

**Proposal for amendments to Regulation No. 49 (Emissions of compression ignition and positive ignition (LPG and CNG) engines)**

**Submitted by the experts from the International Organization of Motor Vehicle Manufacturers**

The text reproduced below was prepared by the experts from the International Organization of Motor Vehicle Manufacturers (OICA). This document aims at permitting the use of hydrogen (H<sub>2</sub>) 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

*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 new paragraph 4.12.3.3.7., to read:*

**"4.12.3.3.7. 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 the approval has been granted. This letter/s will be as follows:**

- (a) T in case of the PI engine being approved and calibrated for gaseous hydrogen**
- (b) TD in case of the CI engine being approved and calibrated for gaseous hydrogen**
- (c) U in case of the PI engine being approved and calibrated for liquefied hydrogen**
- (d) UD in case of the CI engine being approved and calibrated for liquefied hydrogen"**

*Paragraph 4.12.3.3.7. (former), renumber as paragraph 4.12.3.3.8., amend to read:*

"4.12.3.3.8. For dual-fuel engines the approval mark shall contain a series of digits after the national symbol, the purpose of which is to distinguish for which dual-fuel engine type and with which range of gases the approval has been granted.

This series of digits will be constituted of two digits identifying the dual-fuel engine type as defined in Annex 15 followed by the letter(s) specified in paragraphs 4.12.3.3.1. to 4.12.3.3.6~~7~~. corresponding to the natural gas/biomethane/**hydrogen** composition used by the engine.

The two digits identifying the dual-fuel engines types according to the definitions of Annex 15 are the following:

- (a) 1A for dual-fuel engines of Type 1A;
- (b) 1B for dual-fuel engines of Type 1B;
- (c) 2A for dual-fuel engines of Type 2A;
- (d) 2B for dual-fuel engines of Type 2B;
- (e) 3B for dual-fuel engines of Type 3B."

*Paragraph 5.3., amend to read:*

"5.3. Emission limits

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

	Limit values							
	CO (mg/kWh)	THC (mg/kWh)	NMHC (mg/kWh)	CH <sub>4</sub> (mg/kWh)	NO <sub>x</sub> *) (mg/kWh)	NH <sub>3</sub> (ppm)	PM mass (mg/kWh)	PM number (#/kWh)
WHSC (CI)	1,500	130			400	10	10	8.0 x 10 <sup>11</sup>
WHTC (CI)	4,000	160			460	10	10	6.0 x 10 <sup>11**</sup>
WHTC (PI)	4,000		160	500	460	10	10	6.0 x 10 <sup>11**</sup>

Notes:

PI = Positive Ignition

CI = Compression Ignition

\*) The admissible level of NO<sub>2</sub> component in the NO<sub>x</sub> 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.

**CO, THC, NMHC and CH<sub>4</sub> do not need to be demonstrated for engines where all of the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4."**

*Paragraph 8.3.3.3.*, amend to read:

"8.3.3.3. For diesel, ethanol (ED95), petrol, E85, **hydrogen**, LNG<sub>20</sub>, 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*

*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)** <sup>1)</sup>"

*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)** <sup>1)</sup>"

*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/LNG<sub>20</sub> 1) /**Hydrogen (T) /Hydrogen (TD) /Hydrogen (U) /Hydrogen (UD)** <sup>1)</sup>"

*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 <sup>1)</sup>	CO ***	THC ***	NMHC ***, ‡	NO <sub>x</sub>	PM Mass	NH <sub>3</sub>	PM Number
Emissions	CO *** (mg/kWh)	THC *** (mg/kWh)	NMHC ***, ‡ (mg/kWh)	NO <sub>x</sub> (mg/kWh)	PM Mass (mg/kWh)	NH <sub>3</sub> ppm	PM Number (#/kWh)
Test result							
Calculated with DF							
CO <sub>2</sub> 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.
- \*\*\* **Not required for engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.**
- ‡ 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 <sup>1)</sup>	CO ***	THC ***	NMHC ***, ‡	CH <sub>4</sub> ***, ‡, †	NO <sub>x</sub>	PM Mass	NH <sub>3</sub>	PM Number

Emissions	CO *** (mg/kWh)	THC *** (mg/kWh)	NMHC ***, ‡ (mg/kWh)	CH <sub>4</sub> ***, ‡ (mg/kWh)	NO <sub>x</sub> (mg/kWh)	PM Mass (mg/kWh)	NH <sub>3</sub> ppm	PM Number (#/kWh)
Cold start								
Hot start w/o regeneration								
Hot start with regeneration <sup>1)</sup>								
kr,u (mult/add) <sup>1)</sup> kr,d (mult/add) <sup>1)</sup>								
Weighted test result								
Final test result with DF								
CO <sub>2</sub> 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.
- \*\*\* **Not required for engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.**
- ‡ 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 1) /**Hydrogen (T) /Hydrogen (TD) /Hydrogen (U) /Hydrogen (UD)** <sup>1)</sup>"

