HarmonHY

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HarmonHy

Harmonization of Standards and Regulations for a sustainable Hydrogen and Fuel Cell technology

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Report on industrial and societal needs

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PREFACE

This work has been developed within the HARMONHY Project, which is a SSA funded by the European Commission. The work has been carried out within the HARMONHY consortium with Centro Ricerche Fiat (CRF) as the principal author. Comments and questions about the test procedure shall be directed to Emanuele Bellerate (emanuele.bellerate@crf.it) at CRF.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

REFERENCES

Part 1

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Part 2

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INTRODUCTION

Automotive and component industries involved in the hydrogen and fuel cell areas need regulations and standards as guidelines for the safe and economic market introduction of the technology.
The final target of the industry (automotive or stationary) is to put on the market a competitive and publicly acceptable technology: devices that can be directly bought (for example cars) or systems/plants that can be available for the society (for example refuelling stations).
A major issue for mass production industry is, therefore, that normal, untrained people can use hydrogen applications at least as safely as conventional applications (hydrogen cars comparable to gasoline cars, hydrogen fuel cell CHP comparable to natural gas CHP, etc.)

The process of introducing hydrogen technology involves both technical and regulatory aspects. Technical aspects are related to the "well-design" concept; regulatory are all those aspects related to governmental approval, which is a necessary step when a fuel often perceived as dangerous is to be put on the market.

Taking hydrogen refuelling stations, for example, there exist regulations and directives that enable approval of these systems but at a local level rather than using internationally accepted ones. Public integrated (with other fuels) hydrogen refuelling stations in e.g. Berlin, Washington, Singapore have been approved. The experience in the CUTE Project shows that approval of hydrogen stations is possible, but the process is time consuming, it varies between different countries depending on the local authorities, their knowledge and other stakeholders.

During the development of the technology necessary to introduce hydrogen as a fuel, various aspects have been put forward, for which the availability of internationally agreed standards is needed or at least opportune for the consistent development of the technology worldwide. On the other side, for the automotive sector, some aspects involving the safety and the environment have been recognised as needing regulations, establishing performance based guidance as the basis of certification.

As a very rough categorisation, Standards, for technical design rules, and Regulations, for government approval, have to be introduced and suitably harmonised in order to prescribe reproducible procedures, agreed at the international level, as a prerequisite for a general diffusion of the technology. The key is to have harmonised requirements and standards at a global level.

PART 1

INDUSTRIAL NEEDS

P1 1. OBJECTIVES

A first step in the pathway towards creation and harmonisation of Regulations, Codes and Standards (RCS) is the identification of those key issues that will allow industry to go beyond barriers to technology commercialisation. They are often called "industrial needs", implying industry requirements and wishes to allow the industrialisation of the technology.

It must be pointed out that hydrogen is a well-known gas used by many industries, including oil refineries for diesel hydro cracking processes, for many years. The aerospace industry also, has managed hydrogen as a fuel for propulsion systems for some decades. Oil and aerospace industries show, therefore, that hydrogen can be managed and that existing technology is available. Most of the knowledge is transferable, but the wide spread use of hydrogen in new industry sectors that are much more public-oriented (automotive, micro power generation, infrastructure for hydrogen distribution) introduce a series of new issues that the available technology does not cover.

The demand coming from these new hydrogen industry sectors is driven by a need for equal competitive conditions at a global level and highly reliable and safe hydrogen systems or plants. With respect existing industrial uses of hydrogen, two key factors must be taken into consideration when speaking of knowledge transfer to mass production industry:

- hydrogen devices would be used in much wider areas without the benefit of skilled personnel knowing how to handle it
- cost is an important issue for automotive and stationary for mass production. The requirements of the aerospace industry permit acceptance of higher costs

Standards and Regulations aim to give answers and tools to satisfy this demand, giving possibility to the public use of hydrogen devices.

Other needs from the industry side are associated with the analysis of market potential of the new technology, since the aim of industry is to make a profit. Moreover, recent approach from the Governmental (European Community) side put attention on the economics associated to new technology under the process of Regulation development[1].

Development of RCS documents is already under way (as shown by previous WP[2] reports) and many coming from different RCS Bodies are already available.

Figure 1, proposed by the HarmonHy consortium, shows possible interactions between different FCS bodies in hydrogen and fuel cells.

[1] By the way, economic aspects are beyond the scope of this document and they will not be taken into account

[2] Refer to Deliverable D1.1 and D2.1 for more information about the state of the art of S&R (D1.1) and research activities related to this field (D2.1).

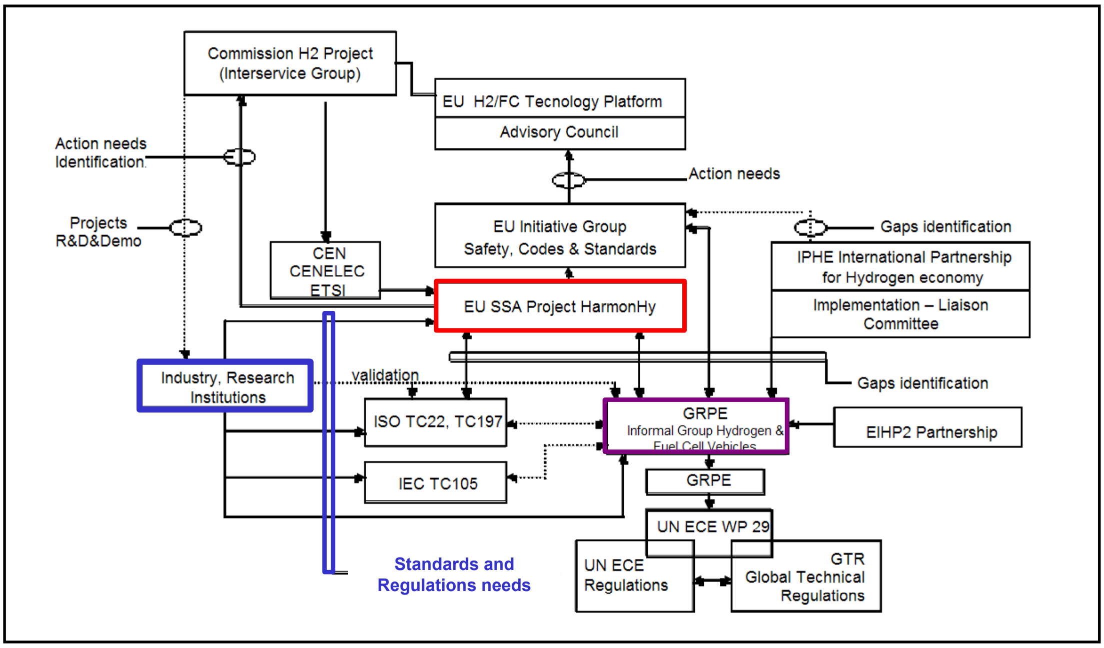

Figure 1. Possible interactions between RCS bodies in Hydrogen and FC [1]

Industrial and research institution's inputs are required at ISO, IEC, WP29 level. The aim of HarmonHy is to give a picture of the industrial needs in a "cross-reference" way, taking into consideration all the stages of the hydrogen chain (Figure 2). An example of such "cross-referenced" issues is the hydrogen sensors: it involves all the stages of the chain, from production to utilization, but, for example, technological targets and specifications for vehicular application are different from requirements in oil refineries, for example.

It must be pointed out that particular attention is focussed on the utilization stage of the hydrogen chain (Figure 2) since issues related to production and distribution of hydrogen are quite known from existing industries.

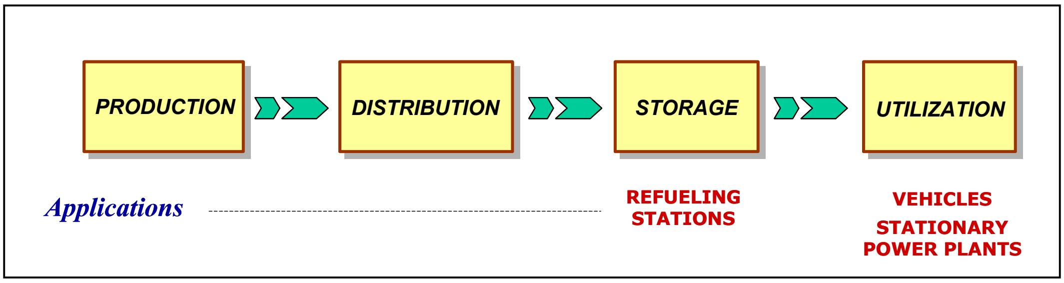

Figure 2. Hydrogen chain and main applications taken into consideration in the WP

Applications may be different also for the type of technology that is adopted as "hydrogen user". In some cases, in fact, fuel cells have different needs (see Table 3) than other kind of end users. A schematic of adopted technology is given in Table 1 where shadowed cells (colours have no meaning, it is only for an aesthetic factor) are those related to applications that are taken into consideration within the report.

	Hydrogen	Fuel cells
STATIONARY		
Refuelling stations		
Power plants		
VEHICLES[3]		

Table 1. Matrix of technologies taken into consideration in the report

Sources for the inventory of such industrial needs are mainly:

- Experience of different partners involved in hydrogen and fuel cell technology research and development
- Workshop "Regulations and Standards on H_2 and FC technologies for vehicles"
- RCS Bodies activity
- European IG-RCS activity

Referring to main tasks, not all of them have the same relevance.
As pointed out in deliverable D2.1, establishment of a quantitative metrics is not so easy, especially when speaking of a new technology far from market introduction. The market potential associated to a certain industrial need may be a key parameter: the higher is the influence of that certain need on market introduction of hydrogen technology, the higher is its priority. But, at the moment, it is very difficult to make market forecasts in this field[4].
Traffic light is a methodology used to give a qualitative measurement. It was used by the IG-RCS and HarmonHy WP2, when evaluating state of the art of research projects, also adopted it. In WP4 matters, the association between colours and priorities seems not to be so clear and easy to understand; as a result it has been preferred to link the priority to a four steps ranking:

Rank	Features
3	an essential issue for market introduction and commercialization
2	an important issue for market introduction and commercialization
1	Relevant but not important for market introduction and commercialization
0	Not relevant

[3] Vehicles taken into consideration in the report have hydrogen on-board as fuel. Vehicles with an on-board fuel processor are not here considered, mainly because most of the car manufacturers are no more putting their attention on it

[4] When speaking of the future of hydrogen and fuel cell technology, the reference way to assess it is the "scenario" methodology, not a precise marketing analysis.

