

UN Regulation No. 96

Proposal for a new Supplement to the 05 series of amendments to UN Regulation No. 96 (Uniform provisions concerning the approval of engines to be installed in agricultural and forestry tractors and in nonroad mobile machinery with regard to the emissions of pollutants by the engine.)

The text reproduced below was prepared by the experts from the European Association of Internal Combustion Engine Manufacturers (EUROMOT). This document aims at permitting the use of hydrogen (H₂) as fuel for approval of internal combustion engines to be installed in agricultural and forestry tractors and in non-road mobile machinery, with regard to the emissions of pollutants by the engine. 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 3.1.1 to read:

“3.1.1. In the case of an application for type approval of engines operated solely on hydrogen, hydrogen shall be the fuel the engine is designed to operate on primarily. Requirements for dual-fuel hydrogen engines have not yet been established under this regulation.

Paragraph 5.1.3., amend to read:

“5.1.3. In accordance with Appendix 4 to this Regulation, the testing of an engine type or engine family to determine whether it meets the emission limits set out in this Regulation shall be carried out by using the following reference fuels or fuel combinations, as appropriate:

- (a) Diesel;
- (b) Petrol;
- (c) Petrol/oil mixture, for two stroke SI engines;
- (d) Natural gas/bio methane;
- (e) Liquid petroleum gas (LPG);
- (f) Ethanol;
- (g) Hydrogen.**

The engine type or engine family shall, in addition, meet the exhaust emission limits set out in this Regulation in respect of any other specified fuels, fuel mixtures or fuel emulsions included by a manufacturer in an application for type approval and described in the Appendix 4 to this Regulation.

Paragraph 5.6.4., amend to read:

“5.6.4. Test requirements

The test shall be carried out immediately after the applicable NRSC as follows:

- (a) The test of the randomly selected torque and engine speed points shall either be carried out immediately after the discrete-mode NRSC test sequence described in sub-paragraphs (a) to (e) of paragraph 7.8.1.2. of Annex 4 but before the post test procedures (f) or after the Ramped Modal non-road steady-state test Cycle ("RMC") test sequence described in sub-paragraphs (a) to (d) of paragraph 7.8.2.3. of Annex 4 but before the post test procedures (e) as relevant;
- (b) The tests shall be carried out as required in sub-paragraphs (b) to (e) of paragraph 7.8.1.2. of Annex 4 using the multiple filter method (one filter for each test point) for each of the test points chosen in accordance with paragraph 3.;
- (c) A specific emission value shall be calculated (in g/kWh or #/kWh as applicable) for each test point;
- (d) **For engines operated solely on hydrogen as specified in Appendix 4 paragraph A.4.4., emissions values shall be calculated using Annex 11. For engines operated on all other fuels, emissions values may be calculated on a mass basis using Appendix A.1. of Annex 5 or on a molar basis using Appendix A.2. of Annex 5. In all cases, the method used for the transient test cycle (where applicable) but shall be consistent with the method used for the discrete mode NRSC or RMC test.;**
- (e) For gaseous and PN, if applicable, summation calculations, N_{mode} in equation (A.5-64) or (A.5-136) and (A.5-180) shall be set to 1 and a weighting factor of 1 shall be used;
- (f) For particulate calculations the multiple filter method shall be used; for summation calculations, N in equation (A.5-67) shall be set to 1 and a weighting factor of 1 shall be used.

Paragraph 6.1.4., amend to read:

- “6.1.4. **For engines other than those operated solely on hydrogen as specified in Appendix 4 paragraph A.4.4. Manufacturers shall make available to OEMs the value of the carbon dioxide (CO₂) emissions determined during the type-approval process and shall instruct the OEMs to communicate that information, together with explanatory information on the test conditions, to the end-user of the non-road mobile machinery or category T vehicle in which the engine is intended to be installed. For engines operated solely on hydrogen as specified in Appendix 4 Paragraph A.4.4., it is not required to make this value available to the OEM.**”

Paragraph 8.7.2.3. amend to read:

- “8.7.2.3. Engines shall be subjected to emissions testing in accordance with the requirements of Annex 4, or, in the case of dual-fuel engines, in accordance with Annex 7, **or, in the case of engine operated solely on hydrogen, in accordance with Annex 11**, and shall be subject to the test cycles relevant for the engine type in accordance with Appendix A.6 to Annex 4.”

