.4.2.3. and A.1.4.3.2., the applicable limit shall in that case be the methane emission limit only.

For engines fuelled with gases other than natural gas, the manufacturer, technical service or Type Approval Authority may choose to measure the total hydrocarbon (THC) emissions instead of measuring the non-methane hydrocarbon emissions. In that case, the emission limit for the total hydrocarbon emissions is the same as shown in paragraph 5.3. of this Regulation for non-methane hydrocarbon emissions. For the purposes of the calculations of the conformity factors pursuant to paragraphs A.1.4.2.3. and A.1.4.3.2., the applicable limit shall in that case be the non-methane emission limit.

For engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4, the manufacturer may choose to measure only the total hydrocarbon (THC), carbon monoxide (CO), nitrogen oxides (NO_x) and PM number. In this case lambda and optionally air mass flow shall be measured as well to enable the data consistency check as described in paragraph A.1.3.2."

Table 1 in Annex 8, Appendix 1, paragraph A.1.2.2., amend to read:

"Table 1
Test parameters

Parameter	Unit	Source
THC concentration[1]	ppm	Gas analyser
CO concentration[1]	ppm	Gas analyser
NO_x concentration[1]	ppm	Gas analyser
CO_2 concentration[1, 5]	ppm	Gas analyser
CH_4 concentration[1, 2, 5]	ppm	Gas analyser
PM number concentration	#/cm^3	PM number analyser
Dilution setting (if applicable)	-	PM number analyser

Parameter	Unit	Source
Exhaust gas flow	kg/h	Exhaust Flow Meter (hereinafter EFM)
Exhaust temperature	K	EFM
Ambient temperature[3]	K	Sensor
Ambient pressure	kPa	Sensor
Engine torque[4]	Nm	ECU or Sensor
Engine speed	rpm	ECU or Sensor
Engine fuel flow	g/s	ECU or Sensor
Engine coolant temperature	K	ECU or Sensor
Engine intake air temperature[3]	K	Sensor
Vehicle ground speed	km/h	ECU and GPS
Vehicle latitude	degree	GPS
Vehicle longitude	degree	GPS
Lambda value [6]	**-**	**ECU or Sensor**
Air mass flow [7]	**kg/h**	**ECU or Sensor**

Notes:

[1] Measured or corrected to a wet basis
[2] Only for gas engines fuelled with natural gas
[3] Use the ambient temperature sensor or an intake air temperature sensor
[4] The recorded value shall be either (a) the net brake engine torque according to paragraph A.1.2.4.4. of this appendix or (b) the net brake engine torque calculated from the torque values according to paragraph A.1.2.4.4. of this appendix.
[5] Not applicable for engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.
[6] Only for engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4
[7] Optional for engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4"

Annex 8, Appendix 1, paragraph A.1.3.2.1., amend to read:

"A.1.3.2.1. Analysers and EFM data

The consistency of the data (exhaust mass flow measured by the EFM and gas concentrations) shall be verified using a correlation between the measured fuel flow from the ECU and the fuel flow calculated using the formula in paragraph 8.4.1.7. of Annex 4 to this Regulation. **If the molar carbon to hydrogen ratio of all the fuels used is 0 as defined in paragraph 8. of Annex 4, then the formula in paragraph 8.4.1.6. of Annex 4 shall be used instead.** A linear regression shall be performed for the measured and calculated fuel rate values. The method of least squares shall be used, with the best fit equation having the form:

…"

*Annex 9**A**, Table 2, paragraph 3.2.2.*, amend to read:

"Table 2
OTLs (positive ignition engines)

	Limit in mg/kWh	
	NO_x	CO [1), 2)]
Phase-in period	1,500	7,500

General requirements	1,200	7,500

[1)] The transitional provisions related to introduction of the CO OTLs are specified in paragraphs 13.2.2. and 13.3.2. of this Regulation.

[2)] **Not applicable if the molar carbon to hydrogen ratio of all the fuel used is 0 as defined in paragraph 8. of Annex 4."**

Annex 9B, paragraph 3.26., amend to read:

"3.26. Abbreviations

AES Auxiliary Emission Strategy

CI Compression Ignition

CV Crankcase Ventilation

DOC Diesel Oxidation Catalyst

DPF Diesel Particulate Filter or Particulate Trap including catalyzed DPFs**,** ~~and~~ Continuously Regenerating Traps (CRT) **and other soot particle filters**

DTC Diagnostic trouble code

EGR Exhaust Gas Recirculation

HC Hydrocarbon

LNT Lean NOx Trap (or NOx absorber)