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 <sup>1)</sup>	CO ***	THC ***	NMHC ***, ‡	NO <sub>x</sub>	PM Mass	NH <sub>3</sub>	PM Number
Emissions	CO *** (mg/kWh)	THC *** (mg/kWh)	NMHC ***, ‡ (mg/kWh)	NO <sub>x</sub> (mg/kWh)	PM Mass (mg/kWh)	NH <sub>3</sub> ppm	PM Number (#/kWh)
Test result							
Calculated with DF							
CO <sub>2</sub> 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.
- \*\*\* **Not required for engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.**
- ‡ 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 <sup>1)</sup>	CO ***	THC ***	NMHC ***, ‡	CH <sub>4</sub> ***, ‡, †	NO <sub>x</sub>	PM Mass	NH <sub>3</sub>	PM Number
Emissions	CO *** (mg/kWh)	THC *** (mg/kWh)	NMHC ***, ‡ (mg/kWh)	CH <sub>4</sub> ***, ‡ (mg/kWh)	NO <sub>x</sub> (mg/kWh)	PM Mass (mg/kWh)	NH <sub>3</sub> ppm	PM Number (#/kWh)
Cold start								
Hot start w/o regeneration								

Hot start with regeneration <sup>1)</sup>								
kr,u (mult/add) <sup>1)</sup>								
kr,d (mult/add) <sup>1)</sup>								
Weighted test result								
Final test result with DF								
CO <sub>2</sub> 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.
- \*\*\* **Not required for engines where all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4.**
- ‡ 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

Annex 3, Table 2, amend to read:

"

<i>Engine type</i>	<i>Code</i>
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
<b>Hydrogen fuelled engine</b>	<b>See paragraph 4.12.3.3.7. of this Regulation</b>
Dual-fuel engines	See paragraph 4.12.3.3.78. of this Regulation

"

## Annex 4

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

$\alpha$  Molar hydrogen ratio ( $H/C$ )

**$\beta$  Molar carbon ratio**

$\gamma$  Molar sulphur ratio ( $S/C$ )

$\delta$  Molar nitrogen ratio ( $N/C$ )

$\varepsilon$  Molar oxygen ratio ( $O/C$ )

referring to a fuel  $C_{\beta}H_{\alpha}O_{\varepsilon}N_{\delta}S_{\gamma}$ , with  $\beta=1$  for fuels containing carbon and  $\beta=0$  for fuels not containing carbon"

*Annex 4, paragraph 3.4., amend to read:*

"3.4. Symbols and abbreviations for the chemical components

C1 Carbon 1 equivalent hydrocarbon

CH<sub>4</sub> Methane

C<sub>2</sub>H<sub>6</sub> Ethane

C<sub>3</sub>H<sub>8</sub> Propane

CO Carbon monoxide

CO<sub>2</sub> Carbon dioxide

DOP Di-octylphthalate

HC Hydrocarbons

**H<sub>2</sub> Hydrogen**

H<sub>2</sub>O Water

NMHC Non-methane hydrocarbons

NO<sub>x</sub> Oxides of nitrogen

NO Nitric oxide

NO<sub>2</sub> Nitrogen dioxide

**O<sub>2</sub> 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) 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<sub>1.86</sub>O<sub>0.006</sub> for diesel (B7),

CH<sub>2.92</sub>O<sub>0.46</sub> for ethanol for dedicated C.I. engines (ED95),

CH<sub>1.93</sub>O<sub>0.032</sub> for petrol (E10),

CH<sub>2.74</sub>O<sub>0.385</sub> for ethanol (E85),

CH<sub>2.525</sub> for LPG (liquefied petroleum gas),

CH<sub>4</sub> for NG (natural gas) and biomethane-,

**H<sub>2</sub> 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 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., amend to read:*

"8.1. Dry/wet correction

If the emissions are measured on a dry basis, the measured concentration shall be converted to a wet basis according to the following equation:

$$c_w = k_w \times c_d \quad (12)$$

Where:

$c_d$  is the dry concentration in ppm or per cent volume

$k_w$  is the dry/wet correction factor ( $k_{w,a}$ ,  $k_{w,r}$ ,  $k_{w,e}$ , or  $k_{w,d}$  depending on respective equation used)

**If all the fuels used have a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. to this annex, then the concentration of CO ( $c_{CO}$ ) and CO<sub>2</sub> ( $c_{CO2}$ ) shall be set to zero in paragraph 8.1.1. and 8.1.2. to this annex."**

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

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

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

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

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

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

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 8.4.1.78. may be used."

Annex 4, paragraph 8.4.1.2., amend to read:

"8.4.1.2. Response time

For the purpose of emissions calculation, the response time of any of the methods described in paragraphs 8.4.1.3. to 8.4.1.78. shall be equal to or less than the analyser response time of  $\leq 10$  seconds, as required in paragraph 9.3.5.

