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## Economic Commission for Europe

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**Working Party on Pollution and Energy**

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**Gaseous and Hydrogen Fuelled Vehicles –Hydrogen and Fuel Cell Vehicles – Subgroup Environment**

# Report summarizing the findings and recommendations in the different areas addressed by the informal group on Hydrogen Fuel Cell Vehicles – Sub Group Environment in support of the harmonization process

### Submitted by the Chair of the informal group on Hydrogen Fuel Cell Vehicles – Subgroup Environment *

The text reproduced below was prepared by the informal working group on Hydrogen Fuel Cell Vehicles – Subgroup Environment (HFCV-SGE) summarizing the outcome of discussions and recommendations available in the different regions in support of the harmonization process. This document is based on Informal document No. GRPE-61-03 distributed at the sixty-first session of the Working Party on Pollution and Energy (GRPE) (ECE/TRANS/WP.29/GRPE/61, paras. 38 and 39). The Working Party on Noise (GRB) considered this report at its February 2011 session and noted no reservations were experessed on this document.

* In accordance with the programme of work of the Inland Transport Committee for 2010–2014 (ECE/TRANS/208, para. 106 and ECE/TRANS/2010/8, programme activity 02.4), the World Forum will develop, harmonize and update Regulations in order to enhance the performance of vehicles. The present document is submitted in conformity with that mandate.

# Report summarizing the findings and recommendations in the different areas addressed by the informal group on Hydrogen Fuel Cell Vehicles – Sub Group Environment in support of the harmonization process

## Contents

# I. Introduction

1. The informal working group on Hydrogen Fuel Cell Vehicles (HFCV) has been operative for several years now. In June 2005, the World Forum for Harmonization of Vehicle Regulations (WP.29) and the Executive Committee (AC.3) of the 1998 Agreement agreed on a proposal submitted by Germany, Japan and the United States of America (USA) on how to manage the development process of a global technical regulation (gtr) on hydrogen powered vehicles. However, because of different circumstances, it was not until April 2007 that the group received a clear mandate and a roadmap to achieve its goal of establishing a gtr for this class of vehicles (ECE/TRANS/WP.29/AC.3/17). The following premises have to be kept in mind when defining the gtr:

(a) The aim is to attain levels of safety equivalent to those of conventional gasoline powered vehicles;

(b) The gtr shall be performance based; and

(c) The gtr shall not restrict future technologies.

2. Given that hydrogen powered vehicles are a still emerging technology, WP.29 and AC.3 agreed that input from researchers is a vital component of this effort. Based on a comparison of existing HFCV Regulations and standards with conventional vehicles, the following have to be investigated and considered:

(a) The main differences in safety and environmental aspects; and

(b) Which items need regulation and justification.

3. Under the agreed process, when AC.3 had developed and approved the action plan for the development of a gtr, two subgroups were formed to address the safety and the environment aspects of the gtr:

(a) The subgroup safety (HFCV-SGS), which is chaired by Japan and USA, reports to the Working Party on Passive Safety (GRSP), and

(b) The environmental subgroup (HFCV-SGE), which is chaired by the European Commission (Joint Research Centre), reports to GRPE.

4. In order to ensure communication between the subgroups and continuous engagement with WP.29 and AC.3, the designated project manager (Germany) coordinates and manages the various aspects of the work ensuring that the agreed action plan is properly implemented and that milestones and timelines are set and met throughout the development of the gtr.

5. The gtr will cover Fuel Cell (FC) and internal combustion engines (ICE), compressed gaseous hydrogen ($CGH_2$) and liquid hydrogen ($LH_2$).

6. The final goals of SGE are to investigate the possibility of harmonizing environmentally related requirements and to propose actions in those cases where harmonization may not be possible.

# II. Scope

7. The present document summarizes the SGE findings on the different areas addressed by the group and discusses whether it is adequate or not to support a harmonization process on the environmental and energetic aspects of HFCV.

# III. Methodology used

8. SGE has considered that a very practical solution may be the drafting of a technical report consisting of dedicated chapters for each of the SGE areas of interest and address the following points:

(a) Explanation and specification of the issue;

(b) Overview of the existing Regulations/standards and explanation of the possible existing links;

(c) Overview of the state of the art;

(d) Ongoing/finalized research activities stating references in both cases;

(e) Finalized projects and ongoing ones;

(f) If further research is still needed, then specify what and why;

(g) Assessment of harmonization:

(i) Is it needed?

(ii) Specify the harmonization.

(iii) Is it foreseeable? Why?

(iv) Reference list.

9. In particular, a common structure for the technical report (TR) was adopted and each chapter consisted of the following sections:

(a) Purpose/explanation: Introduce the item, including a technical description. Give a statement about the purpose (this section needs to bear a resemblance to the chapter "purpose" in each gtr).

(b) Application/scope: Address the type of vehicle: vehicle classes (Special Resolution No. 1), propulsion system (FC, hybrid, ICE, etc.) and fuels (mono, bi, flex, etc.).

(c) Definitions (if any): Include all necessary definitions either to understand the TR chapter or because controversial discussions in meetings showed the need for clarification.

(d) Regulations/Directives/standards: Give a brief and comprehensive overview on existing Regulations, Directives and standards and those under development. Their details are referenced in subparagraph (g) below.

(e) Research: Brief and comprehensive overview on the state of the art and ongoing research. Summarize the results and conclusions, as well as further research results needed (references should be listed in subparagraph (g) below). Also describe further research needed for the development of a Regulation.

(f) Assessment of harmonization: Include, based on the information from subparagraphs (a) to (e) above, a statement about harmonization requirements for a specific item under the 1998 Agreement. If harmonization seems not to be possible, suggest other solutions (e.g. an amendment of an existing Regulation).

(g) References.

10. Technical reports (see Chapter IV below) are an integral part of the document (chapters). Unfortunately, not all the areas are supported by the technical report.

# IV. Aspects addressed by the Sub Group Environment

11. The areas addressed within the field of competence of the SGE are aspects other than the ones addressed by SGS including energy and environmental considerations. The following is a list of the areas the group has addressed within its mandate:

(a) Pollutant emissions;

(b) Hydrogen and water emissions;

(c) Fuel consumption;

(d) Recycling;

(e) FC disposal/hazardous materials;

(f) Fuel quality;

(g) Engine power;

(h) Noise.

Item (h) (Chapter IX – Noise) was also considered by the Working Party on Noise (GRB).

12. One note of cautions needs to be indicated here, APU (Auxiliary Power Units) are not part of the gtr, as it should only address FC and ICE engines running both with $CGH_2$ and $LH_2$ and it has not been included in AC3's action plan.

13. It is also apparent that electromagnetic compatibility is a more safety related subject discussed in the Working Party on Lighting and Light-Signalling (GRE) for conventional vehicles as well as for electro-hybrid, pure electric and FC vehicles.

14. $H_2$/FC vehicles are emitting hydrogen (exhaust, purge, leakage). Hydrogen is mainly a safety concern and covered by SGS. Therefore, the issue of hydrogen emissions are not included in this report.

15. Water emissions might be a safety problem in the future (water freezing in winter). It is mainly a safety concern and minor an environmental issue. Some scientists consider water emissions from vehicles as a contribution to climate change. The water emissions from $H_2$-ICE and FC vehicles are much higher compared to conventional vehicles. The foreseeable number of HFCV in the short term will be low and, therefore, no Regulation is needed at this moment. Therefore, this technical report does not contain a chapter dedicated to water emissions.

16. Table 1 summarizes the environmental and other energetic aspects that are pertinent to the vehicles with different propulsion systems that Regulations could address.

Table 1
**Areas that Regulations could address for vehicles with different propulsion systems**

| | ***FC*** | ***Hybrid*** | | ***ICE*** |
|---|---|---|---|---|
| | *$H_2$* | *FC* | *ICE-$H_2$* | *Mono-fuel ($H_2$)*<br>*Bi-fuel*<br>*Blends*<br>*Dual fuel* |
| | ***Environmental & Energetic aspects*** | | | |
| **Fuel consumption** | x | x | x | x |
| **$CO_2$ emission** | | | | Bi-fuel, blends and dual fuel |
| **External electrical consumption** | | x | x | |
| **Pollutant emissions** | | | x ($NO_x$) | x |
| **$H_2$ and $H_2O$ emissions** | x | x | x | x |
| **Engine power (measurement procedures)** | x | x | x | x |
| **Maximum speed (measurement procedures)** | x | x | x | x |
| **Fuel quality (reference)** | x | x | x | x |
| **Recycling** | x | x | x | x |
| **Disposal (hazardous materials)** | x | x | x | x |
| **Noise** | x | x | x | x |

# V. Fuel consumption, external electrical consumption and maximum speed/engine power measurement

## A. Introduction

17. This chapter discusses hydrogen use in vehicles, the relevant measurement of energy and the performance of the vehicles and their components.

