Transmitted by the secretariat | Informal document **GRB-53-10**
(53rd GRB, 15 to 17 February 2011
agenda item 14(a))

Transmitted by the Chair of the GRPE working group on HFCV-SGE | ~~Informal document No. **GRPE-61-03**~~
~~(61st GRPE, 10-14 January 2011, Agenda item 7.)~~

Note: GRPE requested the secretariat to transmit GRPE-61-03 to GRB for consideration at its February 2011 session and especially for receiving comments on chapters 9 to 11. GRPE agreed to resume consider of this subject at its next session in June 2011 on the basis of an official document. In this respect, the secretariat was requested to distribute GRPE-61-03 with an official symbol including the comments by GRB.

UNECE – WP.29 – HYDROGEN FUEL CELL VEHICLES - (HFCV) GRPE - SUB-WORKING GROUP ENVIRONMENT (SGE)

Report summarising the findings and recommendations in the different areas addressed by the SGE in support of the harmonisation process.

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1. INTRODUCTION

The UN ECE informal GRPE working group on hydrogen/fuel-fuel cell vehicles (GRPE-H2FCV) has been operative for several years now. In June 2005, WP.29/AC.3 agreed on a proposal by Germany, Japan and United States of America regarding how to **manage the development** process for 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 in order 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:

1. The aim is to attain equivalent levels of safety as those for conventional gasoline powered vehicles;
2. The GTR shall be performance based and
3. The GTR shall not be restrictive for future technologies.

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

1. The **main differences** in safety and environmental aspects and
2. Which **items** need to be regulated and the **justification** behind it.

Under the agreed process, once AC.3 had developed and approved the action plan for the development of a GTR, two subgroups has been formed to address the safety and the environment aspects of the GTR:

1 The subgroup safety (**HFCV-SGS**) which is chaired by Japan and the USA reports to GRSP.

2. The environmental subgroup (**HFCV-SGE**) which is chaired by the European Commission (JRC) and reports to GRPE.

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 implemented properly and that milestones and timelines are set and met throughout the development of the GTR.

The GTR will cover fuel cell (FC) and internal combustion engine (ICE), compressed gaseous hydrogen (CGH2) and liquid hydrogen (LH2).

The **final goal** of the environmental informal sub-group (**HFCV-SGE**) is to investigate the possibility of harmonization of environmentally related requirements and to propose actions in those cases where harmonization might not be possible.

2. SCOPE

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

3. METHODOLOGY USED

The SGE has considered that a very practical way of going ahead might be the drafting of a technical report consisting of dedicated chapters for each of the areas of interest to the SGE and addressing 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-art
d) ongoing/finalised research activities stating references on both cases; finalised projects and ongoing ones
e) if further research is still needed, then specify what and why
f) assessment of the harmonization:
    - is it needed?,
    - specify the harmonisation,
    - is it foreseeable (explain why),
    - reference list.

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

1. Purpose / explanation:

   This section will introduce the item, including a technical description, with a clear statement about the purpose of a regulation concerning the subject of the report (this section needs to bear a resemblance to the chapter "purpose" in each GTR).

2. Application / scope:

   It will address the type of vehicle to which the report is dedicated: vehicle classes (SR1), propulsion system (FC, Hybrid, ICE) and fuels (mono, bi, flex ...).

3. Definitions (if any)

   It will include only definitions deemed necessary because of either it is needed to understand the TR chapter, or a controversial discussion in meetings show the need for clarification.

4. Regulations / directive / standards:

   The section will give a brief but comprehensive overview about existing regulations, directives and standards (RCS?) together with those under development. The details on them need to be referenced in section 7 (see below).

5. State and review of research:

   Brief and comprehensive overview about finalised and ongoing research pertinent to the chapter summarising their results and conclusions and pointing out any lack of research results needed. (References should be listed in section

7)). If further research is needed for the development of a regulation, this section should also describe it.

6. Assessment of harmonisation:

   This section should include, based on the information provided in sections 1 to 5, a statement about possible harmonisation of requirements for a specific item under the 1998 agreement. If harmonisation seems not to be possible, other solutions can be suggested (e.g. an amendment of an existing ECE-Regulation).

7. References:

   A list of references made to publications, regulations, standards etc. made in the previous chapters (in this report the references are in chapter 12.).

The technical reports dedicated to the different areas (see below) are an integral part of this document (chapters). Unfortunately not all the areas are supported by a technical report as no experts in that missing particular area were found although they were actively sought.

4. ASPECTS ADDRESSED BY THE SGE

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:

1. Pollutant Emissions
2. Hydrogen and Water Emissions
3. Fuel Consumption
4. Recycling
5. FC Disposal / Hazardous Materials
6. Fuel Quality
7. Engine Power
8. Noise

Item 8 (chapter 9 - Noise) was also considered by GRB.

One note of cautions needs to be indicated here, APUs (Auxiliary Power Units) are not part of the GTR, as it should only address FC and ICE engines running both with CFH2 and LH2 and it has not been included in AC3's action plan.

It is also apparent that Electromagnetic Compatibility is a more safety related subject discussed in GRE for conventional vehicles as well as for Electro-Hybrid-, Pure Electric- and Fuel Cell Vehicles.

H2/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.

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 H2-ICE- and Fuel Cell 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

Table 1 summarises 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) Bi-fuel Blends Dual fuel
	Environmental & Energetic aspects			
Fuel Consumption	x	x	x	x
CO_2 emission				Bi-fuel, blends & dual fuel
External Electrical consumption		x	x	
Pollutant emissions			x (NO_x)	x
H_2 & 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 mat.)	x	x	x	x
Noise	x	x	x	x

5. FUEL CONSUMPTION, EXTERNAL ELECTRICAL CONSUMPTION AND MAXIMUM SPEED / ENGINE POWER MEASUREMENT

5.1. Introduction

This chapter is related to the Hydrogen use in vehicle application and relevant measurement of energy and operation performance of the vehicle and components.

The following applications are considered (out of the matrix previously established)

1. Fuel cell system: stack, components,
2. Fuel cell vehicles
3. Hybrid fuel cell vehicles
4. Hybrid H2 - I.C.E. vehicles

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

- Fuel consumption
- External Electricity Consumption of Hybrid Vehicles
- Maximum speed

The scope of the chapters is to list and analyse the elements necessary to prepare harmonised standards/regulations on this matter and ultimately GTRs, starting from existing normative documents and data coming from research result.

