FINAL TECHNICAL REPORT

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ACRONYM: EIHP2

TITLE: European Integrated Hydrogen Project – Phase 2

PROJECT CO-ORDINATOR: L-B-Systemtechnik GmbH

PARTNERS:

L-B-Systemtechnik GmbH, Adam Opel AG, Air Liquide SA, Air Products Plc., Bayerische Motoren Werke AG, BP International Ltd., Commissariat à l'Energie Atomique, DaimlerChrysler AG, National Centre for Scientific Research Demokritos, Det Norske Veritas, EC-Joint Research Centre, Ford Werke AG, Forschungszentrum Karlsruhe, Vandenborre Technologies NV, Instituto Nacional de Técnica Aeroespacial, Messer Griesheim GmbH, Norsk Hydro ASA, Shell Research Ltd., Volvo Technology Corp., Raufoss Alternative Fuel Systems AS, Linde AG

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1 Publishable Final Report

1.1 Executive Publishable Summary

The interest in hydrogen fuelled vehicles, especially those utilising fuel cells, has increased significantly in recent years. Hydrogen is the optimum fuel for PEM fuel cells in vehicle applications, providing the highest overall energy efficiency and can provide the lowest overall emissions. Therefore, hydrogen as a future vehicle fuel supports important societal goals in reducing local pollutants as well as global greenhouse gas emissions. Hydrogen is the most versatile and flexible energy 'carrier', allowing transport and storage of energy from renewable primary energy sources.

In the first 2-year phase of EIHP, proposals for harmonised draft regulations for the approval of hydrogen fuelled road vehicles were developed.

EIHP2, the 3 year follow-up to EIHP, provides inputs for regulatory and standardisation activities on a European and global level facilitating the safe development, introduction and daily operation of hydrogen fuelled vehicles on public roads and their associated refilling stations. Comparative risk and safety analyses developed from the work undertaken in EIHP with respect to the release of hydrogen will provide data in sufficient depth to enable the partnership, comprising 21 partners from 9 countries, to optimise the required inputs for hydrogen related standards and regulations. The proposals for draft ECE regulations for the approval of hydrogen systems on road vehicles were submitted to UN-ECE WP.29 in spring 2001 for further discussion, and have since been monitored and continuously improved to achieve wide international consensus.

The various tasks being undertaken by EIHP2 are divided into 6 work packages, each of which is divided into a number of sub-tasks:

WP1 Overall Coordination	**WP2** Refilling Station	**WP3** Refilling Interface	**WP4** Vehicles	**WP5** Safety	**WP6** Links "EU-USA", Cluster Activities

WP1: ***Overall Co-ordination***

Overall co-ordination of the project; Liaison with the European Commission; Public relations (including EIHP web-site); Organisation of meetings and workshops; Report compilation.

WP2: ***Refuelling Station***

Survey of existing codes and standards relevant for refueling infrastructure

Collection of existing codes and standards with references, has been established, based on searching into web-sites of European and international standardization organizations, among these BSI, AFNOR, EN, ISO, etc.

An overview of Safety Distances recommended for hydrogen dispensing in existing standards and codes has been established

Input to risk assessment studies, risk reducing measures and recommendations of aspects to be addressed in future development of regulations and standards

Conceptual design of refuelling station concepts was established using simplified flow. The flow diagrams were used as a basis for coarse risk assessment studies – so called Rapid Risk Ranking analyses.

The intention was initially to carry out quantitative risk assessment in WP5.2. However, very sparse technical input was available at the time of analyses. This was due to confidentiality aspects related to accident statistics and technical input. In addition the concepts were not finally designed and there is still some way to go until technical information is ready for some of the production units. More detailed technology information could therefore not be obtained, and the basis for carrying out quantitative studies was therefore not available.

The concepts analysed were: Hydrogen filling station based on compressed hydrogen and hydrogen production by 1) Water electrolysis 2) Natural gas reforming, 3) Methanol steam reforming, 4) Ammonia splitting, 5) Compressed H_2 trucked in. A design based on Liquefied hydrogen was also included, but liquefied hydrogen systems has not been examined as much in detail as gaseous systems. The recommendations related to aspects coupled to high pressures may therefore not be valid for liquefied systems. The only difference between the concepts analysed were the hydrogen production technology. Downstream the production unit the concepts were assumed to be similar, consisting of purification, compression, gas distribution, storage and dispenser.

As a result of the coarse risk assessment studies hazards were identified for the different concepts and segments of the refuelling stations studied. Risk reducing measures were identified. These aspects should be addressed in future development of regulations and standards, in the form of practical guidelines on how to minimize the risk involved.

Gaseous hydrogen vehicle refuelling stations – Working Draft prepared:

“Gaseous Hydrogen Vehicle Refuelling Stations” – [includes Guidelines for Design, Installation, Operation and Maintenance] has been prepared. This draft has been submitted to ISO TC 197 WG11 “Gaseous Hydrogen. Service Stations” to be evaluated as a basis for development of an international standard. Development of this document has been the main task of the work in WP2.