18. The following applications are considered (see the previously established matrix):

(a) FC system: stack, components;

(b) FC vehicles;

(c) Hybrid FC vehicles;

(d) Hybrid $H_2$-ICE vehicles.

19. For these applications, the following aspects are considered as appropriate:

(a) Fuel consumption;

(b) External electricity consumption of hybrid vehicles;

(c) Maximum speed.

20. The chapter aims at listing and analyzing the necessary elements for preparing harmonized standards/Regulations on this matter and ultimately gtrs, starting from existing normative documents and data from results of research.

21. The chapter addresses the following content:

(a) Overview of existing Regulation, standards and possible links;

(b) Overview of the state of the art;

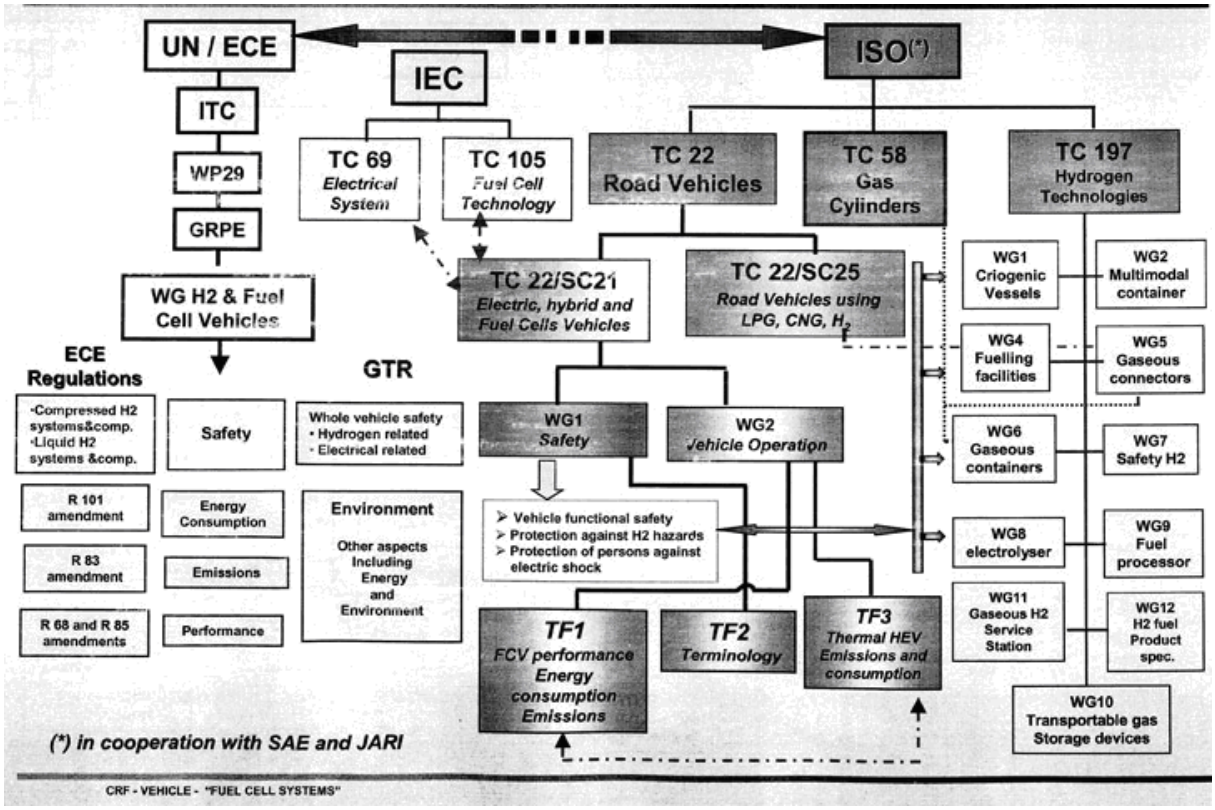
(c) Missing standardization topics;

(d) Ongoing/finalized research activities relevant to the matter;

(e) Further research possibly needed.

22. Figure 1 presents the international standards and Regulation bodies dealing with HFCV with their fields of action and links.

Figure 1
**International standard and Regulation bodies dealing with HFCV**



## B. Fuel consumption

### 1. Explanation and specification of the issue

23. Legislation requires the fuel consumption of passenger cars, Light Duty Vehicles (LDV) and motorcycles be tested on a roller test bench; however Heavy Duty Vehicles (HDV) are tested on an engine test bench, according to a test cycle or steady state test.

24. National/regional prescriptions provide specifications for test procedures and driving profile both for Regulation and for standard.

25. Fuel consumption is a fundamental issue for all vehicle categories, since it constitutes:

(a) A required element for certification/homologation;

(b) A parameter for possible definition of taxation;

(c) A common basis for comparing energy performance of different vehicle types and different power train solutions, and;

(d) A basis to determine the "well-to-wheel" energy effectiveness of the various solutions with respect to the primary energy source.

### 2. Measurement of $H_2$ fuel consumption

26. $H_2$ fuel consumption is defined as the mass amount of fuel used by a vehicle in a prescribed test cycle, expressed in g/km. Three basic methods exist for determining gaseous $H_2$ consumption in FC or ICE vehicles: (i) determination of fuel mass change in the container before and after test, (ii) determination of $H_2$ flow rate, and (iii) measuring the concentration of relevant species in the exhaust with subsequent back-calculation to fuel consumption. A compilation of available methods is given in Table 2.

27. Methods (i) and (ii) require a test vehicle to be supplied with hydrogen from an external, rather than the onboard tank. This requires dedicated live hydrogen feeds during testing and adjustment of various components in the test vehicle (with associated safety implications). These methods are also not suitable for vehicles with liquid hydrogen storage.

#### 2.1. Determination of mass change

28. Mass change is measured statically before and after the test, either by weighing the fuel tank with its $H_2$ contents, or by determining the equilibrium temperature and pressure before and after testing in a storage tank of known volume (PVT). The former method suffers from the disadvantage that the weight of $H_2$ is very small compared to that of the tank, resulting in low measurement accuracy. PVT measurement needs also less instrumentation and test personnel, and hence potentially offers higher repeatability and lab-to-lab reproducibility. It requires the use of a standardized equation for hydrogen density as a function of temperature and pressure.

#### 2.2. Flow rate measurement

29. This type of measurement allows determining the instantaneous flow rate of hydrogen. Different measurement principles exist: mechanical, optical, thermal, ultrasonic, Coriolis, etc. They all require an intervention to the fuel supply line which can introduce inaccuracies. Also dedicated signal treatment and analysis equipment is needed for all but the simplest flow meters.

### 2.3. Method based on emission measurement

30. At the present time, the United States Environmental Protection Agency (US-EPA) only accepts weighing, PVT and Coriolis mass flow according to SAE J2572 for the determination of $H_2$ gas fuel consumption in FC and FC hybrid vehicles. Adaptation of a method based on emission measurements to determine fuel consumption in conventional ICE vehicles receives increasing attention. It uses identical equipment as for emission measurement and works on the conservation of mass principle: what goes into the engine or FC must come out as exhaust components. This measurement of fuel consumption does not require direct contact with the fuel, which contributes to enhanced accuracy and simplicity.

31. For gasoline- and diesel-fuelled ICE vehicles the carbon-balance method is used. The total amount of carbon in the exhaust must have gone in as fuel (C-containing species in the exhaust from non-fuel sources are much lower than from the fuel and are hence neglected). The measured concentrations of C-containing species (CO, $CO_2$, THC) in the diluted exhaust volume that is collected during the test cycle are calculated into a fuel consumption for the particular test cycle.

32. For $H_2$ powered vehicles, a hydrogen-balance method (sometimes also called water-balance) is applied, which measures the hydrogen-containing compounds $H_2O$ (non-dispersive infra-red analyzer) and unburned $H_2$ (sector field mass spectroscopy) from the exhaust. This method requires some modifications to the testing procedures and constant volume sampling (CVS) system that are used for conventional ICE vehicles. These arise mainly from two factors:

(a) It must be ensured that all $H_2O$ present in the exhaust is effectively measured. This requires avoiding condensation on cold parts (e.g. vehicle exhaust pipe at cold starts, exhaust gas lines to monitor) and diffusion of $H_2O$ from the exhaust into the dilution pipe.

(b) $H_2O$ in the exhaust may originate from other sources than oxidation of the $H_2$ fuel, namely the humidity in the environment (motor intake) and in the dilution air, which must not only be known but also remain constant during the test cycle

33. When the above points are appropriately addressed, the fuel consumption determined by the hydrogen-balance method agrees with the results obtained by the three EPA-recognized methods [1]. The method works for FC as well as for ICE vehicles.