LPG Liquefied Petroleum Gas

MECS Malfunction Emission Control Strategy

NG Natural Gas

NOx Oxides of Nitrogen

OTL OBD Threshold Limit

PI Positive Ignition

PM Particulate Matter

SCR Selective Catalytic Reduction

SW Screen Wipers

TFF Total Functional Failure monitoring

VGT Variable Geometry Turbocharger

VVT Variable Valve Timing"

Annex 9B, paragraph 5.2.3., amend to read:

"5.2.3. Low fuel level

Manufacturers may request approval to disable monitoring systems that are affected by low fuel level / pressure or running out of fuel (e.g. diagnosis of a malfunction of the fuelling system or misfiring) as follows:

	~~Diesel~~	~~Gas~~	
		~~NG~~	~~LPG~~
~~(a) The low fuel level considered for such a disablement shall not exceed 100 litres or 20 per cent of the nominal capacity of the fuel tank, whichever is lower.~~	~~X~~		~~X~~

~~(b) The low fuel pressure in the tank considered for such a disablement shall not exceed 20 per cent of the usable range of fuel tank pressure.~~		~~X~~	

	Liquid fuel storage	**Gaseous fuel storage**
(a) The low fuel level considered for such a disablement shall not exceed 100 litres or 20 per cent of the nominal capacity of the fuel tank, whichever is lower.	**X**	
(b) The low fuel pressure in the tank considered for such a disablement shall not exceed 20 per cent of the usable range of fuel tank pressure.		**X**

"

Annex 9B, Appendix 3 – Item 6, amend to read:

"Appendix 3 - Item 6

Exhaust Gas Recirculation (EGR) system monitoring

The OBD system shall monitor the following elements of the EGR system on engines so equipped for proper operation:

	~~Diesel~~ **CI engine**	~~Gas~~ **PI engine**
(a1) EGR low/high flow: the EGR system's ability to maintain the commanded EGR flow rate, detecting both “flow rate too low” and “flow rate too high” conditions – emission threshold monitoring.	X	
(a2) EGR low/high flow: the EGR system's ability to maintain the commanded EGR flow rate, detecting both “flow rate too low” and “flow rate too high” conditions – performance monitoring		X
(a3) EGR low flow: the EGR system's ability to maintain the commanded EGR flow rate, detecting “flow rate too low” conditions – total functional failure or performance monitoring as specified in this item.	X	X
(b) Slow response of the EGR actuator: the EGR system's ability to achieve the commanded flow rate within a manufacturer specified time interval following the command – performance monitoring.	X	X
(c1) EGR cooler under cooling performance: the EGR cooler system's ability to achieve the manufacturer's specified cooling performance – performance monitoring.	X	X
(c2) EGR cooler under cooling performance: the EGR cooler system's ability to achieve the manufacturer's specified cooling performance – total functional failure monitoring as specified in this item.	X	X

…"

Annex 9B, Appendix 3 – Item 7, amend to read:

"Appendix 3 - Item 7

Fuel System monitoring

The OBD system shall monitor the following elements of the fuel system on engines so-equipped for proper operation:

	~~Diesel~~ **CI engine**	~~Gas~~ **PI engine**
(a) Fuel system pressure control: fuel system ability to achieve the commanded fuel pressure in closed loop control – performance monitoring.	X	
(b) Fuel system pressure control: fuel system ability to achieve the commanded fuel pressure in closed loop control in the case where the system is so constructed that the pressure can be controlled independently of other parameters – performance monitoring.	X	
(c) Fuel injection timing: fuel system ability to achieve the commanded fuel timing for at least one of the injection events when the engine is equipped with the appropriate sensors – performance monitoring.	X	
(d) Fuel injection quantity: fuel system ability to achieve the commanded fuel quantity by detecting errors from desired fuel quantity in at least one of the injection events when the engine is equipped with the appropriate sensors (e.g. in pre- main- or post-injection) – emission threshold monitoring.	X	
(e) Fuel injection system: ability to maintain the desired air-fuel ratio (incl. but not limited to self-adaptation features) – performance monitoring.		X

"

Annex 9B, Appendix 3 – Item 8, amend to read:

"Appendix 3 - Item 8

Air handling and turbocharger/Boost pressure control system

The OBD system shall monitor the following elements of the Air handling and turbo-charger/Boost pressure control system on engines so-equipped for proper operation:

	~~Diesel~~ **CI engine**	~~Gas~~ **PI engine**
(a1) Turbo under/over boost: turbo boost system's ability to maintain the commanded boost pressure, detecting both “boost pressure too low” and “boost pressure too high” conditions – emission threshold monitoring.	X	
(a2) Turbo under/over boost: turbo boost system's ability to maintain the commanded boost pressure, detecting both		X