The chapter addresses the following content:

- Overview of existing regulation, standards and possible links
- Overview of the state-of-art
- Missing standardisation topics
- Ongoing/finalised research activities relevant to the matter
- Possible further research needed

The following Figure 1 presents the International Standards and Regulation Bodies dealing with Hydrogen and Fuel Vehicles with the relevant fields of action and links.

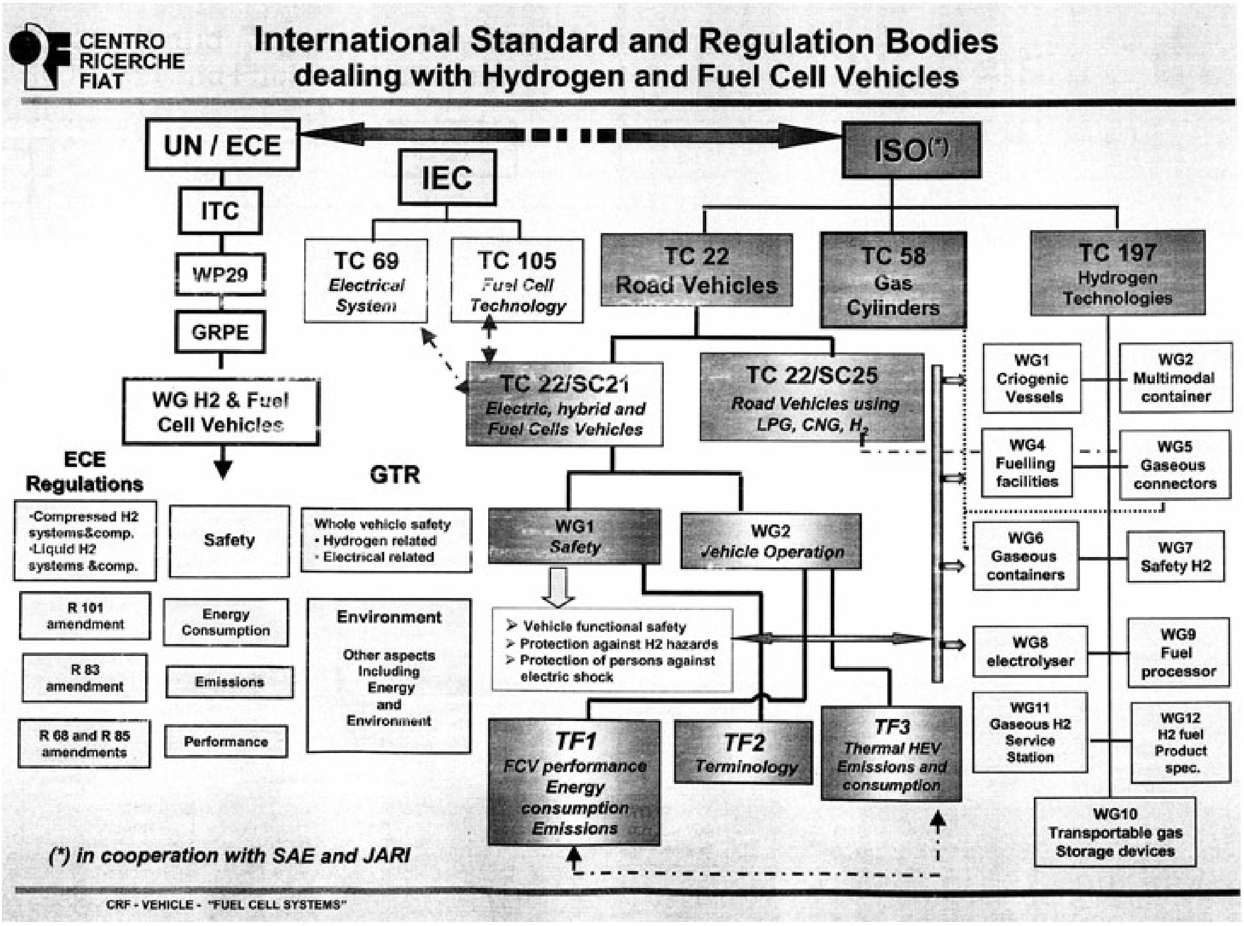

Figure 1 International Standard and Regulation Bodies dealing with H_2 and FC vehicles

5.2. Fuel consumption

5.2.1. Explanation and specification of the issue

In legislation the fuel consumption of Passenger Cars, Light Duty Vehicles and Motorcycles is tested on a roller test bench; for Heavy Duty Vehicles are tested on an engine test bench, following test cycle or steady state test.

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

Determination of fuel consumption is a fundamental issue for all vehicle categories, since it constitutes:

- an element required for certification/homologation
- a parameter for possible definition of taxation
- a common basis for comparing energy performance of different vehicles and different power train solutions
- a basis to determine the "Well To Wheel" energy effectiveness of the various solutions with respect to the primary energy source.

5.2.2. Measurement of H2-Fuel Consumption

H2-Fuel consumption is defined as the mass amount of fuel used by a vehicle in a prescribed test cycle, expressed in g/km. In principle, three methods exist for experimentally determining gaseous H2 consumption in FC or ICE-vehicles: (i) determination of fuel mass change in the container before and after test, (ii) determination of H2 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.

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.

5.2.2.1. Determination of mass change

Mass change is measured statically before and after the test, either by weighing the fuel tank with its H2 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 H2 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 use of a standardised equation for hydrogen density as a function of temperature and pressure.

5.2.2.2. Flow rate measurement

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.

5.2.2.3. Method based on emission measurement

At present, US-EPA only accepts weighing, PVT and Coriolis mass flow according to SAE J2572 for the determination of H2 gas fuel consumption in fuel cell and fuel cell 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 fuel cell 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.

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, CO2, THC) in the diluted exhaust volume that is collected during the test cycle are calculated into a fuel consumption for the particular test cycle.