Table 2: Test measurement methods for $H_2$ powered vehicles

| *Test method* | *Description* | *Advantages* | *Disadvantages and issues* |
|---|---|---|---|
| Carbon balance method | Derived from exhaust gas, carbon content in fuel and exhaust gas are the same | Simultaneous measurement during exhaust gas test<br>Vehicle remodelling unnecessary | N/A for direct hydrogen FC vehicles |
| Flow method | Direct measurement using flow meter | Field-proven for ICE vehicles | Vehicle remodelling needed<br>Verification of flow meters |
| Electrical current method | Calculated from electrical current generated in the FC | Current easily measured from output wiring of the FC | Gas crossover and leak<br>Measurement of $H_2$ purge |
| Hydrogen balance method | Derived from exhaust gas, $H_2$content in fuel and exhaust gas are the same | Simultaneous measurement during exhaust gas test<br>Vehicle remodelling unnecessary | $H_2$ balance complicated<br>Difficult to measure |
| Oxygen balance method | Measuring the decline in $O_2$ concentration in exhaust gas | Simultaneous measurement during exhaust gas test<br>Vehicle remodelling unnecessary | Decline in $O_2$ is low<br>Accuracy of oxygen analyzer |
| Pressure method | Calculated from pressure/temperature change of fuel container | Easily to measurement<br>Support $H_2$ purge | Limited to a high pressure container to store fuel |
| Weight method | Calculated from weight change of fuel container | Direct and simple<br>Support $H_2$ purge | N/A for onboard measurement<br>Connecting to gas line |

Note: Adopted from HarmonHy WP4 Deliverable D4.1 — Industrial and societal needs — September 2006

## 3. Application and scope

### 3.1. Vehicle categories

34. In principle all vehicle categories defined in Special Resolution No. 1 [2] can be powered by $H_2$:

(a) Passenger car (category 1-1 vehicle);

(b) Bus (category 1-2 vehicle);

(c) Truck (category 2 vehicle);

(d) 2 or 3 wheeler (category 3 vehicles).

### 3.2. Propulsion systems

35. The following propulsion systems are considered:

(a) Pure FC vehicle;

(b) FC hybrid (FC and rechargeable electric storage) vehicle;

(c) FC systems and components: stack (inherent characterization);

(d) ICE-$H_2$ (ICE fuelled by hydrogen) hybrid vehicle.

## 4. Definitions

36. The definition of the different propulsion systems and components should be based on those given in standard, Regulation and TR, with appropriate harmonization.

## 5. Overview on existing Regulations and standards

### 5.1. Fuel Cell systems: stack and components

37. Standards existing or under development by:

(a) International Standard ISO/TC 197 on hydrogen technologies:

(i) ISO 14687 Hydrogen fuel-product specification;

(ii) ISO 14687 Hydrogen fuel-product specification — Part 2: Proton Exchange Membrane (PEM) FC application for road vehicles.

(b) International Electrotechnical Commission standard IEC/TC 105 on FC technologies:

(i) IEC 62282-1:2005 FC technologies — Part 1: Terminology (published);

(ii) IEC 62282-2:2004 FC technologies — Part 2: FC modules (published);

(iii) IEC/CDV 62282-3-2 FC technologies — Part 3-2: Stationary FC power plants — Test methods for the performance;

(iv) IEC/PWI 62282-4 FC technologies — Part 4: FC system for propulsion and auxiliary power unit.

(c) Society of Automotive Engineers (SAE) standards:

(i) SAE J2572 Recommended practice for measuring the fuel consumption and range of FC powered electric and hybrid electric vehicles using compressed gaseous hydrogen (revised October 2008);

(ii) SAE J 2615 Reference test procedures of FC systems for automotive application;

(iii) SAE J 2616 Performance test procedures for the fuel processor systems for automotive application;

(iv) SAE J 2617 Performance test procedures of PEM FC stack subsystem for automotive application;

(v) SAE J2719 Information report on the development of a hydrogen quality guideline for FC vehicles.

### 5.2. Pure Fuel Cell vehicles

38. Existing Regulations/standards:

(a) UN Regulation No. 101:

(i) Regulation No. 101 provides methods for consumption measurement of ICE vehicle, with carbon based fuel, battery electric vehicles and hybrid electric vehicles.

(ii) The structure is prepared to incorporate procedures for ICE vehicles fuelled with $H_2$ and FC vehicles pure or hybrid.

(iii) A draft proposal was developed by the consortium of companies (lead by the university RWTH-Aachen) acting on the European Union fuel cell vehicle technologies validation programme (FUEVA).

(b) Standard ISO 23828 FC road vehicles – Energy consumption measurement – Vehicles fuelled with compressed hydrogen, developed by ISO/TC22/SC21:

(i) This standard deals with the measuring methods of hydrogen and the procedures to test the vehicle.

(ii) The procedure prescribes the test on a chassis dynamometer.

(iii) The test consists of the vehicle preconditioning measurement over a reference driving schedule.

(iv) The running mode, including the dynamometer setting, is prescribed differently in the various Regions (Japan, Europe and USA).

(v) The prescribed methods are the following: (see annex to the standard).

a. Pressure method (normative);

b. Gravimetric method (normative);

c. Flow method (normative);

d. Current method (informative).

(vi) The three normative methods (pressure, gravimetric and flow) are considered equivalent, insofar they can produce results within a precision of ±1 per cent, according to the measurements done up to now.

(vii) They are left open according to the test tools of manufacturer and/or testing institution.

(c) Standards from ISO TC 197 on hydrogen technologies:

(i) ISO 14687:1999/Cor. 1:2001 Hydrogen fuel-product specification;

(ii) ISO/TS 14687-2:2008 Hydrogen fuel-product specification — Part 2: PEM FC application for road vehicles (under revision);

(iii) ISO/DIS 16110-2 Hydrogen generators using fuel processing technologies – Part 2: Procedure to determine efficiency.

### 5.3. Missing standards

39. Methods for consumption measurement of $H_2$ stored in liquid phase and in metal hydride tank.

40. Recommendation is given for development of these standards; insofar the technology is already in practical applications.

### 5.4. Hybrid Fuel Cell vehicles

41. The standard ISO 23828 is applicable to FC road vehicles in general, fuelled with compressed $H_2$, both pure FC and hybrids; the different procedures are put in evidence within the standard.

42. A missing standard, to be possibly developed, is related to FC hybrid vehicle – Energy consumption measurement – Externally chargeable vehicles (plug-in vehicles).

43. This standard should cover the procedure to measure both hydrogen and electricity for FC vehicle plug-in, similarly to the standard for ICE hybrid electric vehicles externally chargeable (PHEV).

### 5.5. ICE-$H_2$ hybrid vehicles

44. The prescription for fuel consumption measurement of ICE-$H_2$ hybrid vehicles could be derived from those for hybrid electric road vehicles (ISO 23274) non-externally chargeable, including the provisions for $H_2$ measurements as prescribed in ISO 23828.

### 6. Overview of the state of art

45. At the level of international standard, a standard ISO (TC 22/SC21) is presently under study, concerning the measurement of fuel consumption and emissions for externally rechargeable hybrid vehicles.

### 7. Ongoing finalized research

46. The European Union programme FUEVA (lead by the RWTH – Aachen) includes research related to test and validation of the procedures for hydrogen consumption measurement in vehicles.

### 8. Further research needed

47. Research related to procedure for $H_2$ consumption measurement of $H_2$ stored in liquid phase or in metal hydride tank.

### 9. Assessment of the harmonization

48. Regulations should be established consistently with common agreement on the topics.

49. Bases for Regulations could be standards (national or regional) existing or under development. The related content should be, therefore, harmonized on international basis.

## C. External electrical consumption

### 1. Explanation and specification of the issue

50. The external electrical consumption occurs for dual energy powered vehicles ($H_2$ and electricity).

51. This is the case of either FC hybrid (battery electric with FC electricity generator), or ICE-$H_2$ supplied electric hybrid.

### 2. Application and scope

#### 2.1. Vehicle categories

52. In principle all vehicle categories defined in Special Resolution No. 1 [2] can be involved:

(a) Passenger car (category 1-1 vehicle);

(b) Bus (category 1-2 vehicle);

(c) Truck (category 2 vehicle);

(d) 2 or 3 wheeler (category 3 vehicles).

#### 2.2. Propulsion systems

53. The following propulsion systems are considered:

(a) FC hybrid (FC and rechargeable electric storage) vehicle;

(b) ICE-$H_2$ (ICE powered by hydrogen) hybrid.