Appendix 4 insert new paragraphs to read:

- “A.4.4. **Requirements for an engine operated solely on hydrogen**
- A.4.4.1. **The engine manufacturer shall not indicate at any time that an engine type or engine family may be operated in the territory of any Contracting Party on market fuels other than those that comply with grade D of ISO standard ISO 14687 unless the manufacturer additionally complies with the requirement in paragraph A.4.4.2..**
- A.4.4.2. **If the manufacturer permits engines to run on additional market fuels other than those identified in paragraph A.4.4.1., such as running on other**

grades of hydrogen, all of the following actions shall be taken by the manufacturer:

- (a) Declare, in the information document set out in Annex 1A, the specification of the market fuels on which the engine family is capable to run;
- (b) Demonstrate the capability of the parent engine to meet the requirements of this Regulation on the fuels declared;
- (c) Be liable to meet the requirements of in-service monitoring set out by any Contracting Party, if any, on the fuels declared and the applicable market fuel identified in paragraph A.4.4.1.

A.4.4.3. In order to receive a type-approval of an engine operated solely on hydrogen, the manufacturer shall comply with the requirements set out in Annex 11.”

Appendix 5 Paragraph A.5.6., amend to read:

“A.5.6. **For engines other than those operated solely on hydrogen as specified in Appendix 4 paragraph A.4.4.** ~~¶~~the manufacturer shall provide to the OEM the value of the carbon dioxide (CO₂) emissions in g/kWh determined during the type-approval process and recorded in the engine communication. This value shall be provided by the OEM to the end-users accompanied by the following statements: *‘This CO₂ emission value results from testing over a fixed test cycle under laboratory conditions of an (a parent) engine representative of the engine type (engine family) and shall not imply or express any guarantee of the performance of a particular engine once installed in a type of non-road mobile machinery or category T vehicle’.* **For engines operated solely on hydrogen as specified in Appendix 4 paragraph A.4.4., the manufacturer is not required to provide a value of the carbon dioxide (CO₂) emissions to the OEM. In this case the statement provided by the OEM to the end-user shall be: ‘A CO₂ emission value has not been declared, because the engine has been type-approved to solely operate on hydrogen (H₂).’.**”

Annex 1 Appendix A.3 Paragraph 2.8.1., amend to read:

“2.8.1. Fuel Type: Diesel (non-road gas-oil)/Ethanol for dedicated compression ignition engines (ED95)/Petrol (E10)/ Ethanol (E85)/(Natural gas/Biomethane)/Liquid Petroleum Gas (LPG)/ **Hydrogen**”

Annex 1 Appendix A.3 Paragraph 3.14.1., amend to read:

3.14.1.	Fuel: LPG /NG-H/NG-L /NG-HL/LNG/Fuel specific LNG/ Hydrogen					
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Annex 2 Part A Paragraph 2.8.1., amend to read:

“2.8.1. Fuel Type(s): Diesel (non-road gas-oil)/Ethanol for dedicated compression ignition engines (ED95)/Petrol (E10)/ Ethanol (E85)/(Natural gas/Biomethane)/Liquid Petroleum Gas (LPG)/ **Hydrogen** ²”

Annex 2 Part B Paragraph 11.2., amend to read:

“11.2 CO₂ result⁵:”

Annex 2 Part B Paragraph 11.3.2., amend to read:

“11.3.2. NRTC reference CO₂ (g)⁵.”