Table 2. Ranking to assign priority to industrial issues

Criteria to assign priority to different issues reflect Companies' view point on the technology, even if there is a common agreement on essential tasks.
Among vehicular partners in WP4, BMW and CRF have different politics about on-board hydrogen storage: BMW is involved in liquid, CRF in compressed. Two companies, therefore, are much more sensitive on issues related to their politics on fuels: BMW has put priorities on liquid hydrogen, CRF mainly on compressed.

A final remark involves different organizations, which have to use these industrial needs. From Figure 1, it is clear that, in parallel with S&R Bodies, they should be used also by European Community to take actions towards those areas that require additional research efforts.
Some of the identified issues are therefore discussed more in detail, in order to give more information to justify why it is a requirement from industry.

P1 2. FINDINGS

P1 2.1 Main issues

Table 3 identifies the main industrial need that are related to pre-normative activity It shows requirements from those industry sectors where hydrogen and fuel cells represent a new technology still under evaluation.
In deliverable D2.1, some themes for pre-normative research are identified in order to make an assessment of areas covered by research in recent years. Many of those issues can be classified as industrial needs.

Issues have been included in three main categories:

- General requirements. They are related to general themes, not directly involved with a particular application
- Vehicle Regulations. They are (**mainly**) related to needs coming from the automotive industry for vehicle approval
- Stationary applications. They are (**mainly**) related to needs coming from industry involved in stationary applications

This classification is, obviously, quite rough, since many of the industrial needs are cross-related, referring both to stationary and automotive applications. EMC and protection from electric hazards are mostly debated in an automotive context, but they are very important also in stationary plants (home applications) when fuel cells are involved.

Moreover, some requirements affect only fuel cell technology and not systems with hydrogen combustion (for example, hydrogen quality issue is related to fuel cells, but not with internal combustion engines). For each issue, therefore, application areas are reported.

	Nr	ISSUES	Stationary		Vehicles	
			H_2	FC	H_2	FC
General requirements	1	Terms and definition (terminology)	x	x	x	x
	2	Hydrogen sensors and detection	x	x	x	x
	3	Hydrogen quality		x		x
	4	Materials compatibility	x	x	x	x
	5	Materials Recycling		x	x	x
	6	Hydrogen components	x	x	x	x
	7	CFD modelling validation	x	x	x	x

	8	Safety measures in enclosed spaces	x	x	x	x
	9	Performance standards and codes		x		x
Vehicle regulations	10	Electromagnetic Compatibility		x		x
	11	Protection from electric hazards		x		x
	12	Hydrogen system integrity (normal operations / crash)			x	x
	13	Emission measurements			x	x
	14	Fuel consumption measurement methods			x	x
	15	Fuel cell system power output definition		x		x
Stationary applications	16	Risk assessment and documentation of industry	x	x	x	x
	17	Fuelling hoses, fuelling nozzles and dispenser interface	x		x	
	18	Storage systems	x	x	x	x
	19	Refuelling devices and communication signals	x		x	x
	20	Metering H2 at the HRS (Hydrogen Refuelling Stations)	x	x		
	21	Gas appliance safety	x	x		
	22	Low voltage grid connection	x	x		
	23	Software control systems	x	x		

Table 3. Main issues as "industrial needs"

In the following sections of the deliverable, some details about most of the issues in Table 3 are provided, showing which are problems for industry associated to them and therefore identifying possible areas for pre-normative research.

P1 2.2 General requirements

P1 2.2.1 Terminology

A common terminology must be introduced within the world of hydrogen and fuel cells in order to avoid misunderstandings in:

- definition of operating conditions

- definition of systems/subsystems (example: fuel cell vehicle electric architecture - Figure 3 by ISO TC22/SC21 based on SAE J2574)
- component related issues

It is a very cross-related task, involving both stationary and vehicular applications. Because of differences in applications, different documents about terminology are expected: the key issue is the agreement of shared tasks between these documents.

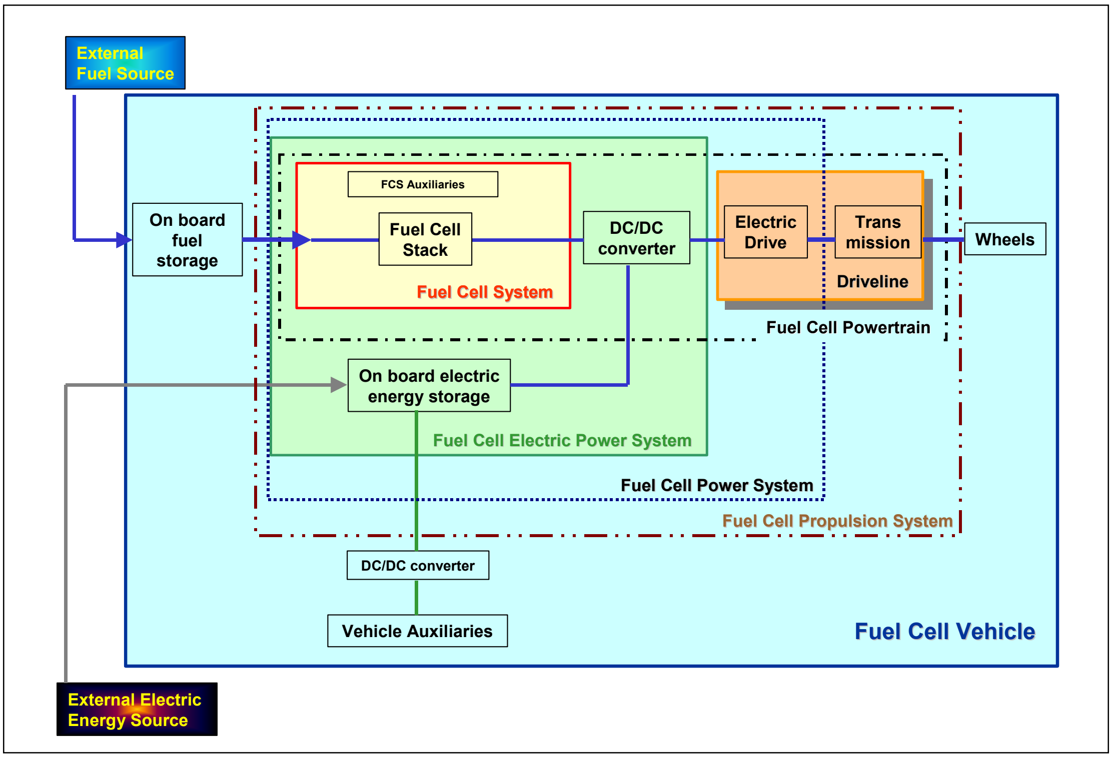

Figure 3. Example of proposal for terminology for electric architecture of fuel cell vehicles [2]

P1 2.2.2 Hydrogen sensors and detection systems

Looking at the activity within the Standardization Bodies, the approach to solve the issue of hydrogen vehicles' safety varies according to different bodies.
The common reference between different ways of interfacing with this issue involves, as primary tasks, the need to measure hydrogen leakage and to prevent gas accumulation.

Concerning hydrogen detection systems, useful practical knowledge is already available and devices, working on different physical principles, are provided by sensor industry. Each kind of sensor has advantages and disadvantages in its performances. For this reason, improvements in sensors' technology are required, especially when speaking of vehicular applications.
Needs from the end user side concern:

- development or technical improvement of existing hydrogen sensors, able to satisfy requirements in terms of:

- response time
- operating conditions (temperature, pressure and humidity)
- electric energy consumption
- cost
- reliability
- sensitivity to target gas (and cross-sensitivity to other gases) and detection range

➢ identification of the location of sensors with respect to hydrogen system integration

➢ agreed trigger levels

P1 2.2.3 Materials compatibility

At present in hydrogen industry the most common way to solve problems due to hydrogen compatibility with materials is a wide use of face-centred cubic metals (the most representative is stainless steel AISI 316). Hydrogen, under high pressure condition, penetrates into the material, lowering local or overall mechanical properties and reducing life by accelerating crack propagation during fatigue cycles. Figure 4 [3] shows a comparison of mechanical resistance of an austenitic steel under cyclic loading in air ambient (black signs) with hydrogen ambient (white signs).

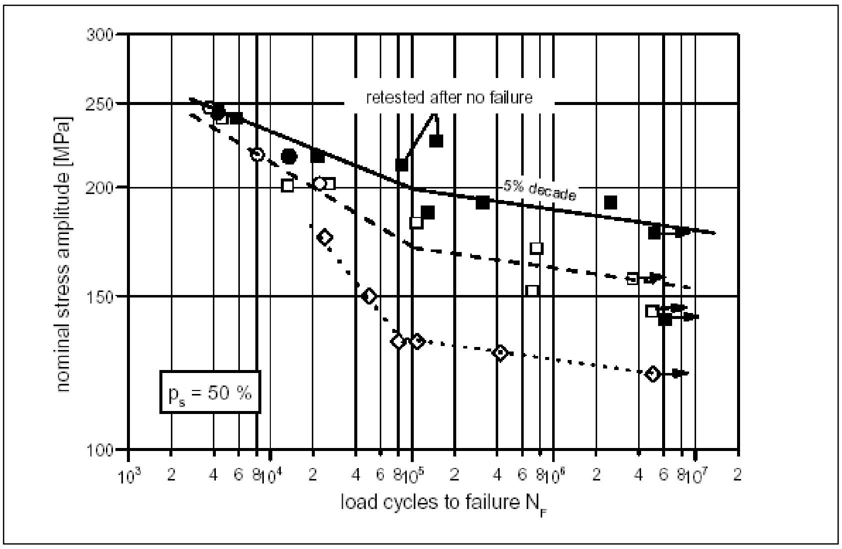

Figure 4. Effect of hydrogen on mechanical resistance of austenitic stainless steel [3]

Austenitic stainless steel is a viable way both for vehicular and stationary applications because of the small market associated with hydrogen at present: benefits coming from safety are higher than costs due to the use of a "precious" material. It is however recognized that the wide spread introduction of hydrogen is linked to the widespread availability of less expensive materials for components throughout the hydrogen chain, from distribution pipelines to end-users applications. An essential requirement for these materials is to keep operational characteristics. In high stress environments (high pressures and temperature gradients), high strength materials are needed, but they are often sensitive to hydrogen embrittlement.