### 3. Overview on existing Regulations and standards

#### 3.1. Fuel Cell hybrid vehicles

54. For passenger cars and LDV, UN Regulation No. 101 provides methods for consumption measurement of ICE vehicles, with carbon based fuel, battery electric and hybrid electric vehicles. The structure could incorporate FC vehicles hybrid vehicles.

55. The external electricity consumption for hybrid vehicles can be derived from procedures included in the standard ISO under development related to hybrid-electric road vehicles externally chargeable (plug-in hybrid), which is presently under development (ISO/WD 23274-2).

## D. Maximum speed measurement – Engine power measurement

### 1. Explanation and specification of the issue

56. The measurement of the maximum speed for electric vehicles is subject to the consideration of the performance variation with the state of charge of the battery and with the thermal status of the electric motor.

57. For these reasons, standard prescriptions exist to consider, for vehicle characterization, the top speed and the maximum 30 minutes speed.

58. Similar provisions exist for the measurement of the engine power.

### 2. Application and scope

#### 2.1. Vehicle categories

59. In principle all vehicle categories defined in Special Resolution No. 1 [2] can be involved:

(a) Passenger car (category 1-1 vehicle);

(b) Bus (category 1-2 vehicle);

(c) Truck (category 2 vehicle);

(d) 2 or 3 wheeler (category 3 vehicles).

### 2.2. Propulsion systems

60. The following propulsion systems are considered:

(a) Pure FC vehicles;

(b) FC hybrid vehicles;

(c) ICE-$H_2$ hybrid vehicles.

### 3. Overview on existing Regulations and standards

61. A TR has been recently developed by ISO TC 22/SC 21, regarding FC vehicles maximum speed (pure and hybrid).

62. This TR, which is presently being issued, is based on the harmonization of the following documents:

(a) UN Regulation No. 68 – Amendment 1: Uniform provisions concerning the approval of power-driven vehicles including pure electric vehicles with regards to the measurement of the maximum speed;

(b) ISO 8715 Electric road vehicles – Road operating characteristics.

63. For ICE-$H_2$ hybrid vehicle, the maximum speed measurement could be done following the general provision of UN Regulation No. 68.

### 3.1. Engine power

64. UN Regulation No. 85 prescribes test for maximum power and maximum 30 minutes power for electric vehicles.

## E. Reference documents

65. Fuel quality and terminology are topics which should be considered for all applications.

66. The relevant documents are reported in the following Table 3.

Table 3

**Standards/Regulations existing, to be developed or to be adapted for application to hydrogen and Fuel Cell systems/vehicles**

| *Topic* | *$H_2$ Stack and components APU generating unit* | *FC (pure) vehicle* | *FC hybrid vehicle* | *ICE-$H_2$ hybrid vehicle* |
|---|---|---|---|---|
| **Fuel consumption** | **IEC 62282-2 (2004)**<br>**SAE 2617**<br>**ISO 14687** Hydrogen fuel-product specification – Part 2: PEM<br>**ISO 13985** Liquid hydrogen land vehicles fuel tanks<br>**ISO/TS 16111 (2006)** Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride | **ISO 23828** FC road vehicles – Hydrogen consumption measurement<br>-Vehicles fuelled with compressed $H_2$<br>To be developed: -Vehicles fuelled with liquid $H_2$<br>To be developed: -Vehicles fuelled with $H_2$ absorbed in metal hydride<br>**Regulation No. 101** (to be adapted for FC vehicles inclusion) | To be developed: FC hybrid vehicle – Energy consumption measurement – Externally chargeable vehicles | **Regulation No. 101** (Applicable for fuel consumption to ICE hybrid, to adapted for $H_2$ use) |
| **External Electrical Consumption** | - | - | **ISO/WD 23274-2** Hybrid-electric road vehicles – Exhaust emissions and fuel consumption measurements – Part 2: Externally chargeable vehicles(under development to be assumed as guideline) | **ISO 23274** Hybrid-electric road vehicles exhaust emission and fuel consumption measurements non externally chargeable vehicle (to be adapted for $H_2$ use)<br>**Regulation No. 101** (to be adapted). |

| *Topic* | | *$H_2$ Stack and components APU generating unit* | *FC (pure) vehicle* | *FC hybrid vehicle* | *ICE-$H_2$ hybrid vehicle* |
|---|---|---|---|---|---|
| **Performance** | **Maximum speed** | - | **ISO** TR FC vehicles<br>Maximum speed (being issued)<br>**ISO 8715** Electric road vehicles – Road operating characteristics<br>**Regulation No. 68** – Amendment 1: Uniform provisions concerning the approval of power-driven vehicles including pure electric vehicles with regards to the measurement of the maximum speed | | **Regulation No. 68** Uniform provisions concerning the approval of power-driven vehicles with regard to the measurements of the maximum speed |
| | **Engine power** | **IEC/CDV 62282-3-2** Stationary FC power plants-test method for the performance | **Regulation No. 85**<br>Annex 6 Amend: 2, 8, 4<br>Maximum power and maximum 30 minutes power for electric vehicles | To be developed (as well as for ICE hybrid electric) | To be developed (as well as for ICE hybrid electric) |
| **Fuel quality (reference)** | | **ISO 14687 (2008)** Hydrogen fuel-product specification | **ISO 14687** | **ISO 14687** | **ISO 14687** |
| **Terminology (reference)** | | US FC Council<br>FC Glossary<br>**IEC/TC 62282-1 (2005)** Terminology | **ISO** Draft TR on SC 21 Vocabulary<br>**ISO 8713** | | - |

# VI. Hydrogen ($H_2$) reference fuel and reference gases

## A. Introduction

67. This chapter addresses the need and feasibility for a hydrogen reference fuel and for other reference gases in the context of the establishment of harmonized Regulations for $H_2$ powered vehicles.

68. Discussions within the SGE [3] identified that reference gases could potentially be relevant and useful in three areas covered by Regulations: fuel quality, emissions and fuel consumption. The question was raised to what extent these different applications resulted in different requirements for a reference gas.

## B. Purpose and resulting requirements for reference gases in support of Regulations for $H_2$ vehicles

### 1. Checking purity (quality) of hydrogen for use as a propulsion fuel

69. $H_2$ purity (quality) is more of an issue in FC vehicles than in $H_2$-ICE vehicles. At present, only PEM type FC are considered for propulsion applications in passenger cars and light vehicles. Impurities in the reactants (both in hydrogen at the anode, but also in air/oxygen at the cathode) affect the catalyst performance and hence the electrochemical reactions as well as the membrane properties. Impurities in the $H_2$ fuel depend primarily on the $H_2$ production method, although the storage method and medium may also play a part. The most important contaminants in $H_2$ produced by natural gas reforming (the most commonly used production method) are CO, sulphur containing compounds ($H_2S$ in particular), nitrogen containing compounds ($NH_3$), and unsaturated and aromatic hydrocarbons.

70. If $H_2$ is not only used for propulsion but it is also used in APU[1] (for which a different type of FC may be used), other purity requirements will prevail. However, because only one kind of $CH_2$ is expected to be stored on board, the most stringent requirements (corresponding to PEM FC for propulsion) will apply.

71. In the context of Regulations, such a reference fuel is not needed for vehicle certification per se, but for reducing the impact of fuel-dependent factors on vehicle performance aspects covered by the Regulation, such as emissions and fuel consumption. When the $H_2$ used during the vehicle certification test complies with the fuel quality specifications the variability in test results is considerable decreased, allowing more accurate verification of true performance.

72. In the context of Regulations, a $H_2$ reference fuel should be globally recognized (which would be achieved by a certification according to international standards, such as ISO Guide 34 [4] and corresponding equivalence studies).

### 2. Monitoring of vehicle emissions (see Chapters VII and VIII)

73. Vehicle certification requires measurement of tail-pipe emissions during a test cycle. This necessitates the use of calibrated emission monitoring equipment. Measurement of

[1] APU (auxiliary power units) are not in the scope of the SGE and, therefore, it is not addressed in this document

tail-pipe emissions from fossil fuelled ICE vehicles uses a constant volume sampling (CVS) system that compensates for load variations during the test cycle by maintaining a constant total flow rate of vehicle exhaust plus dilution air. The diluted exhaust is collected and the concentrations of emission products CO, $CO_2$, HC and $NO_x$ are determined (g/km).

74. When using $H_2$ as a fuel, either in FC or ICE, the emissions are much lower than those from conventional ICE vehicles or simply there are not present (i.e. FC except $H_2O$). The major emission product from $H_2$ powered vehicles is water vapour. The associated humidity may affect the accuracy of measurement of pollutants (e.g. non-dispersive infra-red analysers for CO and $CO_2$ are known to be sensitive to $H_2O$).