Annex 2 Part B Explanatory note to Annex 2, amend to read:

“Explanatory notes to Annex 2

(Footnote markers, footnotes and explanatory notes not to be stated on the type-approval certificate)

- ¹ The distinguish numbers of the Contracting Parties to the 1958 Agreement are reproduced in Annex 3 to the Consolidated Resolution on the Construction of Vehicles (R.E.3), document ECE/TRANS/WP.29/78/Rev.6 - www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29resolutions.html
- ² Strike out the unused options, or only show the used option(s).
- ³ Indicate the applicable option for the category and sub-category in accordance with entry 1.7. of the information document set out in Part A of Appendix A.3 to Annex 1.
- ⁴ Indicate the used test cycle as prescribed in Appendix A.6 to Annex 4 to this Regulation.
- ⁵ **Not mandatory for engines operated solely on hydrogen as specified in Appendix 4 paragraph A.4.4.”**

Annex 2 Appendix A.1 Paragraph A.1.3, TEST REPORT FOR NON-ROAD ENGINES, insert new Paragraphs to read:

“4.6 **Hydrogen**
 4.6.1 **Make:**.....
 4.6.2 **Type:**.....”

Annex 2 Appendix A.1 Paragraph 9.3.3., amend to read:

“9.3.3. Cycle weighted CO₂ (g/kWh) (7):”

Annex 2 Appendix A.1 Paragraph 10.3.1., amend to read:

“10.3.1. Cycle weighted CO₂ (g/kWh) (7):”

Annex 2 Appendix A.1 Paragraph 10.3.4., amend to read:

“10.3.4. Cycle weighted CO₂ (g/kWh) (7):”

Annex 2 Appendix A.1, Paragraph 10.4.1., amend to read:

“10.4.1. Cycle CO₂ (g/kWh) (7):”

Annex 2 Appendix A.1, Paragraph 10.4.4., amend to read:

“10.4.4. Cycle CO₂ (g)(7):”

Annex 2 Appendix A.1, Paragraph 11.2., amend to read:

“11.2. CO₂ result (4)(7):”

Annex 2 Appendix A.1, Paragraph 11.3.2., amend to read:

“11.3.2. NRTC reference CO₂ (g)⁽⁶⁾(⁷):”

Annex 2 Appendix A.1 Explanatory notes to the test report template, amend to read:

“Explanatory notes to the test report template

(Footnote markers, footnotes and explanatory notes not to be stated on the test report)

- (¹) For NRSC note the cycle indicated in paragraph 9.1.; for transient test note cycle indicated in paragraph 10.1.
- (²) Copy the results from table 6
- (³) Copy the results from table 9 or 10, as applicable
- (⁴) For an engine type or engine family that is tested on both the NRSC and a transient cycle, indicate the hot cycle CO₂ emissions values from the NRTC noted in paragraph 10.2.3. or the CO₂ emissions values from the LSI-NRTC noted in paragraph 10.3.3. For an engine only tested on an NRSC indicate the CO₂ emissions values given in that cycle from paragraph 9.3.3.
- (⁵) Where engine is tested on NRTC record value from 10.3.3., otherwise leave blank
- (⁶) Where engine is tested on NRTC record value from 10.3.4., otherwise leave blank
- (⁷) **Not mandatory for engines operated solely on hydrogen as specified in Appendix 4 paragraph A.4.4.”**

Annex 3 Appendix A.1, Table 2 amend to read:

Engine Fuel type (column 1)	Sub-type, where applicable (column 2)	Fuel Type Code (column 3)
Diesel (non-road gas-oil) fuelled CI engine		D
Dedicated Ethanol (ED95) fuelled CI engine		ED
Ethanol (E85) fuelled SI engine		E85
Petrol (E10) fuelled SI engine		P
LPG fuelled SI engine		Q
Natural gas/biomethane fuelled SI engine	Engine approved and calibrated for the H-range of gases	H
	Engine approved and calibrated for the L-range of gases	L
	Engine approved and calibrated for both the H-range and L-range of gases	HL