For the purpose of controlling of a partial flow dilution system, a faster response is required. For partial flow dilution systems with online control, the response time shall be  $\leq 0.3$  second. For partial flow dilution systems with look ahead control based on a pre-recorded test run, the response time of the exhaust flow measurement system shall be  $\leq 5$  seconds with a rise time of  $\leq 1$  second. The system response time shall be specified by the instrument manufacturer. The combined response time requirements for the exhaust gas flow and partial flow dilution system are indicated in paragraph 9.4.6.1. "

Annex 4, paragraph 8.4.1.6., amend to read:

" ...

With

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

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

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

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

Where:

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

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

$\beta$  is the molar carbon ratio of the fuel, with  $\beta=1$  for fuels containing carbon and  $\beta=0$  for fuels not containing carbon

$\lambda_i$  is the instantaneous excess air ratio

$c_{CO2d}$  is the dry CO<sub>2</sub> 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.**

"

Add new paragraph 8.4.1.8. to Annex 4, to read:

**"8.4.1.8. Oxygen balance method**

The following formula can be used for the calculation of the exhaust mass flow on the basis of the oxygen balance method.

$$q_{mew} = q_{mad} \times \left(1 + \frac{H_a}{1000}\right) + q_{mf}$$

$$q_{med} = q_{mf} \times \frac{(1 - 0,08936 \times w_{ALF}) \times 0,232 + f2 - w_{EPS}}{0,232 - \frac{1,439 \times c_{O2d}}{\rho_{ed}}}$$

With

$$f2 = w_{ALF} \times 7,9367 + w_{BET} \times 2,6641 + w_{GAM} \times 0,9979$$

"

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

"Table 5

Raw exhaust gas u values and component densities

Fuel	$\rho_e$	Gas					
		NO <sub>x</sub>	CO	HC	CO <sub>2</sub>	O <sub>2</sub>	CH <sub>4</sub>
		$\rho_{gas}$ [kg/m <sup>3</sup> ]					
		2.053	1.250	<sup>a</sup>	1.9636	1.4277	0.716
		$u_{gas}$ <sup>b</sup>					
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 <sup>c</sup>	1.2661	0.001621	0.000987	0.000528 <sup>d</sup>	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 <sup>e</sup>	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
<b>Hydrogen</b>	<b>1.1872</b>	<b>0.001729</b>	<b>0.001053</b>	<b>0.000075</b>	<b>0.001654</b>	<b>0.001203</b>	<b>0.000603</b>

<sup>a</sup> depending on fuel

<sup>b</sup> at  $\lambda = 2$ , dry air, 273 K, 101.3 kPa

<sup>c</sup> u accurate within 0.2 % for mass composition of: C=66 - 76 %; H=22 - 25 %; N=0 - 12 %

<sup>d</sup> NMHC on the basis of  $\text{CH}_{2.93}$  (for total HC the  $u_{\text{gas}}$  coefficient of  $\text{CH}_4$  shall be used)

<sup>e</sup> 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,  $M_{e,i}$ , shall be derived for a general fuel composition  $\text{C}_\beta\text{H}_\alpha\text{O}_\epsilon\text{N}_\delta\text{S}_\gamma$  under the assumption of complete combustion, as follows:

$$M_{e,i} = \frac{1 + \frac{q_{mf,i}}{q_{maw,i}}}{\frac{q_{mf,i}}{q_{maw,i}} \times \frac{\frac{\alpha}{4} + \frac{\epsilon}{2} + \frac{\delta}{2}}{12,011 + 1,00794 \times \alpha + 15,9994 \times \epsilon + 14,0067 \times \delta + 32,065 \times \gamma} + \frac{H_a \times 10^{-3}}{2 \times 1,00794 + 15,9994 + \frac{1}{M_a}}} \quad (41)$$

$$M_{e,i} = \frac{1 + \frac{q_{mf,i}}{q_{maw,i}}}{\frac{q_{mf,i}}{q_{maw,i}} \times \frac{\frac{\alpha}{4} + \frac{\epsilon}{2} + \frac{\delta}{2}}{12,011 + 1,00794 \times \alpha + 15,9994 \times \epsilon + 14,0067 \times \delta + 32,065 \times \gamma} + \frac{H_a \times 10^{-3}}{1 + H_a \times 10^{-3}}} \quad (41)$$

"

Annex 4, paragraph 8.5.2.3.1. Table 6, amend to read:

"Table 6

Diluted exhaust gas u values and component densities

Fuel	$\rho_{de}$	Gas					
		NO <sub>x</sub>	CO	HC	CO <sub>2</sub>	O <sub>2</sub>	CH <sub>4</sub>
		$\rho_{\text{gas}}$ [kg/m <sup>3</sup> ]					
		2.053	1.250	<sup>a</sup>	1.9636	1.4277	0.716
		$u_{\text{gas}}$ <sup>b</sup>					
Diesel (B7)	1.293	0.001588	0.000967	0.000483	0.001519	0.001104	0.000553
Ethanol (ED95)	1.293	0.001588	0.000967	0.000770	0.001519	0.001104	0.000553
CNG <sup>c</sup>	1.293	0.001588	0.000967	0.000517 <sup>d</sup>	0.001519	0.001104	0.000553
Propane	1.293	0.001588	0.000967	0.000507	0.001519	0.001104	0.000553
Butane	1.293	0.001588	0.000967	0.000501	0.001519	0.001104	0.000553
LPG <sup>e</sup>	1.293	0.001588	0.000967	0.000505	0.001519	0.001104	0.000553