Another requirement is associated to resistance to hydrogen permeability.
Polymers like polyethylene (PE) are widely used in low-pressure pipelines of natural gas local distribution networks. The main issue related to the use of existing natural gas infrastructure for hydrogen transport is the leakage of hydrogen due to permeability of PE. A further example is the use of non-metallic materials in hydrogen containers to reduce weight and cost.

The balance between costs and requirements to guarantee the safety of systems and/or plants must come out from RCS based on:

- hydrogen embrittlement in steady flow
- hydrogen embrittlement under pressure fluctuations
- hydrogen permeability
- hydrogen attack in high temperature applications

P1 2.2.4 Hydrogen quality

Fuel quality is a topic that has been taken into consideration in the recent past by oil companies to evaluate the environmental impact (pollutants and greenhouse gases) in association with new technologies [4] for internal combustion engines.

Hydrogen quality is a requirement mainly for fuel cell operations, where electrochemical reactions are more sensitive to the presence of impurities in reactants. Systems where combustion is involved (internal combustion engines or gas turbines running with hydrogen) are more tolerant of impurities.
This issue, even if it is an issue directly connected to fuel cell operation, has impact also on the hydrogen chain. At the production stage, additional purification devices should be added and refuelling stations should be able to manage different type of hydrogen, differing in costs[5]
Moreover, as it comes out from an activity performed in FUEVA WP5[6], requirements from stack manufacturers are different from:

- those in the Standard ISO14687 (the reference standard about hydrogen quality)
- those coming from car manufacturers, which is the reference Standard for hydrogen quality.

Obviously, these differences stress the necessity for standardization in this area.

	Ballard	NUVERA	Ford / DC	ISO 14687	Anuvu.
H2 purity (%)	99,995	99,9995	99,9	99,99	99,5 / 99,95
O2 (ppm)	ns	1	1 vpm	ns	ns
H2O (ppm)	ns	2	50 (liquid)	not to be condensed	ns
N2 (ppm)	ns	2	200	ns	ns
HC (ppm)	ns	0	1	0,01 µmol/mol	ns

[5] This issue is quite common in fuel stations, where different degree of fuel is available: according to octane number (gasoline) or sulphur content (diesel)

[6] Data in Table 4 were obtained through contacts with fuel cell suppliers and end users.

CO (ppm)	ns	0	2	0,2 µmol /mol	5
CO2 (ppm)	ns	0	2	ns	ns
H2O vapour (%)	ns	ns	0.1		ns
S compounds	ns	ns	1	0,0002 µmol /mol	0
NH3 (ppm)	ns	ns	0.01	ns	ns
He (ppm)	ns	ns	200	ns	ns
Ar (ppm)	ns	ns	200	ns	ns
Particles (ppm)	ns	ns	10	fuelling station requirements	ns
Max. Part. size (µm)	ns	ns	10	ns	ns
Oil	ns	ns	ns	ns	0
Specific requirement				HCHO < 0,04 µmol /mol	

Table 4. Hydrogen quality requirements for fuel cell applications[6] [5]

In order to develop such a standard, some technical feedback is necessary. In particular, influence of hydrogen quality on:

- ➢ performance of the fuel cell [6] (Figure 5)
- ➢ degradation of fuel cell life

should be evaluated.

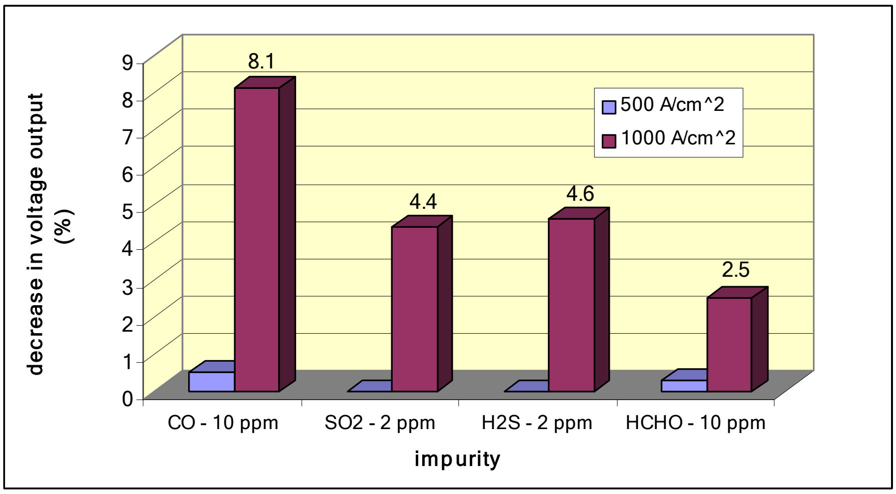

Figure 5. Effect of impurities in fuel cell performances (steady state – 5 minutes sample) [6]

Concerning degradation of fuel cell life, it is important to define which impurities and at which level the cell voltage can be recovered by using pure hydrogen (99.9999%) or the damage is unrecoverable (this is particularly true for sulphur compounds, even at very low concentrations).

P1 2.2.5 Recycling

End of life of vehicle (ELV) issues are getting higher importance when considering whole environmental impact associated to cars. The European Union introduced a directive on end of life vehicles in 2000 [7], which requires auto producers to cover the cost of vehicle recovery and sets several targets for reuse, recycling, and recovery, including a target of 85% reuse and recovery, by weight, by January 1, 2006.
Nowadays, very little information about fuel cell recycling is available. Taking into consideration a stack power density around 1.5 kW/kg (the best technology at the moment), a 90 kW stack would represent around 5% of the whole vehicle weight.

A complete Life Cycle Analysis of a fuel cell system is quite impossible to perform: there are no data for the ELV part[7]. It is quite common for a new technology, when great efforts are focussed to demonstrate the correct behaviour that recycling is seen as a one step beyond issue.
Among different parts to be recycled and recovered a relevant role is played by platinum. FCV uses almost 20 to 30 times the platinum (noble metals) content of ICE vehicles. Because of the availability of such a metal in case of a wide FCV market share, the issue of how to recycle this material is crucial.

P1 2.2.6 Hydrogen components

Conflicting needs emerge from the automotive industry towards standardisation of components that are used in association with hydrogen.
Annex 1 gives a picture of hydrogen related components in the automotive field, showing priorities for development of International Standards

P1 2.2.7 CFD modelling validation

CFD (Computational Fluid Dynamics) may play a relevant role in:

- development of Codes and Standards
- tool for design phase

both in stationary and vehicular applications.

Simulation with very powerful tools covers the study of the time evolution of hydrogen releases in enclosed spaces (garages, tunnel) according to accident scenarios, allowing evaluation of the level of risks that are associated to a certain starting event.
In the automotive field, crash test approval under the UNECE Agreement is possible with simulations, without undergoing very expensive "hardware" crash tests. This procedure is possible only if reliable tools are available.
CFD modelling in hydrogen applications suffers two kind of problems that have to be solved:

- an intensive experimental activity should be carried on in order to validate CFD models

[7] Few available fuel cell LCA give information about LCI and operational phase impact of a fuel cell system, but nothing about EoL is given. Honda showed a methodology to perform such an analysis, but without any kind of data.

- tools should be "certified" in order to have results that are useful for systems approval

P1 2.2.8 Safety measures in enclosed spaces

Hydrogen releases to the atmosphere (because of accidents or some devices malfunctioning or human factors) is one of the key points to be understood in order to make the use of hydrogen acceptable by the public and not only by experts.
The way in which an hydrogen release would behave is strongly dependent on many factors and variables. Important factors are related to the velocity of dispersion: accident damage could bring a large leakage in a short time, a pinhole in an equipment would bring to a slow and constant flow rate leakage
But also very important is the "environmental" factor, i.e. if the release happens in enclosed spaces or in open air. With respect to LPG or gasoline, hydrogen is light and tends to rise in air: this is an advantage in open air, but it may be critical if buildings are not properly designed for hydrogen.

Most considered enclosed spaces are linked to vehicular application, e.g. maintenance facilities or garages, even if storage systems rooms (for example refuelling stations, where pressurized hydrogen at 400 bars or liquid hydrogen are stored) also are enclosed spaces which have to be carefully studied.
Time evolution of hydrogen concentration (and potential risks associated to this concentration) in a garage or a tunnel[8] due to release is a debated issue in the scientific community. Even with "conventional" fuels, where a very long time experience exists, accidents in enclosed spaces are still a problem[9], showing that a stronger relationship between risk assessment and legal approval has to be established.
There are two key factors when generally speaking of enclosed spaces on which Standards and Regulations are required to give clear guidance:

- identification of safety measures to mitigate damages associated to hydrogen-air mixture
- identification of preventative measures in order to avoid some critical situations

Many papers associated with this issue show that a lot of work has been done, but further work is required both from an experimental point of view and from calculation point of view (importance of well-established CFD codes – section 2.2.7).

P1 2.2.9 Performance standards

As reported in Table 3, fuel cells and fuel cell systems are affected by a lack of harmonized testing procedures to evaluate and compare their performance.