	Engine approved and calibrated for a specific gas composition in the H-range of gases and transformable to another specific gas in the H-range of gases by fine tuning of the engine fuelling	HT
	Engine approved and calibrated for a specific gas composition in the L-range of gases and transformable to another specific gas in the L-range of gases after fine tuning of the engine fuelling	LT
	Engine approved and calibrated for a specific gas composition in either the H-range or the L-range of gases and transformable to another specific gas in either the H-range or the L-range of gases by fine tuning of the engine fuelling	HLT
	Engine approved and calibrated for a specific liquefied natural gas / liquefied biomethane composition resulting in a λ -shift factor not differing by more than 3 percent the λ -shift factor of the G20 gas specified in Appendix 4 to this Regulation, and the ethane content of which does not exceed 1.5 percent	LN2
	Engine approved and calibrated for any other (than above) liquefied natural gas / liquefied biomethane composition.	LNG
Dual-fuel engines	for dual-fuel engines of Type 1A	1A#(*)
	for dual-fuel engines of Type 1B	1B#(*)
	for dual-fuel engines of Type 2A	2A#(*)
	for dual-fuel engines of Type 2B	2B#(*)
	for dual-fuel engines of Type 3B	3B#(*)
Engine solely fuelled on Hydrogen		T

(*) Replace ‘#’ with approved gas specification from Table 3.’

Annex 4 Paragraph 5.1.2., amend to read:

“5.1.2. Emissions of gaseous and particulate pollutants

The pollutants are represented by:

- (a) Oxides of nitrogen, NO_x;
- (b) Hydrocarbons, which are expressed as total hydrocarbons, HC (or THC);
- (c) Particulate matter, PM;
- (d) Particle number, PN_r;
- (e) Carbon monoxide, CO.

The measured values of gaseous and particulate matter pollutants exhausted by the engine refer to the brake-specific emissions in grams per kilowatt-hour (g/kWh), while for particulate number the measured values refers to the brake-specific emissions in number of particles per kilowatt-hour (#/kWh). Other system of units may be used with appropriate conversion.

The gaseous and particulate pollutants that shall be measured are those for which limit values are applicable to the engine sub-category being tested as set out in Appendix 2 to this Regulation.

Brake specific emissions shall be determined using Annex 11 for engines operated solely on hydrogen as specified in Appendix 4 paragraph A.4.4., and determined using Annex 5 for engines operated on all other fuels, fuel mixtures or emulsions.

The results determined as set out in paragraph 5.1 of this Regulation shall not exceed the applicable limit values.

The CO₂ emission values shall be measured and reported for all engine sub-categories as **where** required by paragraph 6.1.4. of this Regulation-

The mean emission of ammonia (NH₃) shall additionally be measured, as required in accordance with paragraph 3.4. of Annex 9, when the NO_x control measures that are part of the engine emission control system, include use of a reagent and shall not exceed the values set out in that paragraph.

The emissions shall be determined on the duty cycles (steady-state and/or transient), as described in paragraph 7 of this Annex. The measurement systems shall meet the calibration and performance checks set out in paragraph 8 of this Annex. with the measurement equipment described in paragraph 9 of this Annex. **For engines operated solely on hydrogen as specified in Appendix 4 paragraph A.4.4. the requirements set out in Annex 11 shall additionally apply.**

Other systems or analysers may be approved by the Type Approval Authority if it is found that they yield equivalent results in accordance with paragraph 5.1.3 of this Annex.”

Annex 4, Paragraph 8.1.9.2.3., amend to read:

“8.1.9.2.3. System requirements

A CO NDIR analyser shall have combined H₂O and CO₂ interference that is within ±2 per cent of the expected mean concentration of CO, **or 20ppm, whichever is larger.**”

Annex 4 Paragraph 9.4.10., amend to read:

9.4.10. Air-to-fuel ratio measurements

A Zirconia (ZrO₂) analyser may be used to measure air-to-fuel ratio in raw exhaust for continuous sampling. O₂ measurements with intake air or fuel flow measurements may be used to calculate exhaust flow rate according to Annex 5.