75. Emissions from $H_2$ vehicles powered by FC are different from those with ICE, because different purity requirements and hence impurity contents of the fuel. For ICE additional emissions are $NO_x$ from the combustion of the air-fuel mixture as well as carbon compounds from engine lubrication (HC, CO, $CO_2$).

76. For the calibration of the different types of emission monitors, reference gases are needed. Because of the lower emission levels to be measured these must have a higher purity than those for calibration of emission measurement equipment for conventional ICE vehicles. This also applies for the gases used as "zero-gas" in analysers based on differential measurement (e.g. non-dispersive infra-red (NDIR) analyser). When instead of total emissions over the test cycle ("bag" measurement) emissions are measured instantaneously on a second-by-second basis ("modal" measurement) (e.g. to assess performance of catalyst and engine system at a particular time in the cycle), the instantaneous exhaust mass flow rate must be determined. This represents a serious technical challenge. In this case also more stringent requirements apply for the emission monitors (e.g. response time).

### 3. Measurement of fuel consumption (see Chapter V)

77. Vehicle certification requires measurement of fuel consumption during a test cycle. For $H_2$ powered vehicles a number of methods have been identified and are under investigation. Each of these methods has disadvantages. The need for harmonization of fuel consumption measurement procedures in the context of Regulations is addressed in one of the previous chapters of this technical report. Therefore, the present chapter focuses on the potential role that reference gases could play in this respect.

78. In the context of Regulations, the use of a single universally accepted method definitely provides added value. Moreover, for reasons of economy, efficiency and comparability with certification of non $H_2$ powered vehicles, the use of an "elemental balance" method as for conventional ICE vehicles (carbon-balance) that does not require vehicle modifications, presents huge advantages.

79. This is achieved by using the so-called hydrogen-balance method which measures the hydrogen-containing compounds $H_2O$ (NDIR analyser) and unburned $H_2$ (sector field mass spectroscopy) from the FC or ICE exhaust. The method requires some modifications to the testing procedures and system that are used for conventional ICE vehicles. Because they are based on the same measurement principle, fuel consumption and emission monitoring have similar requirements for equipment calibration. Extra requirements originate from the use of additional $H_2O$ and $H_2$ analysers. Because the expected concentration of $H_2$ in the exhaust is very low, the $H_2$ sensor can be calibrated using a readily available appropriate reference gas. However, calibration of the $H_2O$ NDIR analyser calibration requires a dedicated humidification system.

80. For FC vehicles an oxygen-balance method based on measurement of the oxygen concentration in the exhaust has also been proposed. The method is not directly based on mass conservation, but on the measurement of a relatively small decrease in oxygen

concentration between the inlet and outlet of the FC stack, which requires a high accuracy of the oxygen analyser.

81. For FC vehicles, measurement of electrical current generated by the FC can also be translated into $H_2$ consumption. However, internal losses from hydrogen leaks and cross-over, while definitely contributing to consumption, are not captured by such a measurement.

## C. Requirements

82. The implementation in the context of Regulations of harmonized fuel quality, emission and fuel consumption measurements translates into the following needs for further research and development, and technical requirements for reference gases:

### 1. Fuel quality for Fuel Cell vehicles

83. Issue: tolerance level of impurities to limit degradation of performance to acceptable level.

84. Need: pre-normative research into:

(a) Test methods for quantifying performance under dynamic conditions reproducing typical driving cycles;

(b) Reliable detection and quantification of impurities in gaseous $H_2$, including validation of high-pressure sampling methods; and

(c) Understanding and quantifying the effect of impurities (single as well as multiconstituent) on FC performance and determination of acceptable level of impurities.

85. Implications for feasibility of reference fuel:

(a) Identification of type and amount of impurities in hydrogen carrier gas; and

(b) Investigate stability and conservation/storage period.

### 2. Emission monitoring for Fuel Cell and Internal Combustion Engine vehicles

86. Issue: measurement challenges related to high water vapour and low emissions of other pollutants.

87. Need: pre-normative research into:

(a) Low-cost and reliable analysis methods and emission monitors; and

(b) Calibration of sensors.

88. Implications for feasibility of reference gases:

Calibration of emission analyzers at low detection ranges requires higher purity levels in the reference gas than for conventional ICE vehicles.

### 3. Fuel consumption (Fuel Cell and Internal Combustion Engines)

89. Issue: same as for emission monitoring.

90. Need: additional pre-normative research into

(a) Further validation of hydrogen-balance approach and equations for different vehicle types; and

(b) Cost-effective calibration method for $H_2O$ detectors.

91. Implications for feasibility of reference gases:

(a) Need for dedicated reference gas or gases allowing calibration of $H_2O$ detectors over wide $H_2O$ range; and

(b) For calibration of $H_2$ detectors: none (e.g. 0.5 per cent $H_2$ in $N_2$).

### D. Conclusion and recommendation

92. International collaboration in pre-normative research as well as close interaction with international standardization bodies aimed at harmonizing of test requirements, of test methods and of test equipment performance for fuel quality, emission and fuel consumption measurement can greatly contribute to the establishment of Regulations. This should also include the development and certification of a reference fuel and gases for these three applications according to ISO standards which would ensure their global recognition.

## VII. Pollutant emissions of hydrogen ($H_2$) fuelled vehicles

### A. Explanation and specification of the issue

93. In legislation the emissions of gaseous pollutants carbon monoxide (CO), hydro carbons (HC), oxides of nitrogen ($NO_x$) and the emissions of particulate matter (PM) are limited in g/km or g/kWh. LDV and motorcycles are tested on a roller test bench, engines of HDV (and comparable engines of other vehicles) are tested on an engine test bench, driving a transient test cycle or steady state test. This test procedure including the test cycle is different for vehicle categories and in national legislation. The concentrations of the emissions are measured and then calculated in g/km or g/kWh.

94. Evaporative and low temperature emissions (requirements in UN Regulation No. 83 [5]) are only related to gasoline engines and not relevant for $H_2$ as fuel.

95. FC vehicles don't emit one of the above mentioned pollutants, if $H_2$ is used directly. A FC can also be fuelled with $H_2$, that was reformed (on vehicle) from a different base fuel ($C_xH_y$). In case of a reformer (on vehicle), pollutant emissions are relevant, depending on the base fuel and the reforming process.

96. Theoretically the only component emitted by ICE fuelled with $H_2$ is $NO_x$. The level of $NO_x$ emissions is depending on the air-$H_2$ ratio, respectively exhaust gas temperature and the layout of the aftertreatment system (e.g. catalyst). The use of $H_2$ is possible in positive- and compression ignition engines.

97. In cases where $H_2$ is used together with other fuels ($H_2$-bi-fuel, $H_2$-flex-fuel, $H_2$-dual-fuel), all the other pollutants become relevant. $H_2$-bi-fuel systems (BMW) or hydrogen mixtures (e.g. with Compressed Natural Gas (CNG), [6]) are interesting solutions during the introduction phase of $H_2$ vehicles, until the infrastructure with $H_2$ fuelling stations is more developed. For the time being, BMW and Mazda (LDV) and MAN (buses, HDV) are the only manufacturers producing vehicles with ICE using $H_2$ as fuel. It can be assumed that the level of the pollutant emissions of the three above mentioned vehicles are below the mandatory limit values.

98. The level of $NO_x$ emissions of $H_2$ fuelled ICE is an averaged between 2-30 per cent of the existing mandatory limits of $NO_x$ in Europe and USA [7]. The level of the other pollutants is nearly zero. Theoretically they should be equal to zero, but practically the small amount of emissions are caused by lube oil losses, or in case of $H_2$-bi-fuel concepts, because the injection of the other fuel is pre-activated during $H_2$ fuel mode.

99. $H_2$ can be stored as a liquid ($LH_2$) or as a compressed gaseous ($CGH_2$). The influence on pollutant emissions by the type of storage is not relevant. The only need is to define different reference $H_2$ fuel and reference $H_2$ gas for emission testing.

100. Engines and FC also emit non-regulated components, e.g. ammonia, hydrocyanic acid, organic amine, aldehyde, sulfur dioxide. Today there is no evidence that ICE and FC are emitting any non-regulated component that causes serious environmental or health problems.

## B. Application and scope

### 1. Vehicle categories

101. In principle all vehicle categories defined in Special Resolution No. 1 [1] can be powered by $H_2$:

(a) Passenger car (category 1-1 vehicle);

(b) Bus (category 1-2 vehicle);

(c) Truck (category 2 vehicle);

(d) 2 or 3 wheeler (category 3 vehicle).

102. The use of $H_2$ is also possible in agricultural and forestry tractors [8] and Non Road Mobile Machinery (NRMM) [9]. Today there is not much interest in marketing such solutions. These vehicle categories therefore will not be further covered by this chapter – out of scope.