For H2-powered vehicles, a Hydrogen-Balance method (sometimes also called water-balance) is applied, which measures the hydrogen-containing compounds H2O (non-dispersive infra-red analyser) and unburned H2 (sector field mass spectroscopy) from the exhaust. This method requires some modifications to the testing procedures and CVS system that are used for conventional ICE vehicles. These arise mainly from two factors:

- It must be ensured that all H2O 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 H2O from the exhaust into the dilution pipe.
- H2O in the exhaust may originate from other sources than oxidation of the H2 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

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-recognised methods [1]. The method works for FC as well as for ICE vehicles.

Table 2 Adapted from HarmonHy WP4 Deliverable D4.1 – Industrial and societal needs – Sept. 2006

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 Vehicle remodelling unnecessary	N/A for direct hydrogen FCV
Flow method	Direct measurement using flow meter	Field-proven for Internal combustion engine vehicles	Vehicle remodelling needed Verification of flow meters
Electrical current method	Calculated from electrical current generated in the fuel cell	Current easily measured from output wiring of the fuel cell	Gas crossover and leak Measurement of H2 purge
Hydrogen balance method	Derived from exhaust gas, H2content in fuel and exhaust gas are the same	Simultaneous measurement during exhaust gas test Vehicle remodelling unnecessary	H2 balance complicated Difficult to measure
Oxygen balance method	Measuring the decline in O2 concentration in exhaust gas	Simultaneous measurement during exhaust gas test Vehicle	Decline in O2 is low Accuracy of oxygen analyzer

		remodelling unnecessary	
Pressure method	Calculated from press. / temp. change of fuel container	Easily to measurement Support H2 purge	Limited to a high pressure container to store fuel
Weight method	Calculated from weight change of fuel container	Direct and simple Support H2 purge	N/A for onboard measurement Connecting to gas line

5.2.3. Application and Scope

5.2.3.1.Vehicle categories

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

- passenger car (category 1-1 vehicle)
- bus (category 1-2 vehicle)
- truck (category 2 vehicle)
- 2 or 3 wheeler (category 3 vehicles)

5.2.3.2.Propulsion systems

- Pure Fuel Cell Vehicle
- Fuel Cell Hybrid (Fuel Cell and Rechargeable Electric Storage) Vehicle
- Fuel Cell Systems and components: Stack (inherent characterization)
- I.C.E. – H2 (I.C.E. fuelled by Hydrogen) Hybrid vehicle

5.2.4. Definitions

The definition of the different propulsion systems and components should be based on those given in Standard, Regulation and Technical Report, with appropriate harmonization.

5.2.5. Overview on existing Regulation and Standard

5.2.5.1.Fuel cell systems: Stack and Components

Standards existing or under development by:

ISO/TC 197 Hydrogen technologies

ISO 14687: Hydrogen fuel-product specification

ISO 14687: Hydrogen fuel-product specification

Part 2: Proton exchange membrane (PEM) fuel cell application for road vehicles

IEC/TC 105 Fuel cell technologies

IEC 62282-1:2005 Fuel cell technologies - Part1: Terminology (published)

IEC 62282-2:2004 Fuel cell technologies - Part 2: Fuel cell modules (published)

IEC/CDV 62282-3-2 Fuel cell technologies - Part 3-2: Stationary fuel cell power plants - Test methods for the performance

IEC/PWI 62282-4 Fuel cell technologies - Part 4: Fuel cell system for propulsion and auxiliary power unit

SAE

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

SAE J 2615 Reference test procedures of fuel cell systems for automotive application

SAE J 2616 Performance test procedures for the fuel processor systems for automotive application

SAE J 2617 Performance test procedures of PEM fuel cell stack subsystem for automotive application

SAE J2719: Information Report on the Development of a Hydrogen Quality Guideline for Fuel Cell Vehicles.

5.2.5.2.Pure Fuel Cell Vehicles

Existing Regulations/Standards:

- Regulation UN ECE R 101

  The R 101 provides methods for consumption measurement of ICE vehicle, with carbon based fuel, battery electric vehicles and hybrid electric vehicles.

  The structure is prepared to incorporate procedures for ICE vehicles fuelled with H2 and fuel cell vehicles pure or hybrid.

  A draft proposal was developed by the consortium of Companies (lead by RTWH-Aachen) acting on EU Programme FUEVA.

- Standard ISO 23828:

  “Fuel Cell Road Vehicles-Energy Consumption measurement-Vehicles fuelled with compressed hydrogen”, developed by ISO/TC22/SC21.

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

  The procedure prescribes the test on a chassis dynamometer.

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

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

  The prescribed methods are the following: (see Annex to the Standard)

  1. Pressure method (normative)
  2. Gravimetric method (normative)
  3. Flow method (normative)
  4. Current method (informative)

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

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

- Standards from ISO TC 197 "Hydrogen technologies"

  ISO 14687:1999 / Cor. 1:2001 "Hydrogen fuel-Product specification"

  ISO/TS 14687-2:2008 "Hydrogen fuel-Product specification- Part 2: Proton exchange membrane (PEM) fuel cell application for road vehicles (under revision)

  ISO/DIS 16110-2 "Hydrogen generators using fuel processing technologies-Part 2: procedure to determine efficiency

5.2.5.3.Missing standards

Methods for consumption measurement of H2 stored in liquid phase and in Metal Hydride tank.

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

5.2.5.4.Hybrid Fuel Cell Vehicles

The standard ISO 23828 is applicable to Fuel Cell road vehicles in general, fuelled with compressed H2, both pure FC and Hybrids; the different procedures are put in evidence within the standard.

A missing standard, to be possibly developed, is related to Fuel Cell Hybrid Vehicle-Energy consumption measurement- Externally chargeable vehicles (plug-in vehicles).

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 vehicles (PHEV).

5.2.5.5.ICE-H2 Hybrid Vehicles

The prescription for fuel consumption measurement of ICE-H2 Hybrid Vehicles could be derived from those for Hybrid Electric road vehicles (ISO 23274) non externally chargeable, including the provisions for H2 measurements as prescribed in ISO 23828.

5.2.6. Overview of the state of art

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.

5.2.7. On going finalised research

The EU Programme FUEVA (lead by RTWH – Aachen) includes research related to test and validation of the procedures for hydrogen consumption measurement in vehicles.

5.2.8. Further research needed

Research related to procedure for H2 consumption measurement of H2 stored in liquid phase or in Metal Hydride tank.