Petrol (E10)	1.293	0.001588	0.000967	0.000499	0.001519	0.001104	0.000554
Ethanol (E85)	1.293	0.001588	0.000967	0.000722	0.001519	0.001104	0.000554
<b>Hydrogen</b>	<b>1.293</b>	<b>0.001588</b>	<b>0.000967</b>	<b>0.000070</b>	<b>0.001519</b>	<b>0.001104</b>	<b>0.000554</b>

<sup>a</sup> depending on fuel

<sup>b</sup> at  $\lambda = 2$ , dry air, 273 K, 101.3 kPa

<sup>c</sup> u accurate within 0.2 % for mass composition of: C=66 - 76 %; H=22 - 25 %; N=0 - 12 %

<sup>d</sup> NMHC on the basis of  $\text{CH}_{2.93}$  (for total HC the  $u_{\text{gas}}$  coefficient of  $\text{CH}_4$  shall be used)

<sup>e</sup> u accurate within 0.2 % for mass composition of: C3 = 70 - 90 %; C4 = 10 - 30 %

<sup>f</sup> **calculated based on  $\rho_{\text{gas}}$  for Diesel (B7)"**

Annex 4, paragraph 8.5.2.3.2., amend to read:

"8.5.2.3.2. Determination of the background corrected concentrations

...

The dilution factor shall be calculated as follows:

- a) For diesel fuelled engines, ~~and~~ LPG fuelled gas engines **and dual-fuel hydrogen engines**

$$D = \frac{F_S}{c_{\text{CO}_2,e} + (c_{\text{HC},e} + c_{\text{CO},e}) \times 10^{-4}}$$

- b) For natural gas fuelled gas engines

$$D = \frac{F_S}{c_{\text{CO}_2,e} + (c_{\text{NMHC},e} + c_{\text{CO},e}) \times 10^{-4}}$$

- (c) **For hydrogen fuelled engines**

$$D = \frac{35,03}{c_{\text{H}_2\text{O}} - c_{\text{H}_2\text{O},\text{DA}} + c_{\text{H}_2} \times 10^{-4}}$$

Where:

$c_{\text{CO}_2,e}$  is the wet concentration of  $\text{CO}_2$  in the diluted exhaust gas, per cent vol

$c_{\text{HC},e}$  is the wet concentration of HC in the diluted exhaust gas, ppm C1

$c_{\text{NMHC},e}$  is the wet concentration of NMHC in the diluted exhaust gas, ppm C1

$c_{\text{CO},e}$  is the wet concentration of CO in the diluted exhaust gas, ppm

$F_S$  is the stoichiometric factor

$c_{\text{H}_2\text{O}}$  **is the wet concentration of  $\text{H}_2\text{O}$  in the diluted exhaust gas, per cent vol**

$c_{\text{H}_2\text{O},\text{DA}}$  **is wet the concentration of  $\text{H}_2\text{O}$  in the air used for dilution, per cent vol**

$c_{H_2}$  is the wet concentration of hydrogen in the diluted exhaust, ppm

Annex 5

Annex 5, amend to read:

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

Type: Hydrogen

Constituents <sup>1)</sup>	Unit	Limits		Test method
		Minimum	Maximum	
Hydrogen purity <sup>2)</sup>	% mole	99.97		ISO 14687:2019
Total non-hydrogen gases	µmol/mol		300	ISO 14687:2019
Water (H <sub>2</sub> O)	µmol/mol		5	ISO 14687:2019
Total hydrocarbons except methane <sup>3)</sup> (C1 equivalent)	µmol/mol		2	ISO 14687:2019
Methane (CH <sub>4</sub> )	µmol/mol		100	ISO 14687:2019
Oxygen (O <sub>2</sub> )	µmol/mol		5	ISO 14687:2019
Helium (He)	µmol/mol		300	ISO 14687:2019
Nitrogen (N <sub>2</sub> )	µmol/mol		300	ISO 14687:2019
Argon (Ar)	µmol/mol		300	ISO 14687:2019
Carbon Dioxide (CO <sub>2</sub> )	µmol/mol		2	ISO 14687:2019
Carbon Monoxide (CO) <sup>4)</sup>	µmol/mol		0.2	ISO 14687:2019
Total Sulphur compounds <sup>5)</sup> (S1 equivalent)	µmol/mol		0.004	ISO 14687:2019
Formaldehyde (HCHO) <sup>4)</sup>	µmol/mol		0.2	ISO 14687:2019
Formic acid (HCOOH) <sup>4)</sup>	µmol/mol		0.2	ISO 14687:2019
Ammonia (NH <sub>3</sub> )	µmol/mol		0.1	ISO 14687:2019
Halogenated compounds <sup>6)</sup> (Halogen ion equivalent)	µmol/mol		0.05	ISO 14687:2019
Maximum particulate concentration <sup>7)</sup>	mg/kg		1	ISO 14687:2019

Notes:

<sup>1)</sup> For the constituents that are additive, such as total hydrocarbons and total sulphur compounds, the sum of the constituents shall be less than or equal to the acceptable limit.