[8] The choice of garage and tunnel as enclosed spaces is due to different kind of releases that may happen: in garage a slow release, in tunnel a high release in short time because of accidents

[9] In many garages, for example, vehicles with LPG are not allowed to park because of the potential for the formation of a potential explosive vapour cloud on the floor.
Tunnel accidents, even when involving gasoline vehicles, have sometimes a high number of fatalities because of a lack of tunnel safety measures (see for example Mont Blanc tunnel accident some years ago)

Disagreements between laboratory results and real operation behaviour of fuel cells/systems are undoubtedly due to the lack of reproducible procedures demonstrating how the stack would behave under real operating conditions.
Lack of procedures include tests on:

- stack life
- particular ambient conditions (freezing temperatures, for example)
- resistance to vibrations

P1 2.3 Requirements related to vehicle Regulations[10]

In order to allow public use of vehicles, vehicle manufacturers have to fulfil legal requirements. This is true all around the world, e.g. in Europe EU Directives or ECE Regulations or in United States FMVSS. The technical requirements often differ between markets. A further difference is in the procedure to meet this legal approval: in Europe it is a Type Approval (referred as WVTA – Whole Vehicle Type Approval), in US it is self-certification.
Nevertheless, many of the issues that have to be satisfied by industry, in order to make the vehicle running on streets, are the same: final documents, where major changes due to hydrogen as a fuel and fuel cells as an electric generator would be placed (UNECE Regulations in Europe or SAE recommendations in US), are different, must be modified through answers at common questions and requirements coming from industry.
More recently GTR[11] (Global Technical Regulations) aims to have common technical requirements for vehicle approval all-over the world. GTR are now recognized to be the final aim of all work on vehicle approval requirements. Work is now in progress for the development of a GTR for hydrogen vehicles, however, differences in philosophy between Europe, US and Japan is a key issue.
The impact of pre-normative research in vehicular applications was the basis of a workshop [8] organized by European Community, in which the link between status of pre-normative research, standards development and GTR development was shown. A summary of the workshop is reported in Appendix D of Deliverable D2.1

In the following, attention is focussed on European Type Approval. Each Regulation is a legal requirement that the vehicle must satisfy. However, technical issues associated to EU WVTA have a general "validity", since they can be related in most cases also to outputs coming from ISO, SAE, and other SDO.
As an example, UNECE R83 and R101 (see Table 5) deal with the same problems as SAE Standard proposal SAE J2572 ("Recommended practice for measuring the Exhaust Emissions, Energy Consumption and Range of Fuel Cell Powered Electric Vehicles Using Compressed Gaseous H2").

Existing UNECE Regulations and EU Directives can be taken as a starting point to evaluate which kind of changes are necessary. Anyway, Japanese and US requirements have to be considered with the

[10] Issues related to vehicle introduction on th emarket are also debated in Part 2 (Section P2 2.2.1)

[11] GTR refer to the UNECE Agreement in 1997

aim to develop a GTR. It is not the aim of this deliverable to focus on this aspect of vehicle Regulation (it is a difficult task to be solved), but it has been preferred to give look at the requirements from industry to have a WVTA for hydrogen vehicles.

Hydrogen vehicles introduce three major new items in the world of regulations:

- a carbon-free fuel
- an electric powertrain not driven by batteries or other electrochemical storage systems (fuel cell powertrain)
- Significant technical developments of existing technology, e.g. advanced gaseous and liquid hydrogen containers

All these three issues have implications on some of the existing documents. A list of Regulations to be modified is shown in Table 5[12]

Reg. nr	Title
R10	Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility
R34	Uniform provisions concerning the approval of vehicles with regard to the prevention of fire risks
R68	Uniform provisions concerning the approval of power-driven vehicles including pure electric vehicles with regard to the measurement of the maximum speed
R83	Uniform provisions concerning the approval of vehicles with regard to the emission of pollutants according to engine fuel requirements
R85	Uniform provisions concerning the approval of internal combustion engines or electric drive trains intended for the propulsion of motor vehicles of categories M and N with regard to the measurement of the net power and the maximum 30 minutes power of electric drive trains
R94	Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a frontal collision
R95	Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a lateral collision
R100	Uniform provisions concerning the approval of battery electric vehicles with regard to specific requirements for the construction, functional safety and hydrogen emission
R101	Uniform provisions concerning the approval of passenger cars powered by an internal combustion engine only, or powered by a hybrid electric power train with regard to the measurement of the emission of carbon dioxide and fuel consumption and/or the measurement of electric energy consumption and electric range, and of categories M_1 and N_1 vehicles powered by an electric

[12] Other EU projects deal with Regulatory issues, showing which documents have to be modified to obtain a WVTA. For example EIHP II

	power train only with regard to the measurement of electric energy consumption and electric range
R110[13]	Uniform provisions concerning the approval of: I. Specific components of motor vehicles using compressed natural gas (CNG) in their propulsion system; II. Vehicles with regard to the installation of specific components of an approved type for the use of compressed natural gas (CNG) in their propulsion system
R122	Uniform technical prescriptions concerning the approval of vehicles of categories M, N and O with regard to their heating systems

Table 5. UNECE regulations that have to be under examination for hydrogen (FC and ICE) vehicles

Table 3 partially takes into account needs coming from modifications to these regulations. Table 6 shows the links between identified industrial needs and regulations.

Nr	Issue	Regulation
6	*Hydrogen Components*	*"R110"*
10	Electromagnetic Compatibility	R10
11	Protection from electric hazards	R100
12	*Hydrogen system integrity (normal operations / crash)*	*R94 / R95*
13	Emission measurements	R83
14	Fuel consumption measurement methods	R101
15	Fuel cell system power output definition	R85
18	Storage systems	R34

Table 6. Links between existing UNECE Regulation and identified industrial needs

P1 2.3.1 EMC and electric hazards

EMC and electrical hazards are mainly related to fuel cell powertrains, where high voltage power bus and many electronic devices are placed on the vehicle.

[13] The automotive industry is almost unanimous in NOT wanting R110 to form the basis of any future H2 Regulation. Here the reference of R110 is taken in order to stress the necessity of something similar as a new intermediate Regulation for hydrogen vehicles

Concerning electrical hazards, it is a primary issue, since it involves protection of people. Existing documents for battery electric vehicles are a main source, as a high voltage power bus is also placed on them: hazards due to electric sources are identified (electrical shock, direct & in-direct contact, protection failure, over-current and over-voltage). In contrast to battery vehicles, major attention has to be focused on the behaviour of the fuel cell system during certain operating conditions (e.g. start-up, shut-down), and on safety requirements associated to the fuel cell itself as an electrical generator.

EMC implies the ability of the vehicle to properly function in an electromagnetic environment, mainly electric transients, voltage fluctuations and load changes during normal operations. The presence of many electronic devices (traction inverters, dc/dc converters, actuators control devices) implies a harder electromagnetic environment than on common ICE vehicles.
The vehicle should not be a source of electromagnetic disturbances, but neither be intrinsically unsafe in terms of electromagnetic immunity (the ability of a vehicle or other electronic devices without performances degradation under an electromagnetic environment): all sensors and transducers, that play a relevant role in safety, and must not suffer of disturbances due to electronic devices within the powertrain itself.
The approach has to be both at a component and at system level. EMC involves also cabling electrical design and interactions between different sources may lead to consequences not expected from the EMC behaviour of each single component.

P1 2.3.2 Fuel consumption

According to current Regulations, fuel consumption is measured evaluating the carbon content at vehicle tail pipe. It is clear that the use of a fuel without carbon, such as hydrogen, means that Regulation for measuring fuel consumption has to be changed:

- concerning measurement methods
- concerning testing procedures (vehicle conditioning)

Several measuring methods were proposed and are under evaluation at international level. The main task is the accuracy of measurement. In Europe the required accuracy is 1% on NEDC test procedure: each of the methods under evaluation have critical weak points, bringing disagreements in results.

Annex 2 provides a summary of hydrogen measuring methods taken into consideration during recent years, especially by bench and field tests performed by JARI [9]

P1 2.3.3 Emissions

Vehicles running with hydrogen have less pollutant emissions than conventional fuels ones. When driven by a fuel cell powertrain, emissions are water (in liquid and vapour state) and hydrogen (when purging); while nitrogen oxides have to be taken into consideration when hydrogen feeds an ICE.
The regulatory bodies should discuss whether measurement of water emissions is something required for WVTA.

P1 2.3.4 Storage systems

Storage system is the source of energy on the vehicle and at the refuelling stations. The way to manage it is therefore very important both for transportation and stationary applications.

R34 gives requirements for fuel tanks (liquid fuels) in order to prevent fire risk. It is clear that this Regulation has to be modified according to hydrogen properties (different from liquid fuels) and to specific physical state of hydrogen (compressed or liquid).

For stationary applications, it would play a role documentation about hydrogen dispensing mode. Safety measures associated to cascade filling or booster storage systems must be identified, taking into consideration that booster can reduce the amount of hydrogen to be stored at the station and therefore it can increase safety.

P1 2.4 Requirements related to stationary applications

Stationary applications hereafter primarily refer to refuelling stations. The process of achieving legal approval is very time consuming. As it has been reported by EIHP II, this process in Europe involves around six steps, each of them taking time, while licences & certification involves more than one Authority: among them there are fire and municipal building authorities.

Because of the lack of Codes and Standards, plant design is performed according to certain guidelines that are based upon best practice and industry's knowledge putting, as primary scope, the safety of the refuelling station in all its aspects

P1 2.4.1 Refuelling connection devices and communication

As a general issue, refuelling connection devices include the refuelling nozzle, hoses, valves, and all those components[14] that are necessary to move the fuel[15] from the station storage to the vehicle.
The necessity for standardization in this issue is quite obvious: to avoid different interfaces according to different device manufacturers with the practical and safety issues that would result. This is the current situation for liquid hydrogen where different manufacturers supply nozzle and receptacle that, in most cases, are not interchangeable. Standardization under SAE & ISO is moving towards a unique nozzle/receptacle design for different hydrogen storage pressures for compressed hydrogen storage.

[14] A common terminology is accepted at SAE and ISO level

[15] Three forms of hydrogen refuelling are encompassed in the following assessment: compressed gaseous hydrogen, liquid hydrogen, and blends of CNG and hydrogen.
The dispenser equipment used for these three types of hydrogen refuelling will be different and distinct.

Looking at the system, requirements involve both system approach (which components have to be compatible) and design level (how components have to be designed in order to satisfy constraints associated to operative conditions).
Experiences so far indicate that the components and performance of the refuelling connection device need to be improved: this applies to all components (fuelling hoses, nozzle, receptacle and dispenser interface).
Critical parameters identified for the standardisation of hydrogen refilling devices are the following:

- mechanical resistance
- hydrogen compatibility
- refuelling pressure
- nozzle/receptacle interface geometry
- lower pressure receptacles (vehicle) must not be compatible with higher pressure nozzles (refilling station).