The sensor shall be mounted directly on the exhaust pipe where the exhaust gas temperature is high enough to eliminate water condensation.

The accuracy of the sensor with incorporated electronics shall be as follows:

- (a) ±3% of reading for $\lambda < 2$;
- (b) ±5% of reading for $2 \leq \lambda < 5$;
- (c) ±10% of reading for $5 \leq \lambda$.”

Annex 5 Title, amend to read:

“Annex 5

Method for data evaluation and calculation for engines other than those operated solely on hydrogen”

Annex 5 Paragraph 1, amend to read:

“1. General requirements

For engines other than those operated solely on hydrogen as specified in Appendix 4 paragraph A.4.4., calculation of emissions shall be performed according to either Appendix A.1 (mass based calculations) or Appendix A.2 (molar based calculations). Mixture between the two methods is not permitted. It shall not be required to perform the calculations according to both Appendix A.1 and Appendix A.2.

The specific requirements for particle number (PN) measurement, where applicable, are laid down in Appendix A.6.”

Annex 5 Appendix A.1 Paragraph A.1.1.6.3., amend to read:

“A.1.1.3. Dry-to-wet concentration conversion

If the emissions are measured on a dry basis, the measured concentration c_d on dry basis shall be converted to the concentration c_w on a wet basis by means of equation (A.5-3). **If water injection is used, Equations (A.5-4) and (A.5-7) are not applicable.**”

Annex 5 Appendix A.1 Paragraph A.1.1.6.3., amend to read:

“A.1.1.6.3. Air flow and air to fuel ratio measurement method

This involves exhaust mass calculation from the air flow and the air to fuel ratio. The instantaneous exhaust gas mass flow $q_{mew,i}$ [kg/s] shall be calculated by means of equation (A.5-17):

$$q_{mew,i} = q_{maw,i} \cdot \left(1 + \frac{1}{A/F_{st} \cdot \lambda_i} \right) \quad (\text{A.5-17})$$

with:

$$A/F_{st} = \frac{138.0 \cdot \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma \right)}{12.011 + 1.00794 \cdot \alpha + 15.9994 \cdot \varepsilon + 14.0067 \cdot \delta + 32.065 \cdot \gamma} \quad (\text{A.5-18})$$

$$\lambda_i = \frac{\left(100 - \frac{c_{COd} \cdot 10^{-4}}{2} - c_{HCw} \cdot 10^{-4} \right) + \left(\frac{\alpha}{4} \cdot \frac{1 - \frac{2 \cdot c_{COd} \cdot 10^{-4}}{3.5 \cdot c_{CO2d}} - \frac{\varepsilon}{2} - \frac{\delta}{2}}{1 + \frac{c_{COd} \cdot 10^{-4}}{3.5 \cdot c_{CO2d}}} - \frac{\varepsilon}{2} - \frac{\delta}{2} \right) \cdot (c_{CO2d} + c_{COd} \cdot 10^{-4})}{4.764 \cdot \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma \right) \cdot (c_{CO2d} + c_{COd} \cdot 10^{-4} + c_{HCw} \cdot 10^{-4})} \quad (\text{A.5-19})$$

where:

$q_{maw,i}$	= wet intake air mass flow rate [kg/s]
A/F_{st}	= stoichiometric air-to-fuel ratio [-]
λ_i	= instantaneous excess air ratio calculated by Equation (A.5-19) or measured by a lambda sensor [-]
c_{COd}	= concentration of CO in the raw exhaust gas on a dry basis [ppm]
c_{CO2d}	= concentration of CO ₂ in the raw exhaust gas on a dry basis [per cent]
c_{HCw}	= concentration of HC in the raw exhaust gas on a wet basis [ppm C1]
α	= molar hydrogen-to-carbon ratio [-]
δ	= molar nitrogen-to-carbon ratio [-]
ε	= molar oxygen-to-carbon ratio [-]
γ	= atomic sulphur-to-carbon ratio [-]"