<sup>2)</sup> The hydrogen fuel index is determined by subtracting the "total non-hydrogen gases" in this table, expressed in mole percent, from 100 mole percent.

<sup>3)</sup> Total hydrocarbons except methane include oxygenated organic species. Total hydrocarbons except methane shall be measured on a C1 equivalent (µmol/mol).

<sup>4)</sup> The sum of measured CO, HCHO and HCOOH shall not exceed 0.2 µmol/mol.

<sup>5)</sup> As a minimum, total sulphur compounds include H<sub>2</sub>S, COS, CS<sub>2</sub> and mercaptans, which are typically found in natural gas.

<sup>6)</sup> All halogenated compounds which could potentially be in the hydrogen gas [for example, hydrogen chloride (HCl) and organic chlorides (R-Cl)] should be determined by the hydrogen quality control plan discussed in ISO 19880-8. Halogenated compounds shall be measured on a halogen ion equivalent (µmol/mol).

7) Particulate includes solid and liquid particulates comprises of oil mist. Large particulates can cause issues with vehicle components and should be limited by using filter as specified in ISO 19880-1. No visible oil shall be found in fuel at a nozzle.

"

*Annex 6*

*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*

*Annex 8, paragraph 6.2., amend to read:*

"6.2. The conformity factors shall be calculated and presented for both the CO<sub>2</sub> 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<sub>2</sub> 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 10.1.8.1., amend to read:*

"10.1.8.1. THC 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 10.1.8.2., amend to read:*

"10.1.8.2. CO 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 10.1.8.4., amend to read:*

"10.1.8.4. CO<sub>2</sub> 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 10.1.9.1., amend to read:*

"10.1.9.1. THC 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 10.1.9.2., amend to read:*

"10.1.9.2. CO 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 10.1.9.4., amend to read:*

"10.1.9.4. CO<sub>2</sub> 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<sub>4</sub> mass [g/s] for ~~P.I.~~ **natural-gas** fuelled engines only"

*Annex 8, paragraph 10.1.9.6., amend to read:*

"10.1.9.6. THC 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 10.1.9.7., amend to read:*

"10.1.9.7. CO 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 10.1.9.9., amend to read:*

"10.1.9.9. CO<sub>2</sub> 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 10.1.9.16., amend to read:*

"10.1.9.16. Work window THC conformity factor [-] **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 10.1.9.17., amend to read:*

"10.1.9.17. Work window CO conformity factor [-] **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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> mass window NO<sub>x</sub> 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<sub>2</sub> 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 10.1.10.8., amend to read:*

"10.1.10.8. THC 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 10.1.10.9., amend to read:*

"10.1.10.9. CO 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 10.1.10.11., amend to read:*

"10.1.10.11. CO<sub>2</sub> 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 10.1.11.2., amend to read:*

"10.1.11.2. Work window THC conformity factor [-] **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 10.1.11.3., amend to read:*

"10.1.11.3. Work window CO conformity factor [-] **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<sub>2</sub> 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<sub>2</sub> mass window NO<sub>x</sub> 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. Work window CO conformity factor [-] **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 10.1.11.11., amend to read:*

"10.1.11.11. CO<sub>2</sub> 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<sub>2</sub> 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 10.1.12.1.*, amend to read:

"10.1.12.1. THC 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, paragraph 10.1.12.2.*, amend to read:

"10.1.12.2. CO 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, paragraph 10.1.12.4.*, amend to read:

"10.1.12.4. CO<sub>2</sub> 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*

*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 nitrogen oxides and PM number. In this case oxygen 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 <sup>1,5</sup>	ppm	Gas analyser
CO concentration <sup>1,5</sup>	ppm	Gas analyser
NO <sub>x</sub> concentration <sup>1</sup>	ppm	Gas analyser
CO <sub>2</sub> concentration <sup>1,5</sup>	ppm	Gas analyser
CH <sub>4</sub> concentration <sup>1,2,5</sup>	ppm	Gas analyser
<b>O<sub>2</sub> concentration<sup>6</sup></b>	<b>ppm</b>	<b>Gas analyser</b>
PM number concentration	#/cm <sup>3</sup>	PM number analyser
Dilution setting (if applicable)	-	PM number analyser
Exhaust gas flow	kg/h	Exhaust Flow Meter (hereinafter EFM)
Exhaust temperature	K	EFM
Ambient temperature <sup>3</sup>	K	Sensor
Ambient pressure	kPa	Sensor
Engine torque <sup>4</sup>	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 <sup>3</sup>	K	Sensor
Vehicle ground speed	km/h	ECU and GPS
Vehicle latitude	degree	GPS
Vehicle longitude	degree	GPS

Notes:

<sup>1</sup> Measured or corrected to a wet basis

<sup>2</sup> Only for gas engines fuelled with natural gas

<sup>3</sup> Use the ambient temperature sensor or an intake air temperature sensor

<sup>4</sup> 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.