EIGA Document IGC 15/96/E “Gaseous Hydrogen Installations” were used as a basis for preparing the draft, and all WP2 partners have contributed with their technical and practical experience in preparation of the guidelines. The document has been prepared for the guidance of designers and operators of gaseous hydrogen vehicle refuelling stations. It is considered that it reflects the best practices currently available. Its application will achieve the primary objective of improving the safety of gaseous hydrogen vehicle refuelling station design and operation. The document is divided into the following main chapters:

- Terms and definitions
- Properties of hydrogen gas
- General design features
- Safety isolations distances
- Compression

- Purification
- Hydrogen vehicle refuelling stations
- Venting
- Dispensing unit
- Gaseous hydrogen refuelling stations in public petrol (gasoline) stations
- Special considerations for operation of hydrogen vehicle refuelling stations
- Electrical equipment and installations
- Fire protection
- Personnel protection training
- Commissioning
- Maintenance and repairs

Risk based maintenance and inspection protocol for hydrogen refuelling stations

A generic risk based maintenance and inspection protocol for hydrogen refuelling stations has been developed. The protocol gives an indication on which areas that deserve extra attention, but if transferred other refuelling stations design specific aspects need to be considered. These include different technical solutions of refuelling plants, the components and their corresponding risks, which may vary significantly from one installation to another.

Due to all the aspects that need consideration in addition to risk, it is recommended to develop a best industry practice (standard) for developing a maintenance and inspection programme for refuelling stations based on a more complete and validated study.

WP3: ***Refuelling Interface***

Identification of the optimum storage pressure for on-board compressed gaseous hydrogen storage; Seek approval of liquid and compressed hydrogen connectors/ refuelling interface; Development of refuelling procedures; Inputs to the standardisation of hydrogen connectors/ refuelling interface.

WP4: ***Vehicles***

Validation of the proposals for draft ECE regulations by following the approval process for vehicles; Monitor & assist the continuing development of proposals for the draft ECE regulations for hydrogen road vehicles; Assist development of Global Technical Regulations for hydrogen road vehicles; Develop procedures for periodic vehicle inspections. Develop proposals for amendments of a number of ECE-Regulations/EC-Directives (see list of Directives/Regulations to be amended). EIHP2 Partners are actively working in the GRPE Informal Group "Hydrogen/ Fuel Cell Vehicles" (IGH) to achieve globally harmonised technical requirements based on the EIHP2 proposals for draft ECE hydrogen vehicle regulations. This Working Group is also strongly supported by ISO TC 197 & ISO TC 22 representation. Additionally EIHP2 Partners are continuing the development of the draft CGH_2 regulation in response to recent experience and comments from EIHP2 Partners and Supporters, industry and authorities.

WP5: ***Safety***

Risk assessment of hydrogen infrastructure. The risk assessments of hydrogen infrastructure included development of a Rapid Risk Ranking methodology suitable for the level of information available at the time of study. Quantitative risk acceptance criteria were also developed. The Rapid Risk Ranking methodology was tested on several different refuelling station concepts for on-site hydrogen generation. These included on-site hydrogen generation based on electrolysis, natural gas reforming, steam methanol reforming, ammonia splitting, as well as liquid and compressed gaseous hydrogen supplied directly to the hydrogen refuelling station by truck or pipeline. A safety study of commercial hydrogen vehicles was undertaken, including numerical simulations of accident scenarios. A comparative study of hydrogen and other fuels was carried out; the results from the safety assessments in WP5 have provided input to support assessments of safety aspects of WP2, WP3 and WP4.

WP6: ***Links "EU-USA" + other Cluster Activities***

The intention of WP6 was to create and maintain international linkages both within the EU and externally, particularly within the US. Through the activities of the partners in WP6 these aims have been achieved:

- Various US bodies including DoE and IHIG are now fully aware of the role and purpose of EIHP. This has been enabled by the unique ability of global companies to span regional divides
- Initial meetings with delegations from the Japanese Electric Vehicle Association and the Japanese Hydrogen Forum have provided a useful first view of the RC&S landscape in Japan
- Summaries of RC&S activities in Europe and the US have been produced and a preliminary high-level gap analysis of European C&S for hydrogen infrastructure has been carried out and shared with key stakeholder in the US

Details of the above initiatives can be found in the summaries of sub-task activities within this document. Some high level conclusions are stated here:

- The leadership of the DoE in the US has provided a much-needed framework for C&S activities in the US which is enabling a focused approach
- Japan is viewed as the most advanced and coordinated with respect to RC&S activities, driven by their desire to commercialise hydrogen vehicles in 2005
- EIHP2 is viewed as a significant strength within Europe by the US but the view still persists that its main function is to create competitive advantage
- Comparison of US and EU gap analyses for infrastructure C&S activities reveals a great deal of similarity in key areas requiring progress. This is a good basis for future international collaboration

1.2 Publishable Synthesis Report

1.2.1 Objectives and Strategic Aspects of the Project

1.2.1.1 WP2 – Refuelling station

WP2.1: Overview of existing regulation and international standards and codes for natural gas, gasoline, diesel, LH_2, $LCGH_2$ and CGH_2:

WP 2.2: Develop refuelling station layout requirements and decide where harmonisation would be beneficial

WP 2.3: List of refuelling station main components. Listing of main components and subsystems and propose where harmonisation and standardisation would be beneficial for the whole industry. Develop draft regulations appropriate to harmonise and standardise components.