5.2.9. Assessment of the harmonization

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

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

5.3. External Electrical Consumption

5.3.1. Explanation and specification of the issue

The external electrical consumption occurs for dual energy powered vehicles (H2 and electricity).

This is the case of either Fuel Cell Hybrid (battery electric with fuel cell electricity generator), or I.C.E.- H2 supplied Electric Hybrid.

5.3.2. Application and scope

5.3.2.1.Vehicle categories

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

- passenger car (category 1-1 vehicle)
- bus (category 1-2 vehicle)
- truck (category 2 vehicle)
- 2 or 3 wheeler (category 3 vehicles)

5.3.2.2.Propulsion systems

- Fuel cell hybrid (Fuel Cell and Rechargeable Electric Storage) Vehicle
- I.C.E. – H2 (I.C.E. powered by Hydrogen) Hybrid

5.3.3. Overview on existing Regulation and Standard

5.3.3.1.Fuel Cell Hybrid Vehicles

For Passenger Cars and Light Duty Vehicles regulation UN ECE R101 provides methods for consumption measurement of ICE Vehicles, with carbon based fuel, Battery Electric and Hybrid Electric Vehicles. The structure could incorporate Fuel Cell Vehicles Hybrid Vehicles

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).

5.4. Maximum speed measurement – Engine Power measurement

5.4.1. Explanation and specification of the issue

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.

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

Similar provisions exist for the measurement of the engine power.

5.4.2. Application and scope

5.4.2.1. Vehicle categories

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

- passenger car (category 1-1 vehicle)
- bus (category 1-2 vehicle)
- truck (category 2 vehicle)
- 2 or 3 wheeler (category 3 vehicles)

5.4.2.2. Propulsion system

- Pure Fuel Cell Vehicles
- Fuel Cell Hybrid Vehicles
- I.C.E. – H2 Hybrid Vehicles

5.4.3. Overview on existing Regulation and Standard

A technical report has been recently developed by ISO TC 22/SC 21, regarding Fuel Cell Vehicles maximum speed (pure and hybrid).

This TR, which is presently being issued, is based on the harmonisation of the following documents

- UN ECE Regulation R68- Amendment 1: Uniform provisions concerning the approval of power-driven vehicles including pure electric vehicles with regards to the measurement of the maximum speed
- ISO 8715: Electric Road Vehicles-Road operating characteristics

For ICE-H2 Hybrid Vehicle, the maximum speed measurement could be done following the general provision of R 68.

Engine Power

Regulation UN ECE R.85 prescribes test for maximum power and maximum 30 min power for electric vehicles.

5.5. Reference documents

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

The relevant documents are reported in **Error! Reference source not found.**.

Table 3 Standards/Regulations existing, to be developed or to be adapted for application to Hydrogen and Fuel Cell Systems/Vehicles

Topic	H2 Stack and Components APU Generating Unit	FC(pure)Vehicle	FC Hybrid Vehicle	I.C.E.-H2 Hybrid Vehicle
Fuel Consumption	**IEC 62282-2 (2004)** **SAE 2617** **ISO 14687** Hydrogen Fuel-product specification- Part 2 Proton exchange membrane (PEM) **ISO 13985** Liquid Hydrogen Land Vehicles Fuel Tanks **ISO/TS 16111 (2006)** Transportable gas storage devices-Hydrogen absorbed in reversible metal hydrid.	**ISO 23828** Fuel Cell road Vehicles-Hydrogen consumption measurement -Vehicles fuelled with compressed H2 To be developed: -Vehicles fuelled with liquid H2 To be developed: -Vehicles fuelled with H2 absorbed in MH **R101** (to be adapted for FC Vehicles inclusion)	To be developed: Fuel Cell Hybrid Vehicle-Energy consumption measurement-Externally chargeable vehicles.	**R101** (Applicable for fuel consumption to ICE Hybrid, to adapted for H2 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 H2 use) **R101** (to be adapted).
Maximum speed	-	**ISO** Technical Report (TR) FC Vehicles Maximum speed (being issued) **ISO 8715** Electric Road Vehicles-Road operating characteristics. **R68**-Amend .1 Uniform provisions concerning the approval of power-driven vehicles including pure electric vehicles with regards to the measurement of the maximum speed.		**R68** Uniform provisions concerning the approval of power-driven vehicles with regard to the measurements of the maximum speed

Performance	**Engine Power**	**IEC/CDV 62282-3-2** Stationary fuel cell power plants-test method for the performance	**R 85** Annex 6 Amend:2,8,4 Maximum power and maximum 30 min. 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 Fuel Cell Council Fuel Cell Glossary **IEC/TC 62282-1 (2005)** Terminology	**ISO** Draft Technical Report(TR) on SC 21 Vocabulary **ISO 8713**		-

6. H2 REFERENCE FUEL AND REFERENCE GASES

6.1. Introduction

This chapter addresses the need and feasibility for a hydrogen reference fuel and for other reference gases in the context of the establishment of harmonised regulations for H2-powered vehicles.

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.

6.2. Purpose and resulting requirements for reference gases in support of regulations for H2 vehicles

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

H2 purity (quality) is an issue in FC vehicles, much less in H2-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 H2 fuel depend primarily on the H2 production method, although the storage method and medium may also play a part. The most important contaminants in H2 produced by natural gas reforming (the most commonly used production method) are CO, sulphur containing compounds (H2S in particular), nitrogen containing compounds (NH3), and unsaturated and aromatic hydrocarbons.

If H2 is not only used for propulsion but it is also used in APU[1] (for which a different type of fuel cell may be used), other purity requirements will prevail. However, because only one kind of CH2 is expected to be stored on board, the most stringent requirements (corresponding to PEMFC for propulsion) will apply.

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 H2 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.

In the context of regulations a H2 reference fuel should be globally recognised (which would be achieved by a certification according to international standards, such as ISO Guide 34 [4] and corresponding equivalence studies)

6.2.2. Monitoring of vehicle emissions (see chapter 7. and 8.)

Vehicle certification requires measurement of tail-pipe emissions during a test cycle. This necessitates the use of calibrated emission monitoring equipment. Measurement of tail-pipe emissions from fossil fuelled ICE vehicles uses a constant volume sampling (CVS)

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[1] APU are not in the scope of the SGE and therefore it is not addressed in this document

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, CO2, HC and NOx are determined (g/km).