Annex 6. insert new Paragraph to read:

“3.3. Type: Hydrogen

<i>Parameter¹</i>	<i>Unit</i>	<i>Limits</i>	<i>Test method</i>
Minimum mole fraction of Hydrogen ²	%	99,97	ISO 21087:2019
Total non-hydrogen gases (maximum)	µmol/mol	300	ISO 21087:2019
Maximum individual contaminant concentrations:			
Water	µmol/mol	5	ISO 21087:2019
Total hydrocarbons except methane ³	µmol/mol	2	ISO 21087:2019
Methane (CH ₄)	µmol/mol	100	ISO 21087:2019
Oxygen (O ₂)	µmol/mol	5	ISO 21087:2019
Helium (He)	µmol/mol	300	ISO 21087:2019
Nitrogen (N ₂)	µmol/mol	300	ISO 21087:2019
Argon (Ar)	µmol/mol	300	ISO 21087:2019
Carbon dioxide (CO ₂)	µmol/mol	2	ISO 21087:2019
Carbon monoxide (CO) ⁴	µmol/mol	0,2	ISO 21087:2019
Total sulphur compounds (s1 equivalent) ⁵	µmol/mol	0,004	ISO 21087:2019
Formaldehyde ⁴	µmol/mol	0,2	ISO 21087:2019
Formic acid ⁴	µmol/mol	0,2	ISO 21087:2019

Ammonia (NH ₃)	µmol/mol	0,1	ISO 21087:2019
Halogenated compounds (Halogen ion equivalent) ⁶	µmol/mol	0,05	ISO 21087:2019
Maximum particulate concentration ⁷	mg/kg	1	ISO 21087:2019

Notes

¹ 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.

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

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

⁴ The sum of measured CO, HCHO and HCOOH shall not exceed 0,2 µmol/mol.

⁵ As a minimum, total sulphur compounds include H₂S, COS, CS₂ and mercaptans, which are typically found in natural gas.

⁶ 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).

⁷Particulate 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 7 Appendix A.2 Paragraph A.2.1., amend to read:

"A.2.1. General

This Appendix defines the additional requirements and exceptions to enable emission testing of dual-fuel engines independent whether these emissions are solely exhaust emissions or also crankcase emissions added to the exhaust emissions according to paragraph 6.10. of Annex 4. In the case that no additional requirement or exception is listed, the requirements of this Regulation shall apply to dual-fuel engines in the same way as they apply to any other approved engine types or engine families.

Emission testing of a dual-fuel engine is complicated by the fact that the fuel used by the engine can vary between pure liquid fuel and a combination of mainly gaseous fuel with only a small amount of liquid fuel as an ignition source. The ratio between the fuels used by a dual-fuel engine can also change dynamically depending of the operating condition of the engine. As a result special precautions and restrictions are necessary to enable emission testing of these engines.

This Appendix is not applicable if one of the fuels used in a dual fuel engine is hydrogen."

Annex 10 Paragraph 2.4.6., amend to read:

"2.4.6. Fuel type

- (a) Diesel (non-road gas-oil);
- (b) Ethanol for dedicated compression ignition engines (ED95);
- (c) Petrol (E10);

- (d) Ethanol (E85);
- (e) Natural gas/Biomethane:
 - (i) Universal fuel — high calorific fuel (H-gas) and low calorific fuel (L-gas);
 - (ii) Restricted fuel — high calorific fuel (H-gas);
 - (iii) Restricted fuel — low calorific fuel (L-gas);
 - (iv) Fuel specific (LNG);
- (f) Liquid Petroleum Gas (LPG);
- (g) **Hydrogen.”**