"boost pressure too low" and "boost pressure too high" conditions – performance monitoring.		
(a3) Turbo under boost: turbo boost system's ability to maintain the commanded boost pressure, detecting "boost pressure too low" conditions – total functional failure or performance monitoring as specified in this item.	X	X
(b) Variable Geometry Turbo (VGT) slow response: VGT system's ability to achieve the commanded geometry within a manufacturer specified time-performance monitoring.	X	X
(c) Charge air cooling: Charge air cooling system efficiency - total functional failure.	X	X

…"

Annex 9B, Appendix 3 – Item 10, amend to read:

"Appendix 3 - Item 10

Misfire Monitoring

	~~Diesel~~ **CI engine**	~~Gas~~ **PI engine**
(a) No prescriptions.	X	
(b) Misfire that may cause catalyst damage (e.g. by monitoring a certain percentage of misfiring in a certain period of time) – performance monitoring.		X

"

Annex 9B, Appendix 3 – Item 13, amend to read:

"Appendix 3 - Item 13

Exhaust gas and oxygen sensors monitoring

The OBD system shall monitor:

	~~Diesel~~ **CI engine**	~~Gas~~ **PI engine**
(a) The electrical elements of the exhaust gas sensors on engines so-equipped for proper operation according to item 1 to this appendix – component monitoring.	X	X
(b) Both the primary and secondary (fuel control) oxygen sensors. These sensors are considered as exhaust gas sensors to be monitored for proper operation according to item 1 to this appendix – component monitoring.		X

"

Annex 9B, Appendix 3 – Item 15, amend to read:

"Appendix 3 - Item 15

Three-way catalyst

The OBD system shall monitor the three-way catalyst on engines so-equipped for proper operation:

	~~Diesel~~ **CI engine**	~~Gas~~ **PI engine**
(a) Three-way Catalyst Conversion efficiency: the catalyst ability to convert NOx and CO – performance monitoring		X

"

Annex 12, paragraph 3.1., amend to read:

"3.1. Raw measurement

This paragraph shall apply, if CO_2 is measured in the raw exhaust gas **and the molar carbon to hydrogen ratio of all the fuels used is greater than 0 as defined in paragraph 8. of Annex 4**."

Annex 12, paragraph 3.2., amend to read:

"3.2. Dilute measurement

This paragraph shall apply, if CO_2 is measured in the dilute exhaust gas **and the molar carbon to hydrogen ratio of all the fuels used is greater than 0 as defined in paragraph 8. of Annex 4**."

Annex 12, insert new paragraph 3.3., to read:

"3.3. Calculation from fuel consumption

This paragraph shall apply, if the molar carbon to hydrogen ratio of all the fuels used is 0 as defined in paragraph 8. of Annex 4.

The fuel consumption shall be determined according to paragraph 4. of this annex and the measured test-averaged fuel consumption shall be used as the base for calculating the test averaged CO_2 emissions.

The mass of CO_2 (g/test) shall be set to zero according to the following equation:

$$m_{CO_2} = \frac{\beta \times M_{CO_2}}{\beta \times A_C + \alpha \times A_H} \times q_{mf}$$

Where:

β is the molar carbon ratio of the fuel, with β=1 for fuels containing carbon and β=0 for fuels with a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4

α is the molar hydrogen ration of the fuel

q_{mf} is the measured test-averaged fuel consumption

A_H is the atomic mass of hydrogen (1,0079 g/mol)

A_C is the atomic mass of carbon (12,011 g/mol)"

Annex 12, paragraph 3.3. *(former),* renumber as paragraph 3.4.

II. Justification

1. Hydrogen-fueled vehicles are covered by UN Regulation No. 83 and UN Regulation No. 154 (LDV emission control), and hydrogen-fueled engines are covered by UN Regulation No. 49, Series 07 (HDV emission control). However, hydrogen-fueled engines are not yet covered in UN Regulation No. 49, Series 05 and 06.

2. Hydrogen fuelled engines could be one complementary option to reduce CO_2 emission of future heavy-duty vehicles

3. Hydrogen fuel should be included in the UN Regulation No. 49, Series 05 and 06 similarly to UN Regulation No. 49, Series 07 (HDV emission control)

4. This amendment aims to integrate only mono-fuel hydrogen engines. Further amendments integrating hydrogen dual-fuel engines are expected to follow when their validation can be accomplished.

5. In relation to the proposed amendment to Appendix 7 to Annex 4, the quantum cascade laser infra-red (QCL-IR) measurement principle for NH3 is already existing in GTR-15 (WLTP) and EU Stage V NRMM legislation. It is deemed appropriate to introduce this same measurement principle in UN Regulation No. 49 and allow widening the temperature range of the sample path (110 - 191 °C).