### 2. Propulsion systems

103. ICE, positive or compression ignition, or in combination with an electric engine (hybrid electric vehicle).

104. Also possible, but not developed for the time being, is a combination of ICE and FC (hybrid vehicle) – out of scope.

### 3. Reformer (on vehicle)

105. For the time being, it's improbable that a vehicle in serial production will be equipped with reformer technology. A procedure to measure the pollutant emissions from the reformer process is not defined. Therefore, this technology will not be further covered by this report – out of scope.

### 4. Fuel types

106. The following fuel types are considered:

(a) $H_2$ fuel;

(b) $H_2$-bi-fuel with gasoline, diesel, CNG or Liquefied Petroleum Gas (LPG);

(c) $H_2$ blend/mixture (flex-fuel/dual-fuel) with gasoline, diesel, CNG or LPG;

(d) $H_2$ reformed (on board) from gasoline, diesel, LPG, CNG, methanol – out of scope (see paragraph 105 above).

## C. Definitions

107. "*Calculation method*" means the calculation method of mass emissions of pollutants, e.g. defined in Appendix 8 of UN Regulation No. 83 [5].

108. "*Reference fuel/Reference gas*" means the definition of specifications of $LH_2$ or $CGH_2$ taken for the emission tests.

109. "*$H_2$ fuel vehicle*" means a vehicle that primarily runs on $H_2$ but may also have a petrol system for emergency purposes or starting only, where the petrol tank does not contain more than 15 litres of petrol.[2]

110. "*$H_2$-bi-fuel vehicle*" means a vehicle that can run part-time on $H_2$ and also part time either on gasoline, diesel, LPG or CNG

111. "*Flex-fuel vehicle*" means a vehicle with one fuel storage system that can run on different mixtures of two or more fuels [10].

112. "*Dual-fuel vehicle*" means a vehicle with two storage systems for different fuels, where the both fuels are mixed either in the intake system or during injection into the combustion chamber.

113. "*Hybrid vehicle*" means a vehicle with at least two different energy converters and two different energy storage systems (on vehicle) for the purpose of vehicle propulsion [5], [10].[3]

## D. Overview on existing Regulations and standards

### 1. Passenger cars

114. The legislation concerning pollutant emissions from category 1-1 vehicles is not harmonized. Different test cycles, measurement methods, reference fuels and limit values are applicable. None of the existing Regulations includes test methods and requirements for $H_2$ vehicles (ICE). The current European Euro 5/6 Regulation [10] already mentions $H_2$ as fuel, but specific test procedures for $H_2$ will be defined at a later stage.

115. A gtr project to develop a Worldwide harmonized Light vehicles Test Procedure (WLTP) is mandated by AC.3 [11]. The documentation in [11] includes a comprehensive overview of the existing national legislation on pollutant emissions. Currently the emission measurement of $H_2$ vehicles is not included in the draft roadmap.

116. UN Regulation No. 83 [5] contains requirements on the pollutant emissions for mono-fuel and bi-fuel vehicles (gasoline, diesel, CNG, LPG). UN Regulation No. 83 will soon be amended to be in line with the European Euro 5/6 requirements [10], including an approach for flex-fuel (gasoline and ethanol).

### 2. Heavy Duty Vehicles

117. With gtr No. 4 [12] on the Worldwide harmonized Heavy Duty Certification procedure (WHDC), a worldwide harmonized emission test procedure for HDV is established (category 1-2 and category 2 vehicles). The appendix to gtr No. 4 (TR) [12] includes an overview about the existing national emission legislation for HDV and relevant

[2] This definition is in line with the definition of "*mono-fuel gas vehicle*" in [10].
[3] [5] and [10] also contains a definition for a "*hybrid electric vehicle*".

standards. Harmonized performance requirements are not included in gtr No. 4 for the time being. $H_2$ vehicles are not covered by gtr No. 4.

### 3. 2/3 wheelers

118. With gtr No. 2 [13], a worldwide harmonized emission test procedure for 2-wheeled motorcycles is established. The appendix to gtr No. 2 (TR) [13] includes an overview about the existing national emission legislation for 2-whelers and relevant standards. Performance requirements (limit values) are not included at the moment, but AC.3 mandated the Worldwide harmonized Motorcycle emission Test Cycle (WMTC) informal group to develop a proposal for the harmonization of limit values. $H_2$ vehicles are not covered by gtr No. 2.

119. The legislation concerning pollutant emissions from mopeds (< 50 $cm^3$, < 50 km/h) and 3-wheelers is not harmonized. Different test cycles, measurement methods, reference fuels and limit values are applicable. None of the existing Regulations includes test methods and requirements for $H_2$ vehicles (ICE).

### 4. Reference fuel and reference gas

120. The international standards ISO 14687 [14] and SAE J2719 [15] defines specifications for $H_2$ as fuel. On this basis, a reference fuel and reference gas can be defined for the purpose of $H_2$ consumption measurement as well as for the purpose of measurement of $NO_x$ emissions. The issue of reference fuel and reference gas is described in more detail in Chapter VI above.

121. A specification for $H_2$ as either flex-fuel or dual-fuel does not exist for the time being.

## E. Work to be done and state of research

122. A calculation method for $NO_x$ emissions from ICE fuelled wit $H_2$ needs to be developed.

123. Concerning $H_2$-flex-fuel and $H_2$-dual-fuel, experience and emission test data are required for the development of a regulatory approach. This includes work on specification of reference fuel(s) and the definition of a calculation method (emissions).

## F. Regulatory approach

### 1. Need for Regulation

124. $NO_x$ emissions of vehicles with ICE using $H_2$ fuel and pollutant emissions of $H_2$-bi-fuel vehicles should be regulated. The level of limit values will be decided by national regulatory decision processes, but probably the limit values will be the same as for conventional vehicles.

### 2. Open issues and need for specification

125. The following issues are still opened:

(a) Definition of $H_2$ reference fuel and gas, if possible accepted worldwide and applicable for all vehicle categories;

(b) Definition of the regulatory approaches (e.g. worst case, measurement with both fuels) for $H_2$-bi-fuel vehicles (and $H_2$-flex-fuel, $H_2$-dual-fuel);

(c) If needed, a definition for a $H_2$-bi-fuel vehicle, to separate clear from $H_2$-flex-fuel or $H_2$-dual-fuel.

### 3. Assessment of harmonization – Development of a gtr

126. In the case of HDV and 2-wheeled motorcycles a worldwide harmonization is possible, because gtrs for the measurement of pollutant emissions already exists. This is not the case for LDV, and the extra development of a worldwide harmonized test cycle and measurement procedure especial for LDV using $H_2$ in ICE is not efficient and feasible.

127. In the case of motorcycles or HDV with ICE using $H_2$ which are ready for marketing, an amendment of gtr No. 2 (WMTC) or gtr No. 4 (WHDC) can easily be developed. Such amendments of the existing gtrs only need the definition of the reference fuel, the calculation method for $NO_x$ ($H_2$ fuel) and the definition of the $H_2$-bi-fuel approach. This can be considered as a midterm activity for both vehicle categories.

128. For LDV, it should be considered to introduce a reference fuel (gas), a calculation method for the $NO_x$ emissions and the definition of the $H_2$-bi-fuel approach with the WLTP gtr [11]. In the meantime, existing national legislation or UN Regulation No. 83 can be amended.

129. As a conclusion, it is not proposed to develop a special gtr for the measurement and limitation of pollutant emissions of $H_2$ vehicles.

# VIII. Carbon dioxide ($CO_2$) emissions of hydrogen ($H_2$) fuelled vehicles

## A. Explanation and specification of the issue

130. In legislation (approval and certification of vehicles) the emissions of $CO_2$ of vehicles are not limited, but in some cases the emissions have to be measured and calculated and are recorded in the test report in g/km. LDV and motorcycles are tested on a roller test bench, driving a transient test cycle. This test procedure including the test cycle is different for vehicle categories and in national legislation. The concentrations of the emissions are measured and then the $CO_2$ emissions are calculated in g/km.

131. In legislation (approval and certification of vehicles) the declared emissions of $CO_2$ are the end-of-pipe emissions. The well-to-wheel emissions of $CO_2$ are disregarded in the test reports. The issue of well-to-wheel emissions is currently considered by the Environmentally Friendly Vehicles (EFV) informal group of the World Forum WP.29 [16].

132. FC vehicles don't emit $CO_2$ if $H_2$ is used directly. A FC can also be fuelled with $H_2$, that was reformed (on vehicle) from a different base fuel ($C_xH_y$). In case of a reformer (on vehicle), $CO_2$ emissions are relevant, depending on the base fuel and the reforming process.