Vehicle refuelling is a critical process that has to be carefully managed. During these operations, vehicle vessel and other components are subjected to high temperature gradients and high pressures (over pressure is used to compensate compression heat) in the case of compressed hydrogen. When liquid hydrogen is refuelled, thermal stresses due to the very low fuel temperature are present
These operating conditions imply a hard attention on mechanical resistance of components associated with the material behaviour when in contact with hydrogen (section 2.2.3).
Major risks during a vehicle refuelling are overfilling and overheating, which depend on tank temperature increase during the operation: the shorter is the time required to fill the vehicle tank, the higher would be the temperature increase.
The importance of a communication protocol between vehicles and station is due to the importance of information exchange, in particular temperature evolution inside the car tank. Unfortunately some problems arise when getting this information:

- equipment (temperature indicator) is installed by vessel or car manufacturer, but is used by station operator who has to control the operation with an unknown equipment
- an additional connection method between vehicle and station must be installed for data exchange, with a protocol suitable for all kind of vehicles
- temperature of gas inside the tank is not homogeneous during refuelling: it means that the most suitable position to place temperature sensors have to be defined

An optimised refuelling procedure must be implemented in order to allow all people to have accessibility to safe refuelling operations.

Even if different problems are associated to liquid hydrogen refuelling procedure (no problem with over heating because of overpressure, for example), the same industry needs come out.
Technical standards for the correct design of components are as major a requirement as a safe procedure for refuelling.

P1 2.4.2 Risk assessment and documentation

Hydrogen refuelling stations have already been built and approved.

Among aspects that are related to Authority approval, risk analysis plays a relevant role because it shows if risks, due to hydrogen systems, are acceptable or if additional measure to reduce risk must be introduced.

A common tool used to perform risk analysis is the so-called QRA (Quantitative Risk Analysis).
Industrial companies designing and operating the stations are responsible for necessary risk and safety analyses. In some cases third parties, e.g. notified bodies such as DNV and TUV will be used. In some cases notified bodies are required e.g. to provide CE – marking.

An open issue concerns the role and relationship between standardization and safety analysis. Experimental results, that can be used to improve knowledge and to put reliable data in databases to perform QRA and other safety analysis tools, is an industrial need because it would be important to establish a liaison between risk analysis and development of hydrogen codes and standards

On the other side, the requirements for safety analysis should not be subject to standardisation and regulations as the need for these studies will probably be reduced in line with more operation experience and development of best practice, guidelines and standard solutions for the stations/installations.

P1 3. PRIORITIES ASSOCIATED TO INDUSTRIAL NEEDS

Industrial needs (Table 3) are requirements from industry to establish hydrogen technology on the market, which is based on agreed RCS. It has to be recognized that different degrees of relevance are associated to industrial needs to speed-up hydrogen and fuel cells commercialization.
Since the aim of Harmonhy is to give indication about pre-normative research, it seems necessary that public efforts would focus on those issues that may help accelerating commercialization of the technology.

Table 7 gives an indication of priorities for each of the main issues that were identified in Table 3 according to the following ranking:

- 3 points → essential for commercialization
- 2 points → important for commercialization
- 1 point → not important for commercialization

Because of different priorities associated to different hydrogen components for vehicular application (taking into consideration a separation between liquid and compressed hydrogen), a separate section (Annex 1) is devoted to this issue.

Nr.	ISSUES	PRIORITY
1	Terms and definition (terminology)	● ● ●
2	Hydrogen sensors and detection	● ● ●
3	Hydrogen quality	● ● ○
4	Materials compatibility	● ● ●
5	Materials Recycling	● ○ ○
6	Hydrogen components*	● ● ●
7	CFD modelling validation	● ● ●
8	Safety measures in enclosed spaces	● ● ●
9	Performance based standards and regulations	● ● ●
10	Electromagnetic Compatibility	● ● ●
11	Protection from electric hazards	● ● ●
12	Hydrogen system integrity	● ● ●
13	Emission measurements	● ● ○
14	Fuel consumption measurement methods	● ● ●
15	Fuel cell system power output definition	● ● ○

16	Risk assessment and documentation of industry	
17	Fuelling hoses, fuelling nozzles and dispenser interface	● ● ●
18	Storage systems	● ● ●
19	Refuelling devices and communication signals	● ● ○
20	Metering H2 at the HRS (Hydrogen Refuelling Stations)	● ● ○
21	Gas appliance safety	● ● ●
22	Low voltage grid connection	● ● ●
23	Software control systems	● ○ ○

Table 7. Priorities for identified industrial needs

With the exception of issues like materials recycling whose last level priority is due to a "time" aspect (they are not so important in the very near time), all the identified issues are important or essentials for hydrogen commercialisation.

Essential to commercialisation are those issues directly related to:

- behaviour of the system
- good operational conditions of the system

Issues related to first category (behaviour of the system) can be well identified.
In the second category (good operational conditions of the system), fuel quality can be taken as an example: it would be difficult to put on the market a device whose performances are affected in a very hard way by the quality of the fuel.

P1 4. CONCLUSIONS

Requirements for a industrial needs analysis stem from the application of hydrogen and fuel cell technology to industrial sectors that are different to those sectors in which hydrogen has been used up to now. This difference is related to the mass introduction of hydrogen technology into areas of daily public use.

The use of hydrogen in the aerospace and other industrial sectors e.g. space bases and oil refineries characterised by the use of specially trained personnel. If the technology is transferred to public applications, new safety aspects must be taken into account, especially in early phases of market introduction while keeping great attention on cost issues.
Regulations, Codes and Standards (RCS) can be seen as the means to reach a well established hydrogen market, since they give requirements for approval (regulations) and technical guidelines (codes and standards). On the other side, development and harmonization of RCS should be done in line with market and technology development and demands.
Even if hydrogen has been used for many years, there is lack of RCS because of the application areas. It means that experience in hydrogen is already present in industry, and that a merge between knowledge from past experience and requirements due to its use in new industrial sectors is a necessary way to speed-up its introduction to a mass public market.
Looking at the hydrogen chain, the main open issues are related to end users, rather than production and delivery. Liquid and compressed hydrogen is carried on trucks to be transported from production plants to different end-users, and hydrogen pipelines are already in operation.
For this reason, industrial needs taken into account in this report are mainly associated with automotive and stationary applications.

The present work shows that many issues have to be solved to establish RCS for hydrogen in both stationary and automotive applications. It must be pointed out that these requirements are linked to pre-normative activities: it is not the aim of RCS development to undertake basic research linked to operational issues. As an example to clarify this point, one of the key points in fuel cells research is the development of high temperature membrane for vehicular applications. It is a research issue, but it is not related to pre-normative research and therefore is not taken into account.
On the other side, an issue like CFD validation does not imply the creation of a specific standard about these tools, but it is important to have a validation of different hydrogen release models in order to save time (during the design phase) and money (to avoid expensive experimental tests): these are two essential needs of industry.

A classification of industrial needs has been done not only on the application, but also on the adopted technology. Fuel cells have different requirements than other hydrogen-based systems. Hydrogen quality, problems of EMC and/or electrical hazards are related to fuel cells, while they are not affecting systems where hydrogen is burned.

Looking at the final target of a mass production industry, issues that are related to “legal” approval of systems play a major role.
Stationary and vehicular applications are at a different stage. Experience from CUTE project showed that approval can be obtained in different countries, with different approaches by Authorities

according to their knowledge on this task. The main problem is the time consuming approach because of different permits and documents to be issued by Authorities.
Concerning vehicles, the situation is much more complex because of the mechanism to have this approval. It is possible to obtain approval from local governments, but procedure varies according to countries or even cities where the approval is required. From an automotive perspective substantial efforts have to be put in action in order to modify where necessary the UNECE Regulations and create a new hydrogen GTR: these efforts can be shared at a world wide level, since industrial needs are the same in Europe as in US and Japan. This is the basis for the GTR development, but different approaches and philosophies around the world on the way to define these industrial requirements is slowing development of such documents.

The priority analysis (Table 7) shows that most of the identified issues are important for commercialisation and many of them are essential for this aim: they are mainly ones associated to regulations and technology development (for example fuel quality). Only exceptions are software control and materials recycling, which can be developed in a second time.
Safety aspects are the common theme in these issues, both for vehicular and stationary applications. Even if the approval process for refuelling stations is currently possible, it has been recognized that some key elements of the refuelling station need special focus on standards in order to achieve safe and simple refuelling operations for public. Among them, user interface (refuelling nozzles and dispensers) are the most important and relevant.

Stress on regulatory aspects does not mean that codes and standards play a minor role. It is difficult, in a phase in which technology is not fully deployed identifying a clear boundary between what is regulation and what is standard and to avoid restricting the development of new and innovative technologies. In many cases an overlap exists between them. Industry asks for a focus on performance based system level requirements.

In summary, the industrial needs from the automotive sector are for globally harmonised technical requirements where needed in the form of a UN ECE GTR using performance based system level requirements except for critical components such as the hydrogen container.
It is commonly agreed, at automakers level, to support all activities towards GTR (BMW, Daimler Chrysler, Fiat, Ford, Volvo Tech). As long as there are no activities in this regard, many of them favour, as interim measure, an EU Regulation.

Where standards are considered necessary, e.g. for refilling connection interfaces, the standards must also have widespread global support, i.e. they should be ISO standards.

PART 2

SOCIETAL NEEDS

P2 1. OBJECTIVES

The report intends to identify the needs concerned with hydrogen management and hydrogen use in general and with the infrastructure (refuelling station)-vehicle interface in particular.
The report will limit to societal needs of RCS (Regulations, Codes & Standards) and therefore does not address cost effectiveness and economic issues in general as they are regarded to be primarily of interest to the industrial needs of RCS section.

P2 2. FINDINGS

P2 2.1 Identified Societal Needs in Relation to Hydrogen RC&S

- Regulatory requirements as a part of Government needs for the vehicle type approval
- Safety hazards abatement
  - consumer
  - general public (e.g. in vicinity of hydrogen installations)
  - workforce
  - risk perception
- Environmental compatibility
  - biosphere
  - atmosphere
  - environmental perception
- Consumer protection aspects
  - global compatibility of user interfaces
  - accessibility and handling issues
  - bureaucratic hurdles
  - consumer information

P2 2.2 Which societal aspects can be ruled by RCS and in which way?