Insert new Annex 11 to read:

“Annex 11

Technical requirements for engines operated solely on hydrogen

1. Scope

This Annex defines the additional requirements and exceptions to enable emission testing of engines operated solely on hydrogen as specified in Appendix 4 paragraph A.4.4. independent of whether these emissions are solely exhaust emissions or also crankcase emissions added to the exhaust emissions according to paragraph 6.10. of Annex 4. In the case that no additional requirement or exception is listed, the requirements of this Regulation shall apply to engines operated solely on hydrogen in the same way as they apply to any other approved engine types or engine families.

2. General requirements

Paragraph 5. of Annex 4 shall apply.

3. Test conditions

Paragraph 6. of Annex 4 shall apply.

4. Test procedures

Paragraph 7. of Annex 4 shall apply except as set out in paragraph 4.1

- 4.1 The total mass of each gaseous constituent shall be determined over the applicable test cycle using continuous sampling where the constituent's concentration is measured continuously from raw exhaust.**

5. Measurement procedures

Paragraph 8. of Annex 4 shall apply except as set out in paragraph 5.1.

- 5.1 The emissions measurement system shall comply with the calibration and performance checks at 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 location.**

6. Measurement equipment

Paragraph 9. of Annex 4 shall apply except as set out in paragraph 6.1 of this Annex.

- 6.1 The dilution procedure set out in paragraph 9.2. of Annex 4 shall not apply to gaseous emissions measurements.**

- 7. **Particle number emissions measurement**
Appendix A.1 to Annex 4 shall apply.
- 8. **Emissions Calculation**
The emissions calculation shall be performed according to Annex 5 Appendix A.1. (mass based calculations) except as set out in paragraphs 8.1. to 8.5. of this Annex.
- 8.1 **The measurement of gaseous emissions shall be conducted from raw exhaust gas according to Annex 5 Appendix A.1 paragraph A.1.1..**
- 8.2 **Dry-to-wet concentration conversion**
If the emissions are measured on a dry basis, Equation A.5-7 shall not be used for engines operated solely on hydrogen.
- 8.3 **Component specific factor u**
Equation A.5-11 shall not be used to calculate u values for engines operated solely on hydrogen. The values in Table A.11.1. may be used for the raw exhaust gas u and component densities. Alternatively, Equation A.5-12 may be used to calculate u values.

Table A.11.1.

Raw exhaust gas u and component densities (for emission concentration expressed in ppm) for engines operated solely on hydrogen

Fuel	ρ_e	Gas					
		NO_x	CO	HC	CO ₂	O ₂	CH ₄
		$\rho_{gas} [kg/m^3]$					
		2.053	1.250	^a	1.9636	1.4277	0.716
		u_{gas}^b					
Hydrogen	1.1872	0.001729	0.001053	0.000075	0.001654	0.001203	0.000603

^a depending on fuel

^b at $\lambda = 2$, dry air, 273 K, 101.3 kPa

- 8.4 **Mass flow rate of the exhaust gas**
- 8.4.1 **Equation A.5-15 or A.5-17 shall be used to calculate the mass flow rate of the exhaust gas.**
- 8.4.2 **Where Equation A.5-17 is used to calculate the mass flow rate of the exhaust, then Equation A.5-18 shall not be used to calculate A/F_{st}, and instead a value of 34.2282 shall be used.**

Equation A.5-19 shall not be used to calculate excess air ratio (λ_i) and instead λ_i shall be measured by a lambda sensor according to Annex 4 paragraph 9.4.10..
- 8.5 **Cycle specific CO₂ emissions**
Calculation of cycle specific CO₂ using equation A.5-63 is not required.
- 9. **Carbon Flow Check**
The carbon flow check set out in Annex 5 appendix A.5 shall not be required. The carbon flow check may be performed on a diesel fuelled engine prior to the installation of the engine operated solely on hydrogen.