WP 2.4: HES: Participate in risk assessment studies and develop a risk-based inspection protocol.

1.2.1.2 WP 3 – Refuelling interface

WP 3.1 Optimum CGH_2 Storage Pressure

The goal of the sub-task is to identify an optimum on-board storage pressure(s) for compressed gaseous hydrogen (CGH_2) non-articulated single deck city buses based on a framework assessment of safety, technical and economic issues, and refilling, vehicle and interface systems. The report also discusses the results in the context of passenger cars because of their different constraints on market acceptance, vehicle range and available storage volume.

WP 3.2 Refuelling Procedures and Testing

The objective of this subtask is to achieve sufficient technical knowledge in order to propose a refuelling procedure for vehicles using compressed hydrogen storage.

The main work consisted in performing modelling and experimental studies on fast filling of a tank with hydrogen under very high pressure in order to simulate refuelling in carefully controlled conditions.

WP3.3 Liquid refuelling interface

The requirements for refuelling procedures for LH_2 vehicles from the point of view of vehicle manufacturers have been defined and possible refuelling concepts were identified. A new coupling for liquid hydrogen has been manufactured and first cryotests with liquid nitrogen were carried out before starting tests with liquid hydrogen.
A test stand for refuelling tests with liquid hydrogen has been designed and constructed and tests with liquid hydrogen were performed. With that it was found that the test equipment had to be further optimised.

For reliable results the CBC (clean break coupling) was equipped with additional high-level temperature and pressure sensors.

A part of the tests were planned to be performed with subcooled liquid hydrogen which is usually done with a pump system but for integration into the existing liquid hydrogen storage test tanks no such system is yet available. For this reasons the test stand was extended by a pressurization system that allowed a liquid hydrogen filling very similar to a pump system.

With the improved test stand and measuring system many fuelling procedure tests for different interface concepts and under various pre-conditions have been performed successfully with liquid hydrogen.

1.2.1.3 WP 4 – Vehicle

WP 4.1/2 - Draft CGH_2 Regulations

During phase 1 of the EIHP, initial proposals were developed for a compressed gaseous hydrogen (CGH_2) regulation for motor vehicles. In EIHP2, the goals of Sub-task 4.1 with respect to the CGH_2 regulation were to:

- i) Submit the draft regulation to the relevant committees,
- ii) Collect and discuss comments from the committees,
- iii) Where appropriate revise the wording of the draft according to comments received.

Following the initial meeting of the GRPE[1] Informal Group "Hydrogen/Fuel Cell Vehicles" (IGH) in November 2001, the EIHP2 CGH_2 working group assisted with further development of the draft ECE[2] CGH_2 regulation within the IGH and activities included:

- i) Compiling comments received on the draft ECE CGH_2 regulation,
- ii) Developing draft responses to comments received,
- iii) Chairing & administering IGH expert working groups.

The draft ECE CGH_2 regulation covers the hydrogen refilling, storage and supply system up to and including the last pressure regulator upstream of the fuel cell system or internal combustion engine.

WP 4.4 - The main objectives of the LH_2 storage validation were:

1. Validation of the EIHP1 draft by following the approval process for vehicles
2. Realisation of a LH_2 - system according to the EIHP1 draft resp. a follow-on draft:
   - tests and approval procedures for LH_2 storage system
   - minor modifications on demand of technical services
   - identification of necessary major hardware changes
   - fulfilment of additional specifications as LH_2 - system shall fit into BMW vehicle

[1] GRPE: See Section 2.
[2] ECE: See Section 1.

3. Identification of necessary changes of EIHP1 draft

1.2.1.4 WP 5 – Safety

WP5.1 Review of Available Safety Data

To provide a critical review of the state of the art in respect of knowledge of hydrogen hazards compared to other fuels

WP5.2 Risk Analysis of Refuelling Infrastructure

The main objective of WP5.2 was to carry out risk assessment studies of hydrogen refuelling infrastructure, with main focus on hydrogen vehicle refuelling stations. The results from these studies would show if the risk of the concepts analysed were acceptable or not, and if further, more detailed risk assessments studies and suggestions of risk reducing measures were necessary. The results were also used as input to development of safety codes and standards for hydrogen vehicle refuelling stations (see WP2).

A detailed HAZOP (hazard and operability study) of one refuelling station concept was completed during the first 12 months. This concept was based on hydrogen production from water electrolysis. The HAZOP results included a list of recommendations to improve the safety of filling stations. The results were used to identify cases for further assessment including quantitative risk analysis (QRA).

As data availability for undertaking detailed risk assessments and HAZOP studies were limited for most technical concepts, an approach with larger focus on course risk assessment was chosen. A specific "Rapid Risk Ranking" methodology was used for these purposes.

"Rapid Risk Ranking" (RRR) of several hydrogen refuelling station concepts with on-site hydrogen generation was performed in order to estimate risks and identify cases for further assessment. The hydrogen re-fuelling station concepts that were considered were: ammonia splitting, water electrolysis, methanol steam reforming, natural gas reforming, CGH_2 supplied from pipeline and truck, and LH_2 from truck.