When using H2 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 H2O). The major emission product from H2 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 CO2 are known to be sensitive to H2O).

Emissions from H2-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 (UHC, CO, CO2).

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. NDIR). 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).

6.2.3. Measurement of fuel consumption (see chapter 5.)

Vehicle certification requires measurement of fuel consumption during a test cycle. For H2-powered vehicles a number of methods have been identified and are under investigation. Each of these methods has disadvantages. The need for harmonisation of fuel consumption measurement procedures in the context of regulations is addressed in one of the previous chapters of this technical report. The present chapter therefore focuses on the potential role that reference gases could play in this respect.

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-H2 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.

This is achieved by using the so-called Hydrogen-Balance method which measures the hydrogen-containing compounds H2O (non-dispersive infra-red analyser) and unburned H2 (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 H2O and H2 analysers. Because the expected concentration of H2 in the exhaust is very low, the H2 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.

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 fuel cell stack, which requires a high accuracy of the oxygen analyser.

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.

6.3. Requirements

The implementation in the context of regulations of harmonised fuel quality, emission and fuel consumption measurements translates into the following needs for further R&D and technical requirements for reference gases:

6.3.1. Fuel quality for FC vehicles

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

Need: pre-normative research into

- test methods for quantifying performance under dynamic conditions reproducing typical driving cycles
- reliable detection and quantification of impurities in gaseous H_2, including validation of high-pressure sampling methods
- understanding and quantifying the effect of impurities (single as well as multi-constituent) on FC performance and determination of acceptable level of impurities

Implications for feasibility of reference fuel:

- identification of type and amount of impurities in hydrogen carrier gas
- investigate stability and conservation/storage period

6.3.2. Emission monitoring for FC and ICE vehicles

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

Need: pre-normative research into

- low-cost and reliable analysis methods and emission monitors
- calibration of sensors

Implications for feasibility of reference gases:

- calibration of emission analysers at low detection ranges requires higher purity levels in the reference gas than for conventional ICE vehicles

6.3.3. Fuel consumption (FC and ICE)

Issue: same as for emission monitoring

Need: additional pre-normative research into

- Further validation of hydrogen-balance approach and equations for different vehicle types
- Cost-effective calibration method for H_2O detectors

Implications for feasibility of reference gases:

- need for dedicated reference gas(es?) allowing calibration of H_2O detectors over wide H_2O range
- for calibration of H_2 detectors: none (e.g. 0.5% H_2 in N_2).

6.4. Conclusion and Recommendation

International collaboration in pre-normative research as well as close interaction with international standardisation bodies aimed at harmonisation 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.

7. POLLUTANT EMISSIONS OF HYDROGEN (H2) FUELLED VEHICLES.

7.1. Explanation and Specification of the issue

In legislation the emissions of gaseous pollutants carbon monoxide (CO), hydro carbons (HC), oxides of nitrogen (NOx) and the emissions of particulate matter (PM) are limited in g/km or g/kWh. Light Duty Vehicles (LDV) and motorcycles are tested on a roller test bench, engines of Heavy Duty Vehicles (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.

Evaporative and low temperature emissions (requirements in ECE-R 83 [5]) are only related to gasoline engines and not relevant for H2 as fuel.

Fuel cell vehicles don't emit one of the above mentioned pollutants, if H2 is used directly. A fuel cell can also be fuelled with H2, that was reformed (on vehicle) from a different base fuel (CxHy). In case of a reformer (on vehicle), pollutant emissions are relevant, depending on the base fuel and the reforming process.

Theoretically the only component emitted by internal combustion engines (ICE) fueled with H2 is NOx. The level of NOx emissions is depending on the air-H2 ratio, respectively exhaust gas temperature and the layout of the aftertreatment system (e.g. catalyst). The use of H2 is possible in positive- and compression ignition engines.

In cases where H2 is used together with other fuels (H2-bi-fuel, H2-flex-fuel, H2-dual-fuel), all the other pollutants become relevant. H2-bi-fuel systems (BMW) or hydrogen mixtures (e.g. with CNG, [6]) are interesting solutions during the introduction phase of H2 vehicles, until the infrastructure with H2 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 H2 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.

The level of NOx emissions of H2-fuelled ICE is an averaged between 2 - 30 % of the existing mandatory limits of NOx 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 H2-bi-fuel concepts, because the injection of the other fuel is pre-activated during H2-fuel mode.

H2 can be stored liquid (LH2) or compressed gaseous (CGH2). The influence on pollutant emissions by the type of storage is not relevant. The only need is to define different reference H2-fuel and reference H2-gas for emission testing.

Engines and fuel cells are emitting also non-regulated components, e.g. ammonia, hydrocianic acid, organic amine, aldehyde, sulfur dioxid. Today there is no evidence that ICE and fuel cells are emitting any non-regulated component that causes serious environmental or health problems.

7.2. Application and Scope

7.2.1. Vehicle categories

In principle all vehicle categories defined in Special Resolution No.1 [1] can be powered by H2:

- passenger car (category 1-1 vehicle)
- bus (category 1-2 vehicle)
- truck (category 2 vehicle)
- 2 or 3 wheeler (category 3 vehicle)

Also possible, is the use of H2 in agricultural and forestry tractors [8] and Non Road Mobile Machinery (NRMM) [9]. Today there is not big interest for marketing of such solutions. Therefore these vehicle categories will not be further covered by this chapter - out of scope.

7.2.2. Propulsion system

Internal combustion engine (ICE), positive or compression ignition, or in combination with an electric engine (Hybrid Electric Vehicle).

Also possible, but not developed for the time being, is a combination of ICE and Fuel Cell (Hybrid Vehicle) - out of scope.

7.2.3. Reformer (on vehicle)

For the time being it's improbable that a vehicle in serial production will be equipped with reformer technology. Furthermore 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.

7.2.4. Fuel Types

- H2-fuel
- H2-bi-fuel with gasoline, diesel, CNG or LPG
- H2 blend/mixture (flex-fuel / dual-fuel) with gasoline, diesel, CNG or LPG
- H2 reformed (on board) from gasoline, diesel, LPG, CNG, methanol - out of scope (see chapter 7.2.3.)