<sup>5</sup> **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.**

<sup>6</sup> **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"**

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 8.4.1.8. 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*

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

"Table 2  
OTLs (positive ignition engines)

	Limit in mg/kWh	
	NO <sub>x</sub>	CO <sup>1), 2)</sup>
Phase-in period	1,500	7,500
General requirements	1,200	7,500

- <sup>1)</sup> The transitional provisions related to introduction of the CO OTLs are specified in paragraphs 13.2.2. and 13.3.2. of this Regulation.
- <sup>2)</sup> **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 Compressed 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 NO<sub>x</sub> Trap (or NO<sub>x</sub> absorber)
- LPG Liquefied Petroleum Gas
- MECS Malfunction Emission Control Strategy
- NG Natural Gas
- NO<sub>x</sub> 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	Gas
CI engine	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 turbocharger/Boost pressure control system on engines so-equipped for proper operation:

	<b>Diesel CI engine</b>	<b>Gas PI engine</b>
(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 “boost pressure too low” and “boost pressure too high” conditions – performance monitoring.		X
(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

	<b>Diesel CI engine</b>	<b>Gas PI engine</b>
(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:

	<b>Diesel CI engine</b>	<b>Gas PI engine</b>
(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:

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



"

*Annex 10, paragraph 5.2.2., amend to read:*

"5.2.2. The applicable emission limits shall be the following:

- (a) For CO: 2,000 mg/kWh<sup>1</sup>;
- (b) For THC: 220 mg/kWh<sup>1</sup>;
- (c) For NOx: 600 mg/kWh;
- (d) For PM: 16 mg/kWh.

<sup>1</sup> **the measurement shall not be required if the molar carbon to hydrogen ratio of all the fuels used is 0 as defined in paragraph 8. of Annex 4.**"

*Annex 12*

*Annex 12, paragraph 3.1., amend to read:*

"3.1. Raw measurement

This paragraph shall apply, if CO<sub>2</sub> 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<sub>2</sub> 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 the 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<sub>2</sub> emissions.**

**The mass of CO<sub>2</sub> (g/test) shall be set to zero according to the following equation:**

$$m_{\text{CO}_2} = \frac{\beta \times M_{\text{CO}_2}}{\beta \times A_{\text{C}} + \alpha \times A_{\text{H}}} \times q_{\text{mf}}$$

"

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

*Annex 12, Appendix 1, Paragraph A.1.2.1.2., amend to read:*

"A.1.2.1.2. Paragraph 5.2.4. of Regulation No.101 shall be understood as follows:

- (1) Density: measured on the test fuel according to ISO 3675 or an equivalent method. For petrol, diesel, ethanol (E85) and ethanol for dedicated C.I. engines (ED95) the density measured at 288 K (15 °C) will be used; for LPG and natural gas/biomethane a reference density shall be used, as follows:

0.538 kg/litre for LPG;

0.654 kg/m<sup>3</sup> for NG.

- (2) Hydrogen-carbon-oxygen ratio: fixed values shall be used which are:

C<sub>1</sub>H<sub>1.93</sub>O<sub>0.032</sub> for petrol (E10);

C<sub>1</sub>H<sub>1.86</sub>O<sub>0.006</sub> for diesel (B7);

C<sub>1</sub>H<sub>2.525</sub> for LPG (liquefied petroleum gas);

CH<sub>4</sub> for NG (natural gas) and biomethane;

C<sub>1</sub>H<sub>2.74</sub>O<sub>0.385</sub> for ethanol (E85);

C<sub>1</sub>H<sub>2.92</sub>O<sub>0.46</sub> for ethanol for dedicated C.I. engines (ED95);

**H<sub>2</sub> for hydrogen."**

*Annex 12, Appendix 1, Paragraph A.1.2.1.2., amend to read:*

- "A.1.2.1.3. Paragraph 1.4.3. of Annex 6. of Regulation No. 101 shall be understood as:

1.4.3. The fuel consumption, expressed in litres per 100 km (in the case of petrol, LPG, ethanol (E85 and ED95) and diesel) or in m<sup>3</sup> per 100 km (in the case of NG/biomethane) is calculated by means of the following formulae:

- (a) For vehicles with a positive ignition engine fuelled with petrol (E10):

$$FC = (0.120/D) \cdot [(0.831 \cdot HC) + (0.429 \cdot CO) + (0.273 \cdot CO_2)]$$

- (b) For vehicles with a positive ignition engine fuelled with LPG:

$$FC_{\text{norm}} = (0.1212/0.538) \cdot [(0.825 \cdot HC) + (0.429 \cdot CO) + (0.273 \cdot CO_2)]$$