Specific Risk Acceptance criteria were also developed for prioritisation and categorisation of hazards in risk analysis.

A quantitative assessment of the risk of hydrogen refuelling stations based on gaseous hydrogen, including compression unit, high-pressure storage, gas distribution and dispenser/ refuelling, was carried out. This assessment included quantification of leak frequencies, ignition/explosion/fire probability and quantification of probability of undesired events using Event Tree analysis. The quantitative assessment also included consequence calculations with CFD tools (hydrogen dispersion and explosions) of specific scenarios relevant for a hydrogen vehicle refuelling station. These scenarios were outdoor leaks at a refuelling station, indoor leaks in a hydrogen production enclosure, leaks from high-pressure reservoirs and relief from safety valves

WP 5.3 - Safety Study For CGH_2 Commercial Vehicles

CGH_2 release scenarios were researched and identified for city buses in various environments (inner city streets, tunnels and maintenance garages) in comparison with an equivalent natural gas release. To estimate the consequences related to these scenarios, numerical simulations of hydrogen dispersion and combustion processes have been performed, the models being validated against data from an accidental hydrogen release in Stockholm in 1983. Different storage pressures, release configurations, locations such as maintenance garage, tunnel and inner city streets, and ignition points were considered in the numerical investigation. The results of the simulations were integrated into a study of CGH_2 vehicles and this includes requirements for the direction of future research for commercial vehicles, suggestions for a pressure relief device release strategy, and other ways of improving safety in CGH_2 commercial vehicles.

WP5.4 Simulation Code Validation

The goal of this sub-task was to perform gas-combustion experiments in order to create an experimental database of hydrogen, methane and propane in semi-confined and vented configurations. The database was instrumental in identifying flame acceleration criteria and transition from deflagration to detonation criteria and in providing a set of experimental data for numerical code benchmarking and validation.

WP5.5 Comparative Study

The main objective of WP5.5 was to perform a comparative study between hydrogen and other fuels. As part of the task, the work was focused not only on safety aspects but also on health, environmental and economical aspects.

1.2.2 Scientific and Technical Description of Results

1.2.2.1 WP2 – Refuelling station

WP2.1: Overview of existing regulation and international standards and codes for natural gas, gasoline, diesel, LH_2, $LCGH_2$ and CGH_2:

Collection of existing codes and standards with references has been established, based on searching into web sites of European and international standardization organizations.

An overview of Safety Distances recommended for hydrogen dispensing in existing standards and codes has been established

WP 2.2: Develop refuelling station layout requirements and decide where harmonisation would be beneficial

Conceptual designs of refuelling station concepts were established.

The intention was initially to carry out quantitative risk assessment in WP5.2. However, very sparse technical input was available at the time of analyses.

The concepts analysed were: Hydrogen filling station based on compressed hydrogen and hydrogen production by 1) Water electrolysis 2) Natural gas reforming, 3) Methanol steam reforming, 4) Ammonia splitting, 5) Compressed H_2 trucked in. A design based on Liquefied hydrogen was also included, but liquefied hydrogen systems has not been examined as much in detail as gaseous systems.

As a result of the coarse risk assessment studies hazards were identified for the different concepts and segments of the refuelling stations studied. Risk reducing measures were identified.

WP 2.3: List of refuelling station main components. Listing of main components and subsystems and propose where harmonisation and standardisation would be beneficial for the whole industry. Develop draft regulations appropriate to harmonise and standardise components.

Agreement was formed within the group that harmonisation of individual components would be non beneficial as it could hold back innovation, at the time of consideration most of the components would soon be covered by the PED (Pressure Equipment Directive). There was a consensus that at least the interface with the customer should be standardised as well as the presence of various safety features, together with the connector but this later part fell in the responsibility of WP3 so was not considered further.

The members of WP2 concluded that only the main sub systems in a hydrogen refuelling station should be defined/standardised as follows:

- 1) The generator of hydrogen (source),
- 2) The H_2 dispenser
- 3) The control system.

All other components on a refuelling station (compressors, purifiers, storage etc) will be treated as optional components and these would therefore not be harmonised.

All partners have contributed in development of a Working Draft for 'Gaseous Hydrogen Vehicle refuelling stations'. The Working Draft cover guidelines for the refuelling station components downstream the production or supply unit. Development of these guidelines has been the main task of the work in WP2. Guidelines for hydrogen production or supply are not included.

WP 2.4: HES: Participate in risk assessment studies and develop a risk-based inspection protocol.

A risk based inspection protocol for hydrogen-refuelling stations, has been developed. This protocol has been based on the results from a FMEA analysis.

Development of conceptual design of refuelling station concepts to be used as basis for RRR analyses.
An overview of Safety Distances recommended for hydrogen dispensing in existing standards and codes has been established.