7.3. Definitions

“Calculation method” - means the calculation method of mass emissions of pollutants, e.g. defined in appendix 8 of ECE-R 83 [5].

“Reference fuel / Reference gas” – means the definition of specifications of the fuel (LH2) or gas (CGH2) taken for the emission tests.

“H2-fuel-vehicle” – means a vehicle that primarily runs on H2 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.

(this definition is in line with the definition of "mono fuel gas vehicle" in [10])

“H2-bi-fuel vehicle” means a vehicle that can run part-time on H2 and also part time either on gasoline, diesel, LPG or CNG

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

"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.

“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]. ([5] and [10] also contains a definition for a “hybrid electric vehicle”).

7.4. Overview on existing Regulations & Standards

7.4.1. Passenger cars

The legislation concerning pollutant emissions from category 1-1 vehicles is not harmonised. Different test cycles, measurement methods, reference fuels and limit values are applicable. None of the existing Regulations includes test methods and requirements for H2 vehicles (ICE). The current European Euro 5/6 Regulation [10] already mentions H2 as fuel, but specific test procedures for H2 will be defined at a later stage.

A GTR project to develop a worldwide harmonised 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 H2 vehicles is not included in the draft roadmap.

ECE-R 83 [5] contains requirements regarding the pollutant emissions for mono-fuel and bi- fuel vehicles (gasoline, diesel, CNG, LPG). ECE-R 83 will be amended soon to be in line with the European Euro 5/6 requirements [10], including an approach for flex fuel (gasoline and Ethanol).

7.4.2. Heavy duty vehicles

With GTR No. 4 [12], a worldwide harmonised emission test procedure for heavy duty vehicles is established (category 1-2 and category 2 vehicles). The Appendix to GTR No. 4 (Technical Report) [12] includes an overview about the existing national emission legislation for heavy duty vehicles and relevant standards. Harmonised performance requirements are not included in GTR No. 4 for the time being. H2 vehicles are not covered by GTR No.4.

7.4.3. 2/3 wheelers

With GTR No. 2 [13], a worldwide harmonised emission test procedure for 2-wheeled motorcycles is established. The Appendix to GTR No. 2 (Technical Report) [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 WMTC informal group to develop a proposal for the harmonisation of limit values. H2 vehicles are not covered by GTR No.2.

The legislation concerning pollutant emissions from mopeds (< 50 cm^3, < 50 km/h) and three wheelers is not harmonised. Different test cycles, measurement methods, reference fuels and limit values are applicable. None of the existing Regulations includes test methods and requirements for H2 vehicles (ICE).

7.4.4. Reference Fuel and Reference Gas

The international standards ISO 14687 [14] and SAE J2719 [15] defines specifications for H2 as fuel. On this basis a reference fuel and reference gas can be defined for the purpose of H2 consumption measurement as well as for the purpose of measurement of NOx emissions. The issue of reference fuel and reference gas is described in more detail in chapter 6 above.

A specification for H2 as either flex-fuel or dual-fuel does not exist for the time being.

7.5. Work to be done and state of research

- A calculation method for NOx emissions from ICE fuelled wit H2 needs to be developed.
- Concerning H2-flex-fuel and H2-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).

7.6. Regulatory approach

7.6.1. Need for regulation

NOx emissions of vehicles with ICE using H2-fuel and pollutant emissions of H2-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.

7.6.2. Open issues and need for specification

- Definition of H2 reference fuel and gas, if possible accepted worldwide and applicable for all vehicle categories.
- Definition of the regulatory approaches (e.g. worst case, measurement with both fuels) for H2-bi-fuel vehicles (and H2-flex-fuel, H2-dual-fuel).
- If needed, a definition for a H2-bi-fuel vehicle, to separate clear from H2-flex-fuel or H2-dual-fuel.

7.6.3. Assessment of harmonisation - development of a GTR

In the case of HDV and 2-wheeled motorcycles a worldwide harmonisation is possible, because GTR's for the measurement of pollutant emissions already exists. This is not the case for LDV, and the extra development of a worldwide harmonised test cycle and measurement procedure especial for LDV using H2 in ICE is not efficient and feasible.

In the case of motorcycles or HDV with ICE using H2 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 GTR's only need the definition of the reference fuel, the calculation method for NOx (H2-fuel) and the definition of the H2-bi-fuel approach. This can be considered as a mid-term activity for both vehicle categories.

For LDV it should be considered to introduce a reference fuel (gas), a calculation method for the NOx emissions and the definition of the H2-bi-fuel approach with the WLTP GTR [11]. In the meantime, existing national legislation or ECE-R 83 can be amended.

As a conclusion, it is not proposed to develop a special GTR for the measurement and limitation of pollutant emissions of H2 vehicles.

8. CARBON DIOXIDE (CO_2) EMISSIONS OF HYDROGEN (H_2) FUELLED VEHICLES

8.1. Explanation and Specification of the issue

In legislation (approval and certification of vehicles) the emissions of CO2 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. Light Duty Vehicles (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 CO2 emissions are calculated in g/km.

In legislation (approval and certification of vehicles) the declared emissions of CO2 are the end-of-pipe emissions. The well-to-wheel emissions of CO2 are disregarded in the test reports. The issue of well-to-wheel emissions is currently considered by the EFV informal group of WP.29 [16].

Fuel cell vehicles don't emit CO2 if H2 is used directly. A fuel cell can also be fuelled with H2, that was reformed (on vehicle) from a different base fuel (CxHy). In case of a reformer (on vehicle), CO2 emissions are relevant, depending on the base fuel and the reforming process.

Internal combustion engines (ICE) fuelled with H2 don't emit CO2.

In cases where H2 is used together with other fuels (H2-bi-fuel, H2-flex-fuel, H2-dual-fuel) CO2 emissions become relevant. H2-bi-fuel systems (BMW) or hydrogen mixtures (e.g. with CNG, [6]) are interesting solutions during the introduction phase of H2 vehicles, until the infrastructure with H2 fuelling stations is more developed. For the time being BMW is the only manufacturer producing vehicles with ICE operating as H2-bi-fuel.