If the composition of the fuel used for the test differs from the composition that is assumed for the calculation of the normalised consumption, on the manufacturer's request a correction factor cf may be applied, as follows:

$$FC_{\text{norm}} = (0.1212/0.538) \cdot (cf) \cdot [(0.825 \cdot HC) + (0.429 \cdot CO) + (0.273 \cdot CO_2)]$$

The correction factor cf, which may be applied, is determined as follows:

$$cf = 0.825 + 0.0693 n_{\text{actual}}$$

Where:

$n_{\text{actual}}$  is the actual H/C ratio of the fuel used

- (c) For vehicles with a positive ignition engine fuelled with NG/biomethane:

$$FC_{\text{norm}} = (0.1336/0.654) \cdot [(0.749 \cdot HC) + (0.429 \cdot CO) + (0.273 \cdot CO_2)]$$

- (d) For vehicles with a positive ignition engine fuelled with ethanol (E85):

$$FC = (0.1742/D) \cdot [(0.574 \cdot HC) + (0.429 \cdot CO) + (0.273 \cdot CO_2)]$$

- (e) For vehicles with a compression ignition engine fuelled with diesel (B7):

$$FC = (0.1165/D) \cdot [(0.859 \cdot HC) + (0.429 \cdot CO) + (0.273 \cdot CO_2)]$$

- (f) For vehicles with a dedicated compression ignition engine fuelled with ethanol (ED95)

$$FC = (0.186/D) \cdot [(0.538 \cdot HC) + (0.429 \cdot CO) + (0.273 \cdot CO_2)]$$

- (g) For vehicles fuelled by gaseous hydrogen:

$$FC = 0.024 \frac{V}{d} \left[ \frac{1}{Z_1 T_1} p_1 - \frac{1}{Z_2 T_2} p_2 \right]$$

**Under previous agreement with the type-approval authority, and for vehicles fuelled either by gaseous or liquid hydrogen, the manufacturer may choose as alternative to the method above, either the formula**

$$FC = 0.1 \cdot (0.1119 \cdot H_2O + H_2)$$

**for vehicles powered by internal combustion engine only, or a method according to standard protocols such as SAE J2572 or ISO 23828.**

In these formulae:

**FC** is the fuel consumption in litre per 100 km (in the case of petrol, ethanol, LPG, diesel or biodiesel) or in m<sup>3</sup> per 100 km (in the case of natural gas)

**HC** is the measured emission of hydrocarbons in g/km

**CO** is the measured emission of carbon monoxide in g/km

**CO<sub>2</sub>** is the measured emission of carbon dioxide in g/km

**H<sub>2</sub>O** is the measured emission of H<sub>2</sub>O in g/km

**H<sub>2</sub>** is the measured emission of H<sub>2</sub> in g/km

**D** is the density of the test fuel. In the case of gaseous fuels this is the density at 288 K (15 °C).

**d** is the theoretical length of the applicable phase or cycle, in km

**p<sub>1</sub>** is the pressure in gaseous fuel tank before the operating cycle in Pa

**p<sub>2</sub>** is the pressure in gaseous fuel tank after the operating cycle in Pa

**T<sub>1</sub>** is the temperature in gaseous fuel tank before the operating cycle in K

**T<sub>2</sub>** is the temperature in gaseous fuel tank after the operating cycle in K

**Z<sub>1</sub>** is the compressibility factor of the gaseous fuel at p<sub>1</sub> and T<sub>1</sub>

**Z<sub>2</sub>** is the compressibility factor of the gaseous fuel at p<sub>2</sub> and T<sub>2</sub>

**V** is the inner volume of the gaseous fuel tank in m<sup>3</sup>

*Annex 15*

*Annex 15, Paragraph 4.2.2.3., amend to read:*

"4.2.2.3. Repair and maintenance of LNG **or Hydrogen** Type A dual-fuel engines and vehicles.

In the case of LNG **or Hydrogen** Type A dual-fuel engines and vehicles, the manufacturer may, instead of limiting the vehicle speed at 20 km/h, opt for limiting the power of the engine to 20 per cent of the declared maximum power in dual-fuel mode, and this at any engine speed, when the service mode is activated during a repair or maintenance operation."

Annex 15, Paragraph 5.2.2.2.2., amend to read:

"5.2.2.2.2. 5.2.2.2.2. LPG and **Hydrogen** engines

The THC emission limits over the WHTC test-cycle applicable to HDDF Type 2A engines and HDDF Type 2B engines operating with LPG **or a fuel that has a molar carbon to hydrogen ratio of 0 as defined in paragraph 8. of Annex 4** in dual-fuel mode are those applicable to CI engines over the WHTC test-cycle and defined in paragraph 5.3. of this Regulation."

Annex 15, Paragraph 10.3. Equation (24), amend to read:

"...

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

Annex 15, Appendix 4, Paragraph A.4.4.4.1., amend to read:

"A.4.4.4.1. Determination of the background corrected concentrations (Annex 4, paragraph 8.5.2.3.2.)