1.2.2.2 WP 3 – Refuelling interface

WP 3.1 Optimum CGH_2 Storage Pressure

Taking into account all of the factors in the assessment framework (safety, technical and economic issues) and the probable direction of storage technology, it appears that for non-articulated single deck city buses an on-board storage pressure not exceeding 35MPa is the optimum. Furthermore, it appears that overnight slow fill may be the most attractive refilling option though this may be influenced by garage land costs (not modelled in this study for slow fill options) if the land-take is substantially greater than fast fill and close vehicle parking. As capital costs account for all of the assumed vehicle costs and dominate the refilling costs, a stable low interest rate future will assist the development of the hydrogen economy. One issue that this study has not investigated is if there is an upper limit in terms of public acceptance based on perceptions of hydrogen and high-pressure system safety. For passenger cars there are clear demands for a vehicle range comparable with conventional vehicles. The shape of the cost/benefit curve is unclear, and restrictions on system cost, safety (i.e. public acceptance), or technical problems other than pressure may become the limiting factor. Given the sparse data on hydrogen systems at very high pressures, no definite recommendation on an optimum pressure for cars can be made, except to support continued research at 70MPa (and above). Limitations on the upper pressure level are not imposed by proposed regulations, directives or standards.

WP 3.2 Refuelling Procedures and Testing

Filling of a 9 litres tank under 40 MPa, without flow rate control has been done. Inlet and outlet temperatures measurements have been done. A good agreement with modelling was obtained.

Conclusion is that to prevent overheating of the inlet wall tank it is necessary to control the hydrogen flow rate (to avoid too fast filling) and perhaps to cool hydrogen before refuelling.

WP 3.3 - Liquid refuelling interface

A) Definition of refuelling procedures In principle two different kinds of refuelling can be distinguished:

1. **Differential pressure systems**
   - 1.1 Two flow system
   - 1.2 One flow system
2. **Pressure raising systems**
   - 2.1 Pump system
   - 2.2 Sub cooled liquid

For these different principles calculations have been done for given boundary conditions.

For differential pressure systems losses in terms of gas evaporation are in the range of at least 8% referring to the refuelled mass. With a pump system these losses can be reduced down to zero.

Fuelling of a liquid hydrogen vehicle storage tank according to defined refuelling concepts has validated the calculations. It was found, that the different approaches for refuelling are extremely influencing the hydrogen losses (evaporation of liquid) and the duration of the filling process:

- differential pressure filling tests produced evaporation losses in the range of 20%
- with the pump simulating filling tests zero evaporation losses were within easy reach and fuelling duration was significantly shorter
- with a pressure raising system evaporation losses of the storage tank at the fuelling station are significantly lower.

For this reason a fuelling system with an integrated LH_2 pump in the fuelling station tank is recommended.

For the case that the fuelling station is equipped with an integrated LH_2 pump a 1-flow system is sufficient for the interface. Such an interface is less complicated and has a less expensive receptacle compared to a 2-flow system.

For the case that a conventional storage tank without pump is used in the fuelling station a differential pressure filling is required. Then a 2-flow system is more reasonable. This leads to a more time saving procedure compared to a 1-flow filling and is advantageous especially at non-optimal conditions.

B) Approved LH_2 connector

A new fuelling coupling, which was originally developed by Messer and further constructed and manufactured by company WEH, has been tested by the German TÜV according to a specific test program. The successful passing of pressure tests leakage tests and functional tests is certified by a test report of the TÜV.

C) Recommendation of requirements for LH_2 interface

a: Fuelling requirements

It was found that requirements for LH_2 refuelling can be divided into three different types of requirements:

i) General requirements for the fuelling system

ii) Requirements for the fuelling process

iii) Requirements for the coupling interface

It was found that 3 main positions which must be fulfilled by the LH_2 interface:

1. Reliable functions
2. Inexpensive receptacle
3. Safety

The requirements, which directly refer to the coupling hardware, may be sub-divided as follows:

1. Fundamental safety requirements
2. Operational needs
3. Ergonomically demands
4. Economical recommendations

The fundamental safety requirements represent a minimum, which, at least, shall be met by the concerned equipment.

The operational requirements for the LH_2- coupling device depend heavily on the refuelling procedure chosen.

The ergonomical requirements demand that an operation by laymen must be without problems.

Concerning the economical requirements it should be considered that in the case of LH_2 vehicle mass-production the number of on-board storage systems would be much higher than the quantity of filling stations.

b: Refuelling signals

Requirements for refuelling signals have been investigated. The results have been summarized and an intermediate recommendation has been worked out for a bi-directional signal transfer.

1.2.2.3 WP 4 – Vehicle

1.2.2.3.1 Summary of results

Within EIHP2, work on the draft ECE regulations continued and has progressed to the most advanced state possible. Both the LH_2 draft and the CGH_2 draft have now reached the status of official documents at GRPE (Working Party On Pollution And Energy a subsidiary body of WP.29 the World Forum For Harmonization Of Vehicle Regulations, of the UNECE) and could be forwarded to WP.29 for political voting.

After EIHP1 was completed, it became obvious that working just on the draft ECE regulations for LH_2 and CGH_2 would not lead to the desired results. Therefore, as another major area of work, communication to outside groups/organisations has been established in order to promote the results of EIHP2 and to ensure that duplication of work is avoided: A workshop with US authorities was held, a meeting with ISO TC 197 took place, a meeting of ISO and GRPE was initiated/held, a workshop with ELEDRIVE was attended as well as the launch of the European Hydrogen Technology Platform.