133. ICE fuelled with $H_2$ don't emit $CO_2$.

134. In cases where $H_2$ is used together with other fuels ($H_2$-bi-fuel, $H_2$-flex-fuel, $H_2$-dual-fuel) $CO_2$ emissions become relevant. $H_2$-bi-fuel systems (BMW) or hydrogen mixtures (e.g. with CNG, [6]) are interesting solutions during the introduction phase of $H_2$ vehicles, until the infrastructure with $H_2$ fuelling stations is more developed. For the time being BMW is the only manufacturer producing vehicles with ICE operating as $H_2$-bi-fuel.

135. The level of the $CO_2$ emissions in $H_2$ mode of a $H_2$-bi-fuel vehicle is very low. In the case of the BMW it is 5 g/km. Theoretically it should be equal to zero, but practically the small amount of emissions are caused by lube oil losses, or in case of $H_2$-bi-fuel concepts,

because the venting of the active carbon filter (evaporative emissions) goes into the intake system of the ICE.

136. $H_2$ can be stored liquid ($LH_2$) or compressed gaseous ($CGH_2$). The influence on $CO_2$ emissions by the type of storage is not relevant. The only need is to define different reference $H_2$ fuel and reference $H_2$ gas for emission testing.

## B. Application and scope

### 1. Vehicle categories

137. In principle all vehicle categories defined in Special Resolution No. 1 [1] can be powered by $H_2$:

(a) Passenger car (category 1-1 vehicle);

(b) Bus (category 1-2 vehicle);

(c) Truck (category 2 vehicle);

(d) 2 or 3 wheeler (category 3 vehicle).

138. The measurement of the $CO_2$ emissions in today's legislation is not required for Heavy Duty Hybrids (HDH), agricultural and forestry tractors and NRMM. Therefore, these vehicle categories will not be further covered by this report – out of scope.

### 2. Propulsion systems

139. ICE, positive or compression ignition, or in combination with an electric engine (hybrid electric vehicle).

140. Also possible, but not developed for the time being, is a combination of ICE and FC (hybrid vehicle) – out of scope.

### 3. Reformer (on vehicle)

141. For the time being, it's improbable that a vehicle in serial production will be equipped with reformer technology. A procedure to measure the $CO_2$ emissions from the reformer process is not defined. Therefore, this technology will not be further covered by this report – out of scope.

### 4. Fuel types

142. The following fuel types are considered:

(a) $H_2$ fuel – out of scope, because no $CO_2$ emissions;

(b) $H_2$-bi-fuel with gasoline, diesel, CNG or LPG;

(c) $H_2$ blend/mixture (flex-fuel/dual-fuel) with gasoline, diesel, CNG or LPG;

(d) $H_2$ reformed (on board) from gasoline, diesel, LPG, CNG, methanol – out of scope (see paragraph 141 above).

## C. Definitions

143. "*Calculation method*" means the calculation method of mass emissions of $CO_2$, e.g. defined in Annex 6 to UN Regulation No. 101 [17].

144. "*Reference fuel/Reference gas*" means the definition of specifications of the fuel or gas taken for the emission tests.

145. "*$H_2$ fuel vehicle*" means a vehicle that primarily runs on $H_2$ but may also have a petrol system for emergency purposes or starting only, where the petrol tank does not contain more than 15 litres of petrol.[2]

146. "*$H_2$-bi-fuel vehicle*" means a vehicle that can run part-time on $H_2$ and also part time either on gasoline, diesel, LPG or CNG.

147. "*Flex-fuel vehicle*" means a vehicle with one fuel storage system that can run on different mixtures of two or more fuels [10].

148. "*Dual-fuel vehicle*" – means a vehicle with two storage systems for different fuels, where the both fuels are mixed either in the intake system or during injection into the combustion chamber.

149. "*Hybrid vehicle*" means a vehicle with at least two different energy converters and two different energy storage systems (on vehicle) for the purpose of vehicle propulsion [17], [10].[4]

## D. Overview on existing Regulations and standards

### 1. Passenger cars

150. The legislation concerning $CO_2$ emissions from category 1-1 vehicles is not harmonized. Different test cycles, measurement methods and reference fuels are applicable. None of the existing Regulations includes test methods and requirements for $H_2$ vehicles (ICE). The current European Euro 5/6 Regulation [10] already mentions $H_2$ as fuel, but specific test procedures for $H_2$ will be defined at a later stage.

151. A (possible) gtr project to develop a WLTP is under preparation [11]. The documentation in [11] includes a comprehensive overview of the existing national legislation on $CO_2$ emissions. Currently the emission measurement of $H_2$ vehicles is not included in the draft roadmap.

152. UN Regulation No. 101 [17] contains requirements regarding on $CO_2$ emissions for mono-fuel and bi-fuel vehicles (gasoline, diesel, CNG, LPG). UN Regulation No. 101 will soon be amended to be in line with the European Euro 5/6 requirements [13], including an approach for flex-fuel (gasoline and ethanol).

### 2. 2/3 wheelers

153. With gtr No. 2 [13], a worldwide harmonized emission test procedure for 2-wheeled motorcycles is established, including the measurement of $CO_2$ emissions. The appendix to gtr No. 2 (TR) [13] includes an overview about the existing national emission legislation for 2 wheelers and relevant standards. $H_2$ vehicles are not covered by gtr No.2.

154. The legislation concerning exhaust emissions from mopeds (< 50 $cm^3$, < 50 km/h) and 3-wheelers is not harmonized. Different test cycles, measurement methods, reference fuels and limit values are applicable. None of the existing Regulations includes test methods and requirements for $H_2$ vehicles (ICE).

[4] [10] and [17] also contains a definition for a "*hybrid electric vehicle*".

### 3. Reference fuel and reference gas

155. The issue of reference fuel and reference gas is described in more detail in Chapter VI above. In case of $H_2$ fuel-vehicles the introduction of a reference fuel/gas is not necessary, because the $CO_2$ emissions are zero.

156. A specification for $H_2$ either as flex-fuel or dual-fuel does not exist for the time being.

## E. Work to be done and state of research

157. Concerning $H_2$-flex-fuel and $H_2$-dual-fuel, experience and emission test data are required for the development of a measurement procedure, including work on specification of reference fuel (s) and the definition of a calculation method (emissions).

## F. Regulatory approach

### 1. Need for Regulation

158. The measurement of $CO_2$ emissions of $H_2$-bi-fuel vehicles should be regulated. The regulatory approach will be decided by national regulatory decision processes, but probably it will be the same as for other bi-fuel vehicles already regulated [17]. Because the $CO_2$ emissions of $H_2$-bi-fuel vehicles operating in $H_2$ mode are very low, it is suggested to disregard the requirement to measure the $CO_2$ emissions during $H_2$ operation mode. The $CO_2$ emissions should be deemed to be zero for that operation mode.

### 2. Open issues and need for specification

159. There are no open issues in this chapter.

### 3. Assessment of harmonization – Development of a gtr

160. Worldwide harmonization is possible in the case of 2-wheeled motorcycles, because gtrs for the measurement of $CO_2$ emissions already exist. This is not the case for LDV, and the development of a worldwide harmonized test cycle and measurement procedure especial for LDV using $H_2$ in ICE as $H_2$-bi-fuel is not efficient and feasible.

161. In the case of motorcycles with ICE using $H_2$ ($H_2$-bi-fuel) which are ready for marketing, an amendment of gtr No. 2 (WMTC) can easily be developed. Such an amendment of the existing gtr only needs the extension of the scope to $H_2$-bi-fuel vehicles and the decision about the measurement of $CO_2$ in the petrol mode only. In this case, there is no need to adapt the existing measurement and calculation methods. The amendment of gtr No. 2 can be considered as a midterm activity.

162. For LDV it should be considered to introduce this $H_2$-bi-fuel approach (see above) with the WLTP gtr [5]. In the meantime, the existing national legislation or UN Regulation No. 101 can be amended.

163. As a conclusion, it is not proposed to develop a special gtr for the measurement of $CO_2$ emissions of $H_2$ vehicles.

# IX. Noise emissions

## A. Explanation and specification of the issue

164. The noise emissions of vehicles (stationary and moving) and of tyres are regulated in legislation.

165. The noise emissions from ICE powered with $H_2$ are comparable to conventional vehicles. FC vehicles can be considered as quiet vehicles, like electric powered vehicles. It is the same situation with tyres as with conventional vehicles.

166. The World Forum WP.29 has determined that road transport vehicles propelled in whole or in part by electric means, can be critical for pedestrians. Further, the World Forum has directed GRB to assess and determine what, if any, steps might be taken by WP.29 to mitigate potential pedestrian hazards through the use of acoustic means, recognizing that other means of communication may also be appropriate. GRB has established an informal working group to carry out activities to determine the viability of "quiet vehicle" audible acoustic signalling techniques and the potential need for their global harmonization [18].