P2 2.2.1 Regulatory requirements as a part of Government needs for the vehicle type approval

For the certification of road vehicles in Europe, regulations or directives are a prerequisite. When standards are used in part or whole, or referenced in the technical portion, the regulation is more acceptable. In order to develop these in a harmonised and recognised form, they have to be established either on UN ECE level as a regulation or on European Commission level as EC directive.

Advantage of a UN ECE regulation (UN ECE, WP.29, GRPE) is that it is not only recognised within the EU but also by a variety of additional countries, depending on which UN agreement they build. The UN 1958 agreement is on the whole vehicle type approval of road vehicles in Europe (UN ECE)

and comprises the following signatories: GERMANY, FRANCE, ITALY, NETHERLANDS, SWEDEN, BELGIUM, HUNGARY, CZECH REPUBLIC, SPAIN, YUGOSLAVIA, UNITED KINGDOM, AUSTRIA, LUXEMBOURG, SWITZERLAND, NORWAY, FINLAND, DENMARK, ROMANIA, POLAND, PORTUGAL, RUSSIAN FEDERATION, GREECE, IRELAND, CROATIA, SLOVENIA, SLOVAKIA, BELARUS, ESTONIA, BOSNIA AND HERZEGOVINA, LATVIA, BULGARIA, TURKEY , THE FORMER YUGOSLAV REPUBLIC OF MACEDONIA, EUROPEAN COMMUNITY, JAPAN, AUSTRALIA, UKRAINE, REPUBLIC OF SOUTH AFRICA.
The UN 1998 agreement provides the basis for Global Technical Regulations (GTRs). Members of this agreement [(E/ECE/TRANS/132 AND Corr.1)] are: CANADA, UNITED STATES OF AMERICA, JAPAN, FRANCE, UNITED KINGDOM, EUROPEAN COMMUNITY, GERMANY, RUSSIAN FEDERATION, PEOPLE'S REPUBLIC OF CHINA, REPUBLIC OF KOREA, ITALY, REPUBLIC OF SOUTH AFRICA, and SPAIN.
In order to bring hydrogen fuelled vehicles on European and global roads, the European as well as global automotive industry have taken the approach to use the United Nations body UNECE WP.29, the global platform for harmonization of legal requirements for road vehicles and here the UN 1998 agreement which also includes the US and China as signatories.
The further advantage of the UN 1998 agreement for GTRs is that it allows the different world regions to pursue their approval procedures in use for the certification of road vehicles, i.e. the whole vehicle type approval approach in Europe and Japan and the self-certification approach in North America.

In Europe, due to mutual recognition of UNECE by the EEC (European Economic Community) directive mechanism, Whole Vehicle Type Approval (WVTA) by EEC will be assured. UNECE regulations and EEC directive cover different parts and items of a vehicle. For Europe only via EEC directives a Whole Vehicle Type Approval (WVTA) is feasible.

As for the hydrogen onboard storage and supply part of the vehicle neither ECE regulations nor EEC directives did exist, since 1999 EIHP undertook the exercise to draft such regulation documents for submission to UNECE. Other ECE regulations and EEC directives rule other safety relevant parts of the vehicle. These regulations had to be adapted to hydrogen technology as well. EIHP also in this area undertook the efforts to develop amendments to these regulations. In particular the following ones:

Subject	EEC-Directive/ECE-Regulation
1. Emissions	70/220/EEC incl. latest amendment & ECE R83
2. Fuel tanks/rear protective device	70/221/EEC incl. latest amendment & ECE R34/58
3. Diesel smoke	72/306/EEC incl. latest amendment & ECE R24
4. Identification of controls	78/316/EEC incl. latest amendment
5. Fuel consumption	80/1268/EEC incl. latest amendment & ECE R 101
6. Engine Power	80/1269/EEC incl. latest amendment & ECE R84
7. Diesel emissions	88/77/EEC & ECE R49
8. Side impact	96/27/EC & ECE R95
9. Frontal impact	96/79/EC & ECE R94
10. Roadworthiness tests	96/96/EC & PTI
11. CO2 labeling	99/94/EC
12. Base Directive	70/156/EEC incl. latest amendment
13. Electric Vehicles	NEW EC Directive & ECE R100
14. Defrost/Demist	78/317/EWG (already under progress)

The globalisation of the approval of hydrogen fuelled road vehicles shall be achieved by developing Global Technical Regulations (GTRs). The GTRs will be submitted to WP.29 of UNECE for discussion and approval.
For a GTR all hydrogen derived safety relevant aspects have to be merged as far as possible into one GTR. The other hydrogen-related safety relevant issues (as e.g. fuel cell, safety in normal and crash condition, fuel consumption, etc.) are to be included as well in a GTR from the beginning.

1.1 On-board storage system safety

Safety of Container and Components
- Lifecycles
- Re-qualification
- Performance
- Purging Limits
- Material Characteristics

Flow Control
Damage Tolerance
Fire Protection
Aging
Material Characteristics
Refuelling
Mechanical Properties

Most items covered in UNECE regulation drafts

1.2 Whole vehicle safety

Crashworthiness
Fire Safety
Hydrogen System Integrity
- Pre-Crash
- Post-Crash

Explosion Protection
Road Hazards Exposure
EMC (EMS)
Spark / Grounding
Electric Shock Protection
- Pre-Crash
- Post-Crash

Emergency Medical Rescue
Controls and Display

Most items not covered in UNECE regulation drafts

1.3 Other aspects including energy and environmental considerations

Pollutant Emissions
Fuel Consumption
Recycling
Regeneration
FC Disposal / Hazmat?
Fuel Quality
Engine Power
EMC (EMI)
Low Temperature

Items not at all covered in UNECE regulation drafts

Figure 6. Established issues to be evaluated for GTR

Consequently, issue to be covered in an upcoming GTR are the following ones:

Informal document No. **GRPE-48-17-Rev.1**
(48th GRPE, 1 - 4 June 2004, agenda item 7.)

For the EU member states an EC directive for the WVTA of hydrogen road vehicles is mandatory and sufficient. In the frame of the European Integrated Hydrogen Project (EIHP/ www.eihp.org) the European industry tried to develop and establish a UN ECE regulation for hydrogen road vehicles between 1998 and 2004. Due to various reasons, the final establishment of a UN ECE regulation failed during the last years.

Due to the laborious and time consuming process of international harmonisation, for the time being, Japan as a first country/ region established a national regulation for the WVTA in Japan in 2005.
In Europe, EC's DG ENTERPRISE, based on the two UN ECE draft regulations:

TRANS/WP.29/GRPE/2003/14 and Add.1,
"UNIFORM PROVISIONS CONCERNING THE APPROVAL OF:
I. SPECIFIC COMPONENTS OF MOTOR VEHICLES USING LIQUID HYDROGEN;

II. VEHICLES WITH REGARD TO THE INSTALLATION OF SPECIFIC COMPONENTS FOR THE USE OF LIQUID HYDROGEN"
[http://www.unece.org/trans/doc/2004/wp29grpe/TRANS-WP29-GRPE-2004-01e.doc]
[http://www.unece.org/trans/doc/2003/wp29grpe/TRANS-WP29-GRPE-45-inf03e.pdf]

TRANS/WP.29/GRPE/2004/3 and Add.1
"UNIFORM PROVISIONS CONCERNING THE APPROVAL OF:
1. SPECIFIC COMPONENTS OF MOTOR VEHICLES USING COMPRESSED GASEOUS HYDROGEN;
2. VEHICLES WITH REGARD TO THE INSTALLATION OF SPECIFIC COMPONENTS FOR THE USE OF COMPRESSED GASEOUS HYDROGEN"
[http://www.unece.org/trans/doc/2004/wp29grpe/TRANS-WP29-GRPE-2004-06e.doc]
[http://www.unece.org/trans/doc/2003/wp29grpe/TRANS-WP29-GRPE-46-inf12e.pdf]

developed by EIHP and a strong effort on the part of GCG to harmonise with ISO standards, and further discussion by the Informal Group on Hydrogen and Fuel Cell Vehicles, started to develop a directive.

The proposal for this directive [10] will use the so-called split level approach that has been used in other pieces of legislation, e.g. in the case of the directive for heavy duty vehicle emissions. This approach foresees that the proposal and adoption of legislation will be made according to two different, but parallel, routes:

- first, the fundamental provisions will be laid down by the European Parliament and the Council in a Regulation through the co-decision procedure;
- secondly, the technical specifications implementing the fundamental provisions will be laid down in a Regulation adopted by the Commission with the assistance of a regulatory committee (CATP – Committee for Adaptation to Technical Progress).

The co-decision proposal will include the general description of the applicable test procedures for the type-approval of the elements of the hydrogen system when liquid or compressed hydrogen is used. It will also specify which of these tests are necessary to carry out in order to obtain type-approval for the components included in the hydrogen fuel system. The basic provisions for the installation of specific components when liquid or compressed hydrogen is used will be included as well. The applicable test procedures and technical specifications for the type-approval of hydrogen components will be specified in detail in the comitology proposal.
This process has been initiated in 2006 and at best may take two years, thus earliest leading to an EC directive ruling the WVTA of hydrogen road vehicles in the EU by end of 2008.
In view of this development, it has to be assumed that also the USA may implement a national regulation based on the FMVSS (Federal Motor Vehicle Safety Standards and Regulations issued by the National Highway Traffic Safety Administration (NHTSA).

A UN GTR then would have to be developed taking into account these three national/ regional regulatory frameworks. The process to develop a UN GTR though has been initiated at WP.29, UN ECE - INFORMAL GRPE WORKING GROUP HYDROGEN FUEL CELL VEHICLES - GRPE-H2FCV). This group is led by Mr. Christoph Albus of the German Federal Ministry of Transportation, Construction and Urban Development [Bundesministerium für Verkehr, Bau und Stadtentwicklung (BMVBS)].

P2 2.3 Safety hazards abatement

Any citizen expects that technical systems used in every day life, should, in addition to providing the services he/she expects from them to be delivered, also behave safely and pose minimal risk, at least comparable to systems he/she already appreciates and knows how to handle and use.