GRPE decided in their 44th session in November 2002 to stop working on Global Technical Regulations (GTRs) and to focus on ECE regulations. During the 47th session in January 2004 the GRPE Informal Group "Hydrogen/Fuel Cell Vehicles" (IGH) presented a roadmap to GRPE proposing that GTRs should be developed. However, no agreement could be reached on how to deal with the two drafts ECE regulations. Further OICA and GRPE-IGH meetings are scheduled ahead of the next GRPE meeting (48th session). The currently favoured "GTR only" approach is not acceptable for near future registration in Europe. Therefore consensus for the "Parallel approach GTR + ECE's" has to be achieved and submitted at the next GRPE session.

In terms of periodic inspection a draft amending the directive 96/96/EC has been created and is prepared for forwarding to ACEA/OICA (European/world association of automobile manufacturers) in order to start the approval process.

The validation of the EIHP1 drafts has made good progress, although this area is facing some challenges due to the fact that there is not as much experience with hydrogen as with other energy carriers.
Storage systems for liquid and compressed gaseous Hydrogen have been manufactured and their function has been proved. Automobiles using these hydrogen storage systems have been developed or are currently progressing through the design phase.

1.2.2.3.2 Monitoring of Draft (WP 4.1):

During the course of EIHP2 the draft ECE CGH_2 regulation has been significantly improved based on initiatives of the Partners. The technical content of the current version of the proposal has wide support from authorities and industry in Europe and North American industry, and it is harmonised to a significant degree with related ISO drafts and the US SAE standardisation activities. Many iteration steps were taken and so the LH_2 draft has progressed from revision 10 to revision 14 plus an addendum. The CGH_2 draft has progressed from revision 8 to 12b.

Both drafts are now official documents at GRPE, however, since representatives of the USA and Japan do not support the draft ECE regulations, they could not be forwarded to WP.29 for voting.

The final results of WP4.1 are documented on the UNECE web sites of WP.29. The LH_2 draft is listed under TRANS/WP.29/GRPE/2003/14 and TRANS/WP.29/GRPE/2003/14/Add.1; the CGH_2 draft is listed under TRANS/WP.29/GRPE/2004/3. The current IGH version of the draft ECE CGH_2 regulation is Rev.12b, dated 12 October 2003. The current GRPE version of the draft ECE CGH_2 regulation is Working Doc. No. TRANS/WP.29/GRPE/2004/3 with minor amendments in Informal Doc. No. GRPE-47-5. An example (cover page only) is shown below:

UNITED NATIONS

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Economic and Social Council

Distr.
RESTRICTED

TRANS/WP.29/GRPE/2003/14
7 March 2003

ENGLISH
Original: ENGLISH
ENGLISH AND FRENCH ONLY

ECONOMIC COMMISSION FOR EUROPE

INLAND TRANSPORT COMMITTEE

World Forum for Harmonization of Vehicle Regulations (WP.29)

Working Party on Pollution and Energy (GRPE)
(Forty-sixth session, 19-23 May 2003,
agenda item 8.)

PROPOSAL FOR A NEW DRAFT REGULATION

UNIFORM PROVISIONS CONCERNING THE APPROVAL OF:
I. SPECIFIC COMPONENTS OF MOTOR VEHICLES USING LIQUID HYDROGEN
II. VEHICLE WITH REGARD TO THE INSTALLATION OF SPECIFIC COMPONENTS FOR THE USE OF LIQUID HYDROGEN

Transmitted by the members of the informal group "hydrogen / fuel cell - vehicles"

Furthermore, relevant regulations and directives that need modification due to hydrogen operation have been identified:

70/220/EEC & ECE R 83	Emissions of vehicles
70/221/EEC & ECE R 34/58	Fuel Tanks / Rear Protective Device
78/316/EEC	Identification of Controls
80/1268/EEC & ECE R 101	Fuel Consumption
96/27/EC & ECE R 95	Side Impact

96/79/EC & ECE R 94	Frontal Impact
99/94/EC	CO_2 Labelling

A proposal for amending these regulations and directives has been developed and discussed in GRPE ad hoc working group but is not yet introduced to the relevant committees.

1.2.2.3.3 Global Technical Regulation (WP 4.2)

At present there is uncertainty as to if and when ECE CGH_2 and LH_2 regulations will be adopted. The ultimate goal of all parties at the GRPE is a Global technical regulation (GTR) to open up a global market at the lowest cost. However, there is disagreement in how to reach this goal. Work on GTRs could start again as early as of June 2004. This would depend on the outcome of the June 2004 sessions of GRPE and WP.29.

The position of the European Commission, many European countries, Canada and ISO is to introduce an ECE regulation and in parallel to start development of a GTR. This approach permits practical experience to be gained using the requirements and provides a reliable interim means of vehicle approval. Japan, supported by the USA, wants to move directly to the development of a GTR.

1.2.2.3.4 Periodic Inspection (WP 4.3)

In order to ensure a safe operation of hydrogen fuelled vehicles during the whole vehicle life, a periodic inspection of the hydrogen storage system is recommended. Therefore a procedure for the periodic inspection of hydrogen vehicles should be created in this work package.

To start this task, the existing directive 96/96/EC (roadworthiness test for motor vehicles) was investigated and compared with national regulations like StVZO (Germany).