The level of the CO2 emissions in H2 mode of a H2-bi-fuel vehicle is very low. In 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 H2-bi-fuel concepts, because the venting of the active carbon filter (evaporative emissions) goes into the intake system of the ICE.

H2 can be stored liquid (LH2) or compressed gaseous (CGH2). The influence on CO2 emissions by the type of storage is not relevant. The only need is to define different reference H2-fuel and reference H2-gas for emission testing.

8.2. Application and Scope

8.2.1. Vehicle categories

In principle all vehicle categories defined in Special Resolution No.1 [1] can be powered by H2:

- passenger car (category 1-1 vehicle)
- bus (category 1-2 vehicle)
- truck (category 2 vehicle)
- 2 or 3 wheeler (category 3 vehicle)

Because in today's legislation the measurement of the CO_2 emissions is not required for Heavy Duty Vehicles, agricultural and forestry tractors and Non Road Mobile Machinery (NRMM), therefore these vehicle categories will not be further covered by this report - out of scope.

8.2.2. Propulsion system

Internal combustion engine (ICE), positive or compression ignition, or in combination with an electric engine (Hybrid Electric Vehicle).

Also possible, but not developed for the time being, is a combination of ICE and Fuel Cell (Hybrid Vehicle) - out of scope.

8.2.3. Reformer (on vehicle)

For the time being it's improbable that a vehicle in serial production will be equipped with reformer technology. Furthermore 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.

8.2.4. Fuel Types

- H_2-fuel - out of scope, because no CO_2 emissions.
- H_2-bi-fuel with gasoline, diesel, CNG or LPG.
- H_2 blend/mixture (flex-fuel / dual-fuel) with gasoline, diesel, CNG or LPG.
- H_2 reformed (on board) from gasoline, diesel, LPG, CNG, methanol - out of scope (see chapter 8.2.3.).

8.3. Definitions

"Calculation method" - means the calculation method of mass emissions of CO_2, e.g. defined in annex 6 of ECE-R 101 [17].

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

"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.

(This definition is in line with the definition of "mono fuel gas vehicle" in [10])

"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

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

"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.

"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]. ([10] and [17] also contains a definition for a "hybrid electric vehicle").

8.4. Overview on existing Regulations & Standards

8.4.1. Passenger cars

The legislation concerning CO2 emissions from category 1-1 vehicles is not harmonised. Different test cycles, measurement methods and reference fuels are applicable. None of the existing Regulations includes test methods and requirements for H2 vehicles (ICE). The current European Euro 5/6 Regulation [10] already mentions H2 as fuel, but specific test procedures for H2 will be defined at a later stage.

A (possible) GTR project to develop a worldwide harmonised light vehicles test procedure (WLTP) is under preparation [11]. The documentation in [11] includes a comprehensive overview of the existing national legislation on CO2 emissions. Currently the emission measurement of H2 vehicles is not included in the draft roadmap.

ECE-R 101 [17] contains requirements regarding the CO2 emissions for mono-fuel and bi- fuel vehicles (gasoline, diesel, CNG, LPG). ECE-R 101 will be amended soon to be in line with the European Euro 5/6 requirements [13], including an approach for flex fuel (gasoline and Ethanol).

8.4.2. 2/3 wheelers

With GTR No. 2 [13], a worldwide harmonised emission test procedure for 2-wheeled motorcycles is established, including the measurement of CO2 emissions. The Appendix to GTR No. 2 (Technical Report) [13] includes an overview about the existing national emission legislation for 2-wheelers and relevant standards. H2 vehicles are not covered by GTR No.2.

The legislation concerning exhaust emissions from mopeds (< 50 cm^3, < 50 km/h) and three wheelers is not harmonised. Different test cycles, measurement methods, reference fuels and limit values are applicable. None of the existing Regulations includes test methods and requirements for H2 vehicles (ICE).

8.4.3. Reference Fuel and Reference Gas

The issue of reference fuel and reference gas is described in more detail in chapter 6 above. In case of H2-fuel-vehicles the introduction of a reference fuel/gas is not necessary, because the CO2 emissions are zero.

A specification for H2 either as flex-fuel or dual-fuel does not exist for the time being.

8.5. Work to be done and state of research

Concerning H2-flex-fuel and H2-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).

8.6. Regulatory approach

8.6.1. Need for regulation

The measurement of CO2 emissions of H2-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 CO2 emissions of H2-bi-fuel vehicles operating in H2 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.

8.6.2. Open issues and need for specification

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8.6.3. Assessment of harmonisation - development of a GTR

In the case of 2-wheeled motorcycles a worldwide harmonisation is possible, because GTR's for the measurement of CO_2 emissions already exists. This is not the case for LDV, and the development of a worldwide harmonised test cycle and measurement procedure especial for LDV using H_2 in ICE as H2-bi-fuel is not efficient and feasible.

In the case of motorcycles with ICE using H_2 (H2-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 need the extension of the scope to H2-bi-fuel vehicles and the decision about the measurement of CO_2 only in the petrol mode. 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 mid-term activity.

For LDV it should be considered to introduce this H2-bi-fuel approach (see above) with the WLTP GTR [5]. In the meantime, existing national legislation or ECE-R101 can be amended.

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

9. NOISE EMISSIONS

9.1. Explanation and Specification of the issue

In legislation the noise emissions of vehicles (stationary and moving) and of tyres are regulated.

The noise emissions from internal combustion engines powered with H2 are comparable to conventional vehicles. Fuel cell vehicles can be considered as quiet vehicles, like electric powered vehicles. Regarding tyres it's the same situation as with conventional vehicles.

The UNECE World Forum WP.29 has determined that road transport vehicles propelled in whole or in part by electric means, can be critical to 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].

9.2. Application and Scope

In principle all vehicle categories can be powered by H2 [1]:

- passenger car (category 1-1 vehicle)
- bus (category 1-2 vehicle)
- truck (category 2 vehicle)
- 2 or 3 wheeler (category 3 vehicle)

Also possible, is the use of H2 in agricultural and forestry tractors [8] and Non Road mobile Machinery (NRMM) [9]. Today there is not big interest for marketing of such solutions. Therefore these vehicle categories will not be further covered by this report.

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

9.3. Definitions

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9.4. Overview on existing Regulations & Standards

ECE Regulation R 41 (motorcycles) and R 51 (passenger cars, trucks, busses) covers test procedures and performance requirements to limit the noise emissions of these vehicles. Rolling sound emissions of tyres are regulated in ECE R 117.