## B. Application and scope

167. In principle all vehicle categories can be powered by $H_2$ [1]:

(a) Passenger car (category 1-1 vehicle);

(b) Bus (category 1-2 vehicle);

(c) Truck (category 2 vehicle);

(d) 2 or 3 wheeler (category 3 vehicle).

168. The use of $H_2$ is also possible in agricultural and forestry tractors [8] and NRMM [9]. Today there is not much interest in marketing such solutions. These vehicle categories therefore will not be further covered by this report.

169. Propulsion system and fuel are not relevant criteria in noise requirements.

## C. Definitions

170. There are no definitions in this chapter.

## D. Overview on existing Regulations and standards

171. UN Regulations Nos. 41 (motorcycles) and 51 (passenger cars, trucks, buses) covers test procedures and performance requirements to limit the noise emissions of these vehicles. Rolling sound emissions of tyres are regulated in UN Regulation No. 117.

172. These existing Regulations are already applicable for $H_2$ powered vehicles.

173. Activities for the development of gtrs in the field of noise emissions are possible in future, but not mandated by AC.3 for the time being.

### E. Work to be done and state of research

174. Special research activities are not necessary for the issue of noise emissions of hydrogen powered vehicles.

### F. Regulatory approach

175. As a conclusion, it is not proposed to develop a special gtr for the measurement and limitation of noise emissions of $H_2$ vehicles.

## X. Reusability, recyclability and recoverability

### A. Explanation and specification of the issue

176. The European Directive 2005/64/EC [19] provides the administrative and technical provisions for the type-approval of vehicles, (categories $M_1$ and $N_1$), which aim to ensure that their component parts and materials can be reused, recycled and recovered in the minimum percentages. It lays down specific provisions to ensure that the re-use of component parts does not give rise to safety or environmental hazards.

177. It is necessary to consider whether the provisions, which are currently set for conventional vehicles, should also be applied to hydrogen powered vehicles.

### B. Application and scope

178. In principle all vehicle categories can be powered by $H_2$ [1]:

(a) Passenger car (category 1-1 vehicle);

(b) Bus (category 1-2 vehicle);

(c) Truck (category 2 vehicle);

(d) 2 or 3 wheeler (category 3 vehicle).

179. The use of $H_2$ is also possible in agricultural and forestry tractors [8] and NRMM [9]. Today there is not much interest in marketing such solutions. Therefore, these vehicle categories will not be further covered by this report.

### C. Definitions

180. There are no definitions in this chapter.

### D. Overview on existing Regulations and standards

181. Hydrogen vehicles with ICE do not crucially differ from conventional vehicles using conventional fuels. In contrast, hydrogen FC drive trains differ substantially from drive trains of conventional vehicles. Apart from the FC with all necessary auxiliary units, the electric system of these vehicles is comparable to the electric system of hybrid vehicles using ICE.

182. Reusability and recyclability are important issues in FC (catalysts, MEA, etc.) due to expensive and rare materials used.

183. Standards or Regulations could be found dealing with recycling, recovering and reusing of hydrogen vehicle components. However, several patents can be found in the literature dealing with processes for recycling FC components [20, 21, 22, and 23] and general life cycle assessment requirements and guidelines could be found in the ISO 14044:2006 [24]

### E. Work to be done and state of research

184. Special research activities does not seem to be necessary on the issue of reusability, recyclability and recoverability of hydrogen powered vehicles.

### F. Regulatory approach

185. Regulations addressing the issue of reusability, recyclability and recoverability of hydrogen vehicle components (especially FC components) need to be considered. However, it is not proposed to develop a special gtr addressing $H_2$ vehicle's reusability, recyclability and recoverability.

## XI. Harmonization assessment in the area of environmental and energetic aspects

186. This chapter summarizes the findings and recommendations on the Regulation approach to be taken based on the chapters dedicated to each issue above.

### A. Fuel consumption

187. Regulations should be established consistently with common agreement on the issues.

188. The basis for Regulations could be standards (national or regional) existing or under development. The related content should be, therefore, harmonized on an international basis.

### B. Fuel quality

189. Once the technology to produce and assure the quality of hydrogen fuel containing minute amounts of impurities as specified in the fuel standards is established and such reference fuel is made available, it will be possible to evaluate the effect of impurities on individual vehicles and thus be helpful in the development of FC vehicles.

### C. Pollutant emissions of hydrogen ($H_2$) fuelled vehicles

190. Worldwide harmonization is possible in case of HDV and 2-wheeled motorcycles, because gtrs for the measurement of pollutant emissions already exists. This is not the case for LDV, and the development of a worldwide harmonized test cycle and measurement procedure especial for LDV using $H_2$ in ICE is not efficient and feasible.

191. In case motorcycles or HDV with ICE using $H_2$ are ready for marketing, an amendment of gtr No. 2 (WMTC) or gtr No. 4 (WHDC) can easily be developed. Such amendments of the existing gtrs only needs the definition of the reference fuel, the

calculation method for $NO_x$ ($H_2$ fuel) and the definition of the $H_2$-bi-fuel approach. This can be considered as a midterm activity for both vehicle categories.

192. For LDV it should be considered to introduce a reference fuel (gas), a calculation method for the $NO_x$ emissions and the definition of the $H_2$-bi-fuel approach with the WLTP gtr. In the meantime, the existing national legislation or UN Regulation No. 83 can be amended.

193. As a conclusion, it is not proposed to develop a special gtr for the measurement and limitation of pollutant emissions of $H_2$ vehicles.

## D. Carbon dioxide ($CO_2$) emissions of hydrogen ($H_2$) fuelled vehicles

194. Worldwide harmonization is possible in case 2-wheeled motorcycles, because gtrs for the measurement of $CO_2$ emissions already exist. This is not the case for LDV, and the development of a worldwide harmonized test cycle and measurement procedure especial for LDV using $H_2$ in ICE as $H_2$-bi-fuel is not efficient and feasible.

195. In case motorcycles with ICE using $H_2$ ($H_2$-bi-fuel) are ready for marketing, an amendment of gtr No. 2 (WMTC) can easily be developed. Such an amendment of the existing gtr only needs an extension of the scope to $H_2$-bi-fuel vehicles and the decision about the measurement of $CO_2$ in the petrol mode only. In this case there is no need to adapt the existing measurement and calculation methods. The amendment of gtr No. 2 can be considered as a midterm activity.

196. For LDV it should be considered to introduce this $H_2$-bi-fuel approach (see above) with the WLTP gtr. In the meantime, existing national legislation or UN Regulation No. 101 can be amended.

197. As a conclusion, it is not proposed to develop a special gtr for the measurement of $CO_2$ emissions of $H_2$ vehicles.

## E. Noise emissions

198. UN Regulation Nos. 41 (motorcycles) and 51 (passenger cars, trucks, buses) covers test procedures and performance requirements limiting the noise emissions of these vehicles. Rolling sound emissions of tyres are regulated by UN Regulation No. 117.

199. These existing Regulations are already applicable for $H_2$ powered vehicles.

200. Activities for the development of gtrs in the field of noise emissions are possible in future, but not mandated by AC.3 for the time being.

201. As a conclusion, it is not proposed to develop a special gtr for the measurement and limitation of noise emissions of $H_2$ vehicles.

## F. Reusability, recyclability and recoverability

202. Regulations addressing the issue of reusability, recyclability and recoverability of hydrogen vehicle components (especially FC components) need to be considered. However, it is not proposed to develop a special gtr addressing $H_2$ vehicle's reusability, recyclability and recoverability.

### G. Summary and conclusions

203. There are three areas in the field of Regulations for HFCV where it makes sense to aim for international harmonization:

(a) Test methods for the measurement of fuel consumption;

(b) Test and calculation method for the measurement of pollutant and $CO_2$ emissions;

(c) Definition of a reference fuel for test purposes.

204. In the first case — fuel consumption —, the recommendation is to use standards that exist or are underdevelopment and harmonize them on an international basis. The open question here is the development of a harmonized test cycle (currently underway at the UN). In the meantime, harmonization will be part of the method for measuring the fuel consumption, thereby allowing each region to apply its own test cycle until the world harmonized test cycle has been approved.

205. On the other hand is perceived as helpful to define a reference fuel (fuel standard) as this will allow evaluating the effect of impurities on individual vehicles and supporting the development of HFCV.

206. It is, however, recommended to waive the development of a stand-alone gtr for environmental related provisions for HFCV. It is preferable to amend case by case existing UN Regulations or gtrs to accommodate this class of vehicles or to consider HFCV directly during the developing process of new Regulations.

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