Existing regulations, codes and standards concerning the periodic inspection of hydrogen storage systems (mobile and stationary application) were analysed. The investigation covered national regulation and standards for hydrogen, natural gas as well as European and international standards and regulations on hydrogen and natural gas. A summary of the existing regulations standards and proposal was compiled. However, this summary could still be extended since national and international standards and regulations are subject to changes.

In order to analyse the hydrogen related components of the onboard hydrogen storage system a generic mechanisation of a liquid hydrogen onboard storage system according to the draft proposal for LH_2 revision 12 was created. The generic mechanisation contains the necessary components as well as the optional components of an onboard storage system for liquid hydrogen.

Based on this mechanisation and the experience gained from the operation of vehicles fuelled with liquid hydrogen, inspection critical components were identified and a proposal for a procedure for the periodic inspection of hydrogen related components during the normal vehicle inspection at the workshop and during the roadworthiness inspection was compiled. This proposal was discussed and improved together with the EIHP project partners (e-mail communication, phone communication and a meeting held at Opel).

The work was first started on liquid hydrogen and in a second step extended to CGH_2 fuelled vehicles.

Based on the experience gained from the operation of vehicles fuelled with compressed hydrogen (pressures up to 70 MPa) inspection critical components were identified and a proposal for a procedure for the periodic inspection of hydrogen related components during the normal vehicle inspection at the workshop and during the roadworthiness inspection was compiled. This proposal was discussed and improved together with the EIHP project partners (e.g. DaimlerChrysler with experience from the operation of busses and passenger cars fuelled with CGH_2).

This proposal was the basis for a draft for an amending directive to 96/96/EC that was created during a work package meeting held at Opel.

Main difficulty for the WP4.3 activity was the lack of real field data concerning reliability and need for inspection of hydrogen storage systems. There are prototype vehicles and even small fleets of vehicles and busses with on board hydrogen storage system on the road since some years but there are no large fleets or private customer cars on the road. Especially in the field of CGH_2 with high storage pressure up to 70MPa the experience is limited.

The draft can now be forwarded to the relevant organisations e.g. ACEA or OICA in order to start the process of amending directive 96/96/EC. However, this is not scope of EIHP2 and would have to be done outside EIHP2 or in a successor project to EIHP2.

1.2.2.3.5 Validation of EIHP1 Draft (WP 4.4)

Storage System:

The first "European Liquid Hydrogen Vehicle Storage Tank" has been constructed by Messer according to the EIHP draft version 10...12. For the approval procedure with two TÜV organisations 103 new items had to be clarified. The approval successfully could be obtained.

As the liquid hydrogen system is planned to be installed into a new BMW 7 vehicle the additional specifications from BMW could be fulfilled to a great extent.

The whole tank system was tested at the Messer liquid hydrogen test stand. It shows excellent data e.g. referring to the overall insulation quality; the autonomy time and the supply flow of up to 20 kg/h (Annex 15-WP4.4).

While working on the tank system the EIHP draft has further been developed together with BMW towards version 14 to be delivered to GRPE by BMW.

Air Liquide has designed and built a LH_2 tank according to the requirement of both EIHP rev 12, BMW and Air Liquide in-house highest standard of safety. This tank has been successfully tested and delivered to BMW during the frame of the project.

LH_2 Vehicle

The BMW Group has been working on the field of automotive hydrogen technology for almost three decades. A lot of positive results were achieved thus proving that hydrogen can substitute petrol/diesel as fuel for automobiles.

The chemical industry shows that the usage of hydrogen is safe. However, one must take into account that up to now hydrogen has been handled by experts.

With respect to public usage of hydrogen for transport purposes, technical concepts and standards have now been developed to enable safe and easy handling of cars. Abuse and extreme situations like collisions have been investigated in order to guarantee at least the same high level of safety as is reached by today's cars fuelled with petrol or diesel.

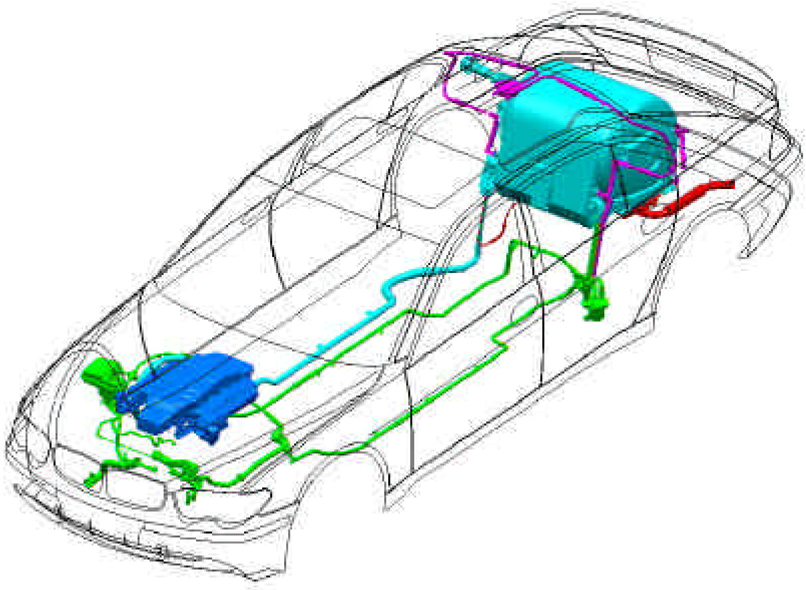
Independently of the vehicle concept (liquid vs. gaseous storage of hydrogen, fuel cell vs. internal combustion engine), there is much communality in safety technology, e.g.:

- Means of hydrogen detection
- Leakages and how to avoid them
- Suitable measures to avoid critical hydrogen/air mixture in- and outside the vehicle
- Crash standards and performance requirements for hydrogen components.