These existing regulations are already applicable for H2 powered vehicles.

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

9.5. Work to be done and state of research

Concerning the issue of noise emissions of Hydrogen powered vehicles special research activities are not necessary.

9.6. Regulatory approach

As a conclusion, it is not proposed to develop a special GTR for the measurement and limitation of noise emissions of H2 vehicles.

10. REUSABILITY, RECYCLABILITY AND RECOVERABILITY

10.1. Explanation and Specification of the issue

The European directive 2005/64/EC [19] provides the administrative and technical provisions for the type-approval of vehicles, (categories M1 and N1), aiming to ensuring 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.

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

10.2. Application and Scope

In principle all vehicle categories can be powered by H2 [1]:

- passenger car (category 1-1 vehicle)
- bus (category 1-2 vehicle)
- truck (category 2 vehicle)
- 2 or 3 wheeler (category 3 vehicle)

Also possible, is the use of H2 in agricultural and forestry tractors [8] and Non Road mobile Machinery (NRMM) [9]. Today there is not a large interest for marketing of such solutions. Therefore these vehicle categories will not be further covered by this report.

10.1. Definitions

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10.2. Overview on existing Regulations & Standards

Hydrogen vehicles with internal combustion engines do not crucially differ from conventional vehicles using conventional fuels. In contrast, hydrogen fuel cell drive trains differ substantially from drive trains of conventional vehicles. Apart from the fuel cell with all necessary auxiliary units the electric system of these vehicles is comparable to the electric system of hybrid vehicles using internal combustion engines.
Due to expensive and rare materials used in fuel cells (catalysts, MEA, etc.), reusability and recyclability are important issues.
No existing 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 fuel cell components [20, 21, 22, and 23] and general life cycle assessment requirements and guidelines could be found in the ISO 14044:2006 [24]

10.3. Work to be done and state of research

Concerning the issue of reusability, recyclability and recoverability of Hydrogen powered vehicles special research activities does not seem to be necessary.

10.1. Regulatory approach

Regulations addressing the issue of reusability, recyclability and recoverability of hydrogen vehicle components (especially fuel cell components) need to be considered.

However it is not proposed to develop a special GTR addressing H2 vehicle's reusability, recyclability and recoverability.

11. HARMONISATION ASSESSMENT IN THE AREA OF ENVIRONMENTAL AND ENERGETIC ASPECTS

This chapter summarises the findings and recommendations on the regulation approach to be taken based on the chapters dedicated to each issue (see above).

11.1. Fuel consumption

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

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

11.2. Fuel Quality

Once the technology to produce and assure the quality of hydrogen fuel containing minute amount 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 FCV.

11.3. Pollutant Emissions of Hydrogen (H2) Fuelled Vehicles

In case of HDV and 2-wheeled motorcycles a worldwide harmonisation is possible, because GTR's for the measurement of pollutant emissions already exists. This is not the case for LDV, and the development of a worldwide harmonised test cycle and measurement procedure especial for LDV using H2 in ICE is not efficient and feasible.

In case motorcycles or HDV with ICE using H2 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 GTR's only need the definition of the reference fuel, the calculation method for NOx (H2-fuel) and the definition of the H2-bi-fuel approach. This can be considered as a mid-term activity for both vehicle categories.

For LDV it should be considered to introduce a reference fuel (gas), a calculation method for the NOx emissions and the definition of the H2-bi-fuel approach with the WLTP GTR. In the meantime, existing national legislation or ECE-R 83 can be amended.

As a conclusion, it is not proposed to develop a special GTR for the measurement and limitation of pollutant emissions of H2 vehicles.

11.4. Carbon dioxide (CO2) Emissions of Hydrogen (H2) Fuelled Vehicles

In case 2-wheeled motorcycles a worldwide harmonisation is possible, because GTR's for the measurement of CO2 emissions already exists. This is not the case for LDV, and the development of a worldwide harmonised test cycle and measurement procedure especial for LDV using H2 in ICE as H2-bi-fuel is not efficient and feasible.

In case motorcycles with ICE using H2 (H2-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 need the extension of the scope to H2-bi-fuel vehicles and the decision about the measurement of CO2 only in the petrol mode. 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 mid-term activity.

For LDV it should be considered to introduce this H2-bi-fuel approach (see above) with the WLTP GTR. In the meantime, existing national legislation or ECE-R 101 can be amended.

As a conclusion, it is not proposed to develop a special GTR for the measurement of CO2 emissions of H2 vehicles.

11.5. Noise emissions

ECE Regulation R 41 (motorcycles) and R 51 (passenger cars, trucks, busses) covers test procedures and performance requirements to limit the noise emissions of these vehicles. Rolling sound emissions of tyres are regulated in ECE R 117.

These existing regulations are already applicable for H2 powered vehicles.

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

As a conclusion, it is not proposed to develop a special GTR for the measurement and limitation of noise emissions of H2 vehicles.

11.6. Reusability, recyclability and recoverability

Regulations addressing the issue of reusability, recyclability and recoverability of hydrogen vehicle components (especially fuel cell components) need to be considered. However it is not proposed to develop a special GTR addressing H2 vehicle's reusability, recyclability and recoverability

11.7. Summary and conclusions

There are three areas in the field of regulations for Hydrogen and Fuel Cell Vehicles (HFCV) where it makes sense to aim for international harmonisation:

1. test methods for the measurement of fuel consumption.
2. test and calculation method for the measurement of pollutant and CO2 emissions.
3. definition of a reference fuel for test purposes.

In the first case i.e. fuel consumption, the recommendation is to use existing or underdevelopment standards and harmonise them on international basis. The open question here is the development of a harmonised test cycle (it is underway at the UN ECE) but in the meantime the harmonisation will be in the method for the measurement of the fuel consumption allowing each region to apply its own test cycle until the world harmonised test cycle is not been approved.

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.

It is, however, recommended to waive a development of a stand-alone GTR for environmental related provisions for HFCV's. It is preferable to amend case by case existing ECE Regulations or Global Technical Regulations to accommodate this class of vehicles or to consider HFCV directly during the developing process of new regulations.

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