Due to a small number of very few prominent accidents over the last 70 years and negative press coverage, especially in the English speaking language area, hydrogen seems to have an image of being particularly dangerous[16] [11, 12]. However, safety records from sectors where professionally trained people use hydrogen (such as in refineries or chemical complexes) [13, 14], show an excellent level of safety and demonstrate that hydrogen does not pose particularly higher risks than other burnable and explosive gases or substances (such as natural gas, LPG, acetylene, DME) [15]. This also counts for the uses of hydrogen in hydrogen fuelling demonstration projects performed during the last 20 years all over the world.

Any hydrogen-specific regulation and standardisation effort has to take care of the transfer of hydrogen use from the protected industrial sector or from captive fleet operations to every day applications as in e.g. private homes, private cars and in publicly accessible refuelling stations. It has to be ensured that normal, untrained people can use hydrogen applications at least as safely as conventional applications (hydrogen cars comparable to gasoline cars, hydrogen fuel cell CHP comparable to natural gas CHP, etc.). This is an area where regulations and standards can ensure proper handling and management of hydrogen.

In addition to protecting the user/consumer of hydrogen, the general public also has to be protected from any hazards possibly involved in the wider use of hydrogen. This means the vicinity of hydrogen installations has to be taken into consideration when such an installation is being planned, approved, erected and operated. This is done today for each installation using combustible or explosive substances as e.g. refuelling stations, fuel storages, etc. The level of protection is related to the distance, the amount of combustible substance to be stored, the characteristics of the substance, the risk and frequency of failure of the installation (probability, severity), etc.

Workforces dealing with hydrogen are specially trained in today's industrial complexes or captive fleet operations. Also personnel operating/ supervising/ inspecting/ maintaining refuelling stations with hydrogen dispensing facilities will be specially trained as it is for today's fuels. As the experience from industry shows, these specially trained persons can operate hydrogen equipment safely.
With regard to the perception of hydrogen and its risks to society, people, life, and investments, appropriate education and training initiatives have to accompany the widespread introduction of hydrogen use in every day life. Government, NGOs, associations and major industrial stakeholders will have to share this obligation. Such communication strategies or information activities are not typically addressed by RCS and most likely will not be in the future.
In order to put the assessment of hydrogen-related risks into a more methodological frame it might be useful to have a look into the work performed in EIHP2 with regard to Risk Acceptance Criteria and Risk Assessment Methodology for hydrogen refuelling stations as performed by DNV and Hydro:

[16] Myth: Hindenburg Fire In 1937 Proves That Hydrogen Is Too Dangerous For The Public To Use [10]

P2 2.3.1 Hydrogen Applications - Risk Acceptance Criteria and Risk Assessment Methodology from 4.1

Risk acceptance criteria are established for all groups of people that can be exposed to accidents originating from a refuelling station. Different types of criterion are used for these groups. The groups are described in the following.

Third party

Third party risk considers how events on the refuelling station can affect areas outside the refuelling station boundaries and includes people living and working in the vicinity of the refuelling station or visiting/travelling through the neighbourhood. Both societal and individual (or geographical) risk measures should be considered (e.g. FN curves and risk contours).

Refuelling station customers (second party)

This will assess people visiting the refuelling station area to use the facilities. These people will be exposed to the risks at the refuelling station for a limited period of time, while visiting the facilities. Therefore, the risk contribution to each individual will be very low. However, it would be unreasonable to use this as an argument for not considering this risk.

Hydrogen refuelling station personnel (first party)

This includes personnel involved in operation, inspection and maintenance of the hydrogen and/or the conventional re-fuelling station. Generally, a higher risk level will be considered acceptable for this group than for Third party. An individual risk criterion, setting limits to the risk of each individual working at the station, is the most relevant.

		PROBABILITY (per year)				
		A (<0.001)	B (0.01-0.001)	C (0.1-0.01)	D (1-0.1)	E (10-1)
Consequence severity	1 (Catastrophic)	H	H	H	H	H
	2(Severe loss)	M	H	H	H	H
	3 (Major damage)	M	M	H	H	H
	4 (Damage)	L	L	M	M	H
	5 (Minor damage)	L	L	L	L	M

Table 8. Risk matrix. Letters H, M, L denote risk levels High, Medium, Low, respectively

Assumptions based on the perceived needs of new installations require the building of consensus on a global basis and subsequent harmonisation on a global scale. These assumptions are of great importance as they will be used in the following exercises:

- *Risk Assessment Exercises* (Risk Assessment, Rapid Risk Ranking, HAZOP), [16, 17, 18]
- *CFD modelling analyses*,
- The methodologies applied to RA and the CFD modelling tools available, [19]
- The interpretation of the modelling results followed by experiments on key findings to validate the CFD modelling results

Knowledge gained from existing demo projects will also be valuable input for this activity.

It is urgent that a global effort be initiated to establish the validity of the Risk Assessment results and of CFD modelling results supported by experiments so that the global community can rely on credible and widely accepted scientific input into the RCS work as recommended in the preliminary HarmonHy WP5.1 report. This is especially important in the absence of actual experience due to the lack of facilities or budgets to perform real scale testing repeatedly.

P2 2.4 Environmental compatibility

RCS have to ensure that hydrogen use does not pose any environmentally negative influence on every day life and the biosphere.
However, it is expected that an increased end-use of hydrogen – displacing conventional carbon rich fuels - would result in a positive environmental effect. This would be due to the fact that the main emission from hydrogen use in combustion or fuel cell reactions is water vapour, with drastically reduced criteria pollutant emissions (e.g. SO_x, NO_x, C_xH_y, CO, PM) as compared to conventional fuels burned in internal combustion processes[17].

Due to safety reasons, safe handling of hydrogen also means tightness of hydrogen components and systems (pipelines, valves, compressors, LH_2 vessels, etc.), RCS will ensure that no hydrogen will escape into the environment in order not to represent a safety risk. As in recent years the influence of hydrogen on the atmosphere in the region of the troposphere has been raised as topic for discussion, the need for tight hydrogen systems also from this angle has to be ensured.

Several environmental effects sometimes attributed to hydrogen (e.g. increased water vapour or contrail formation by aviation in the tropopause/ lower stratosphere, escaping hydrogen atoms due to leaks in technical systems, water vapour formation from road vehicle exhausts) are usually correctly attributed to hydrogen but are not necessarily only related to a "hydrogen economy" [20]. Hydrogen and/or water vapour are already being released in combustion processes, although at somewhat lower total emission levels. Water vapour formation by hydrogen is of different quality if occurring at the ground (potential visibility problems) or lower flight altitudes vs. emissions by aircraft in the upper troposphere/ lower stratosphere where water vapour acts as quite an active GHG [21]. Consequently an eye has to be kept on an increase of these effects by entering into a wider spread use of hydrogen and additional regulatory measures might be needed for that (e.g. H_2 leaks: see above).

In general, like for all other components used in industry or business, hydrogen components also have to fulfil the recycling quotas requested by law (which in particular is a challenge for composite materials-based components). Drafting of standards for hydrogen components may have to consider these requirements, too.

[17] On this aspect it has to be remarked some different views. For example prof. Santilli, speaking of "oxygen depletion" in case of a hydrogen economy

P2 2.5 Consumer protection aspects

Several real or perceived obstacles of different quality may impede the access of citizens to a technology or a service. Generally based on the human 'interfaces' the access to anything in the human environment is achieved *via* visual, aural or haptic capacity. All feedbacks from these channels are coordinated in the human brain. How far a human exercises these capacities depends to some extent on genetic endowment and then mainly on education and training. These capabilities may be summarized under 'knowledge and skills'.

In order to facilitate the easy and safe use of any technology in everyday life, essential prerequisites have to be fulfilled. There has to be a sufficient level of information on the technology or service provided. The language in which it is communicated has to be understandable in order to be received by the user. The logical, geometrical and visual layout of the component/ service or the interface of the component/ service to be used/ accessed has to enable easy use. An appropriate user guidance can be very supportive, especially as it never can be avoided that the level of knowledge and skills of different users is at least to some extent different. In general, the confidence of the user in the product or service he/she wants to use has to be sufficiently developed in order to motivate the consumer to finally buy and use the product without any preoccupation. As an example may serve the following: if a client buys a battery/ accumulator today he/she knows exactly that an A, AA or AAA type fits perfectly for a special use as indicated. The customer of a compressed hydrogen cartridge also would need to have the confidence that the connector and the pressure level of the cartridge meet exactly the requirements of the intended use and that erroneous connections or uses are definitely prevented. This level of compatibility is already achieved for CGH2 vehicle refuelling connectors as a result of the efforts of the GCG (thus representing a more advanced state for hydrogen connectors on global level ruled in ISO 17268 today than ever achieved to date for CNG connectors on a global level, where full coverage harmonisation is still pending).
Consequently, the layout of the interface for the use of the service/ component/ technology has to be in an easy to understand and to read language and in an easy to absorb layout (colour, design, weight, dimension) in order to allow all people participating in normal daily processes (e.g. driving and refuelling a car) to use the service. This example refers to tall and short people, to incapacitated people, to both men and women, to teenagers, to the growing share of older people in society, to people on their way in different missions (business executives, shopping families, vacation/ leisure time travellers), etc.

Furthermore, easy accessibility in the context of RCS could mean that approval processes and procedures are laid out in such a way that they on one side fully ensure safe and correct handling of hydrogen components but on the other hand also ensure that this is achieved in the least bureaucratic way. One of the examples discussed during the last years was: do valves of pressure vessels have to be approved on single tanks prior to the composition/ assembly of tank storage systems when these systems have to be approved for safe operation anyhow ? Some stakeholders regard this as an especially time consuming and costly approach. Other items can be the frequency and type of recurring inspection of components and how often they will have to be performed and according to which method. As an example may serve the earlier discussion some years ago, if hydrogen storage containers or other components have to be removed from a vehicle or not for recurring testing.

In general RCS should be developed not only according to the technological state of the art but also according to principles which will allow their later effective application facilitating also an affordable and easy large-scale introduction of hydrogen components into our energy and transport system and

thus into our society. RCS efforts should also take into account processes which allow for a non-bureaucratic introduction of new technological/ scientific findings into regulatory and standardisation processes. This shall ensure that no undue hurdles are being established by early RCS activities.
A better-informed consumer is required in energy issues in general and about hydrogen in particular [22]. Very often decisions are based on false, incomplete or biased information. This is also valid for hydrogen, e.g. with regard to its product and safety characteristics. Here simple to digest but still thoroughly correct information will have to be provided. In the question of how far such information can be provided in standardised formats or be required by regulatory instruments has to be investigated in more detail and cannot be achieved in this report. Maybe energy or CO_2 labelling 'standards' adopted in the EU or the USA could serve as a first indication which way to go.