To determine the stoichiometric factor, the molar hydrogen ratio  $\alpha$  of the fuel shall be calculated as the average molar hydrogen ratio of the fuel mix during the test according to section A.6.4. of Appendix 6.

Alternatively the  $F_s$  value of the gaseous fuel may be used in equation 59 or 60 of Annex 4. **If the carbon to hydrogen ratio of one the fuels is 0 as defined in paragraph 8. of Annex 4 equation 59 shall be used.**"

Annex 15, Appendix 6, Paragraph A.6.2.1., amend to read:

"A.6.2.1. For Type 1A or 1B dual-fuel engines operating in dual-fuel mode the molar component ratios and the  $u_{gas}$  values of the gaseous fuel shall be used. **For Type 1A or 1B dual-fuel engines fuelled with hydrogen the molar components shall be set to table A6.1.**

**Table A6.1**

**Molar Component Ratios for a mixture @ GER 90% (energy base)**

Gaseous Fuel	$\alpha$	$\gamma$	$\delta$	$\epsilon$
Hydrogen	46.1826	0	0	0.0060

"

Annex 15, Appendix 6, Paragraph A.6.2.2., amend to read:

"A.6.2.2 For Type 2A or 2B dual-fuel engines operating in dual-fuel mode the molar component ratios and the  $u_{gas}$  values from tables A6.12 and A6.23 shall be used.

Table A6.12

Molar component ratios for a mixture of 50% gaseous fuel and 50% diesel fuel (mass %)

Gaseous Fuel	$\alpha$	$\gamma$	$\delta$	$\varepsilon$
CH <sub>4</sub>	2.8681	0	0	0.0040
G <sub>R</sub>	2.7676	0	0	0.0040
G <sub>23</sub>	2.7986	0	0.0703	0.0043
G <sub>25</sub>	2.7377	0	0.1319	0.0045
Propane	2.2633	0	0	0.0039
Butane	2.1837	0	0	0.0038
LPG	2.1957	0	0	0.0038
LPG Fuel A	2.1740	0	0	0.0038
LPG Fuel B	2.2402	0	0	0.0039
<b>Hydrogen</b>	<b>15.7327</b>	<b>0</b>	<b>0</b>	<b>0.0060</b>

Table A6.23

Raw exhaust gas  $u_{\text{gas}}$  values and component densities for a mixture of 50% gaseous fuel and 50% diesel fuel (mass %)

Fuel	$\rho_{\text{dc}}$	Gas					
		NO <sub>x</sub>	CO	HC	CO <sub>2</sub>	O <sub>2</sub>	CH <sub>4</sub>
		$\rho_{\text{gas}}$ [kg/m <sup>3</sup> ]					
		2.053	1.250	<sup>a</sup>	1.9636	1.4277	0.716
$u_{\text{gas}}$ <sup>b</sup>							
CNG/LNG <sup>c</sup>	1.2786	0.001606	0.000978	0.000528 <sup>d</sup>	0.001536	0.001117	0.000560
Propane	1.2869	0.001596	0.000972	0.000510	0.001527	0.001110	0.000556
Butane	1.2883	0.001594	0.000971	0.000503	0.001525	0.001109	0.000556
LPG <sup>e</sup>	1.2881	0.001594	0.000971	0.000506	0.001525	0.001109	0.000556
<b>Hydrogen</b>	<b>1.2175</b>	<b>0.001686</b>	<b>0.001027</b>	<b>0.000513<sup>f</sup></b>	<b>0.001613</b>	<b>0.001173</b>	<b>0.000588</b>

- a) depending on fuel
- b) at  $\lambda = 2$ , dry air, 273 K, 101.3 kPa
- c)  $u$  accurate within 0.2 % for mass composition of: C = 58 - 76 %; H = 19 - 25 %; N = 0 - 14 % (CH<sub>4</sub>, G<sub>20</sub>, G<sub>R</sub>, G<sub>23</sub> and G<sub>25</sub>)
- d) NMHC on the basis of CH<sub>2.93</sub> (for total HC the  $u_{\text{gas}}$  coefficient of CH<sub>4</sub> shall be used)
- e)  $u$  accurate within 0.2 % for mass composition of: C3 = 27 - 90 %; C4 = 10 - 73 % (LPG Fuels A and B)
- f) **calculated based on  $\rho_{\text{gas}}$  for Diesel (B7)"**

## II. Justification

1. Hydrogen fuelled vehicles are covered in UN Regulation 83 and UN Regulation 154 (LD regulation), but hydrogen fuelled engines are not yet covered in UN Regulation 49 and UN Regulation 85
2. Hydrogen fuelled engines could be one complementary option to reduce CO2 emission of future heavy duty vehicles
3. Thus hydrogen fuel should be integrated in UN Regulation 49 and UN Regulation 85 for better alignment with UN Regulation 83 and UN Regulation 154

To mark the proposed amendments to the existing text of the UN Regulations, UN Global Technical Regulations (UN GTRs) and UN Rules, the proposals for consideration by the GRs can be prepared either on track change mode or using bold text (for the additions) and strikethrough (for the deleted text).

---