P2 3. CONCLUSIONS AND NEXT STEPS

P2 3.1 Conclusions

Regulatory requirements as a part of Government needs for whole vehicle type approval:	In order to bring hydrogen fuelled vehicles on European and global roads the European as well as global automotive industry has chosen the approach to use the United Nations body UNECE WP.29, the global platform for harmonization of legal requirements for road vehicles and here the UN 1998 agreement which also includes the US and China as signatories. The further advantage of the UN 1998 agreement for GTRs is that it allows the different world regions to pursue their approval procedures in use for the certification of road vehicles, i.e. the whole vehicle type approval approach in Europe and Japan and the self-certification approach in North America.
Safety hazard abatement	It has to be ensured that normal, untrained people *can use hydrogen applications at least as safely as conventional applications* (hydrogen cars comparable to gasoline cars, hydrogen fuel cell CHP comparable to natural gas CHP, etc.). This is an area where *regulations and standards can facilitate proper handling and management of hydrogen.* As the experience from industry shows, specially trained persons can operate hydrogen equipment safely. Regulations have to ensure that e.g. refuelling station personnel handling and/or supervising hydrogen

	equipment in publicly accessible areas is *properly trained* Government, NGOs, associations and major industrial stakeholders will have to share the obligation of *providing and implementing appropriate education and training initiatives*. Such communication strategies or information activities are not typically addressed by RCS and most likely will not be in the future. It is urgent that a global effort be initiated to establish the validity of the Risk Assessment results and of CFD modelling results supported by experiments so that the global community can rely on credible and widely accepted scientific input into the RCS work, in the absence of actual experience due to lack of facilities or budgets to perform real scale testing repeatedly. ISO already is in the process of considering such a move.
Environmental compatibility	With the entering of hydrogen into a wider spread use in aviation, an eye has to be kept on an increase of water vapour and contrail formation in the tropopause/ lower stratosphere. Additional regulatory measures might be needed. Drafting of standards for hydrogen components may have to consider that hydrogen-specific components may also have to fulfil the recycling quotas requested by law (which in particular is a challenge for composite materials-based components).
Consumer protection aspects	The confidence of the user in the product or service has to be sufficiently developed in order to motivate the consumer to finally buy and use the product without any preoccupation. RCS accompanied by awareness programs and information campaigns have to facilitate the customer safety, ease of handling and thus confidence in any hydrogen-related product. RCS efforts should also take into account processes which allow for a non-bureaucratic introduction of new technological/ scientific findings into regulatory and standardisation processes. This shall ensure that no undue hurdles are being established by early RCS activities. As very often decisions are based on false, incomplete or biased information, a better information of the consumer is required in energy issues in general and about hydrogen in particular. Simple to digest but still thoroughly correct information will have to be provided. To which extent such information can be provided in standardised formats or be required by regulatory instruments/ procedures has to be investigated in more detail and cannot be achieved in this report

P2 3.2 Next steps

Regulatory requirements as a part of Government needs for whole vehicle type approval:	Ensure and support effective and internationally recognised work of the UN ECE - INFORMAL GRPE WORKING GROUP HYDROGEN FUEL CELL VEHICLES - H2FCV in order to come to a GTR as soon as possible.
Safety hazard abatement	Initiate a working group providing inputs to RCS bodies on *layperson user requirements* for hydrogen technologies to be applied to the publicly accessible environment. Ensure installation of working groups on the development of education & training formats in all ISO TCs and in bodies drafting legal frameworks dealing with requirements for professionally trained personnel. Identify those bodies (on government level, at NGOs, in associations and at major industrial stakeholders) where the natural obligation and interest would prevail in *providing and implementing appropriate education and training initiatives*. Initiate a global effort to establish a platform on which input parameters, assumptions, methodologies as well as interpretation procedures and output formats for Risk Assessment exercises and CFD modelling tools are validated and harmonized.
Environmental compatibility	Ensure installation of working groups in all ISO and IEC TCs ensuring the consideration of any legal requirements on recycling, reduction of materials use, increase of energy efficiency, etc. (e.g. oriented at the directives issued by EC).
Consumer protection aspects	Particularly standardisation bodies like ISO and IEC should establish working groups which develop approaches allowing for non-bureaucratic extension of standards as soon as new technological/ scientific findings have to find their way into existing standards (e.g. advanced hydrogen storage technologies into existing CGH2 or LH2 standards documents). A cross cutting initiative of RCS, public awareness programs, education & training and marketing/ multi media experts has to be initiated on the societal needs of RCS by defining the approaches, measures and formats with which customer confidence in hydrogen products can be established and maintained. The product has to be simple to digest though thoroughly reflecting the reality. Possibly the EU HFP Implementation Panel should consider the form of an ***RCS Platform*** as a sub part of the Implementation Panel to make sure RCS is covered by its Cross Cutting Issues sub-group as well as its other four sub-groups. This would ensure that all RCS matters (up and down) would be dealt with to promote better understanding

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ANNEX 1. HYDROGEN COMPONENTS FOR STANDARDIZATION EVALUATION AND PRIORITIES

Standards Matrix		Priority
Components	**Type of H2**	
Hydrogen storage tanks	*Gaseous H_2 and H_2 blends*	2
	Liquid H_2	
Metal hydride storage tanks	*Gaseous H_2*	
Refuelling connectors	*Gaseous H_2*	3
	H_2 Blends	
	Liquid H_2	3
Interface between the filling station and vehicles	*Gaseous H_2*	2
	H_2 Blends	
	Liquid H_2	
Dispensers	*Gaseous H_2*	2
	H_2 Blends	
	Liquid H_2	1
Pumps	*Gaseous H_2 and H_2 Blends*	
	Liquid H_2	1
Pressure relief valves	*Gaseous H_2 and H_2 Blends*	
Burst discs	*Liquid H_2*	
	Gaseous H_2 and H_2 Blends	
Automatic shut-off valves	*Liquid H_2*	
	Gaseous H_2 and H_2 Blends	
Manual shut-off valves	*Liquid H_2*	
	Gaseous H_2 and H_2 Blends	
Check valves	*Liquid H_2*	
	Gaseous H_2 and H_2 Blends	
Pressure regulators	*Liquid H_2*	
	Gaseous H_2 and H_2 Blends	3
Pressure gauges	*Liquid H_2*	
	Gaseous H_2 and H_2 Blends	
Hydrogen flow meters	*Liquid H_2*	1
	Gaseous H_2	2
	H_2 Blends	
Rigid pressure lines	*Liquid H_2*	3
	Gaseous H_2 and H_2 Blends	3
Flexible pressure lines	*Liquid H_2*	3
	Gaseous H_2 and H_2 Blends	3

Fittings	*Liquid H_2* *Gaseous H_2 and H_2 Blends*	 3
Hydrogen injectors	*Liquid H_2* *Gaseous H_2*	3
Hydrogen vent systems	*H_2 Blends* *Liquid H_2* *Gaseous H_2*	 3 2
Hydrogen leak detectors	*Liquid H_2* *Gaseous H_2*	2 2
Detectors of hydrogen impurities	*Gaseous H_2* *Liquid H_2*	
Filters	*H_2 Blends* *Liquid H_2* *Gaseous H_2*	 3
Hydrogen mass measurement devices	*H_2 Blends* *Liquid H_2* *Gaseous H_2*	 2 2
Heat exchangers	*H_2 Blends* *Liquid H_2* *Gaseous H_2*	 3 1
Seals	*H_2 Blends* *Liquid H_2* *Gaseous H_2*	 3
Pressure sensors	*H_2 Blends* *Liquid H_2* *Gaseous H_2*	 2 1
Level sensors	*H_2 Blends* *Liquid H_2* *Gaseous H_2*	 2 1
Break away devices	*H_2 Blends* *Liquid H_2* *Gaseous H_2*	 1
Hydrogen combustors	*H_2 Blends* *Liquid H_2* *Gaseous H_2*	 2
Gas Cylinders	*H_2 Blends* *Liquid H_2* *Gaseous H_2*	 1 1

Some remarks about components are the same as for some of the industrial needs that are treated in the document. Standardization of hydrogen pipelines is mainly required because of high pressure and low temperature environment, which affect material mechanical resistance (par 2.2.3). Moreover leak detectors were treated in section 2.2.2.

Concerning some of the other components:

- pumps: liquid H2 must be conditioned (temperature, pressure) in order to obtain a safe and efficient filling process. Pumps need standardisation
- hydrogen flow meters: the liquid H2 filling process (filling station to car) will always generate some return flow of H2 from the car back to the filling station. These back flows need correct measuring for proper charging of hydrogen amount that is filled into the car
- hydrogen injectors: no adequate (size, material) H2 injectors are available on the market
- heat exchangers: they are critical since their interior has to cope with temperature differences of more than 350 degree centigrade (liquid hydrogen on one side, cooling liquid of engine on other side)
- sealing: sealing in H2 systems is difficult, since H2 is very volatile. Currently available seals either are very expensive or not good enough
- hydrogen combustor: boil off is unavoidable when using liquid H2. Boil off H2 has to be rendered harmless. H2 combusting/using systems need standardisation

ANNEX 2. HYDROGEN CONSUMPTION MEASUREMENT METHODS

Name of test	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 remodeling unnecessary	N/A for direct hydrogen FCV
Flow method	Direct measurement using flowmeter	Field-proven for Internal combustion engine vehicles	Vehicle remodeling needed Verification of flowmeters
Fill up tank method	Measure to quantity of supplied fuel to a fuel tank	Possible in highway	Low accuracy
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 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 Vehicle remodeling unnecessary	H_2 balance complicated Difficult to measure
Oxygen balance method	Measuring the decline in O_2 conc. in exhaust gas	Simultaneous measurement during exhaust gas test Vehicle remodeling unnecessary	Decline in O_2 is low Accuracy of oxygen analyzer
Pressure method	Calculated from press. / temp. change of fuel container	Easily to measurement 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 Support H_2 purge	N/A for onboad measurement Connecting to gas line