The draft ECE regulation for onboard storage of liquid hydrogen has served as a basis for the development of the LH_2 system for the new BMW 7series.

BMW 7 series with internal combustion engine using LH2

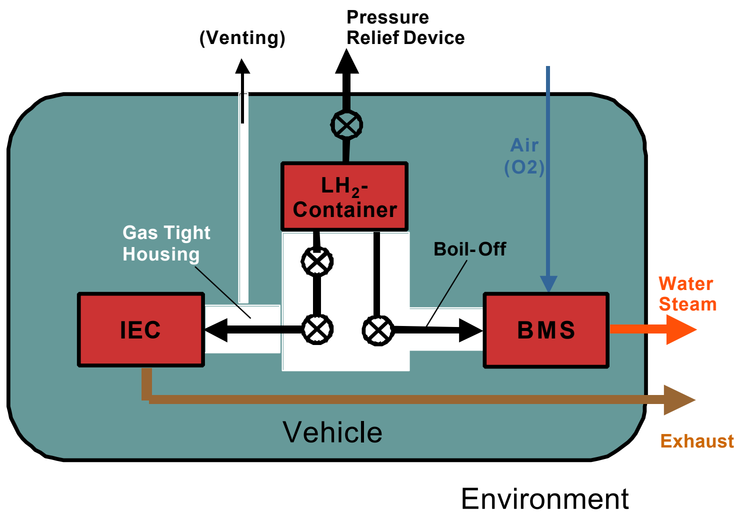
A super insulated container for liquid hydrogen has been developed according to the draft ECE regulation and has been commissioned for and implemented into the present BMW 7 series:



BMW 7 series: LH2 storage and fuel supply system

Initial tests confirm that the safety principles applied to the draft ECE regulation are effective:

- Barrier concept (inside the car the H_2-tubes have double walls as long as connections are not welded)
- Closing and safety valves are redundant, i.e. replace each other when necessary
- High mechanical safety for all components exposed to pressure



BMW 7 series: Hydrogen system with gas tight housing concept

BMW use a so-called boil-off-management system (BMS). If the pressure of the gaseous hydrogen phase in the fuel tank reaches a threshold value, the „boil off-valve“ opens and gaseous hydrogen is transferred to a catalytic converter. Hydrogen and oxygen from the air are then transformed into water steam and released into the environment. This catalytic reaction takes place without the need of additional energy or external control devices. First tests of the system have been successfully passed.

Currently, all hydrogen specific components are strictly required to meet the specifications laid down in the draft regulation and have to withstand hardest testing procedures.

In the near future detailed measurements of the hydrogen consumption and the overall emissions of the car are planned.

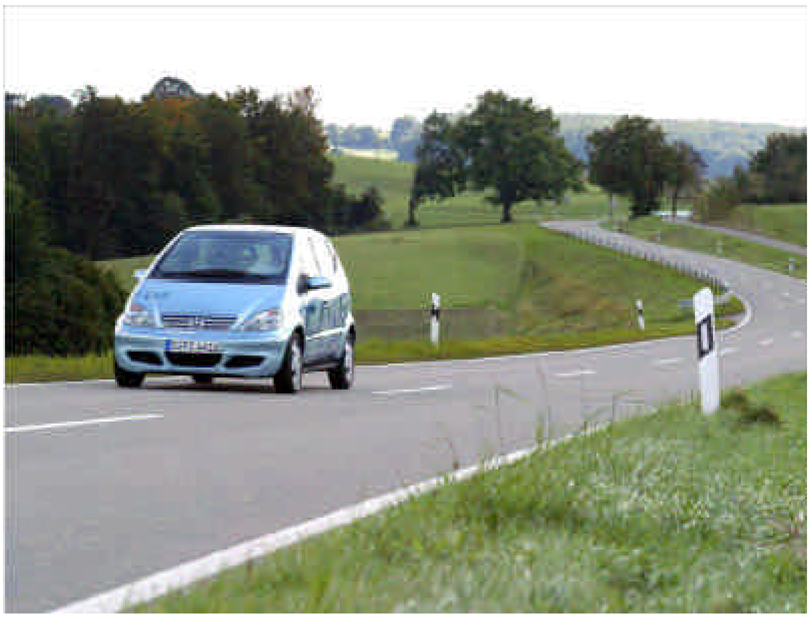
CGH_2 Vehicle

The validation of the CGH_2 draft took place by applying the approval procedures for components and vehicles according to the requirements of the CGH_2 draft. A Technical Service did support these activities and a state of the art fuel cell vehicle with compressed hydrogen onboard storage system was used.

The objectives were to prove the feasibility of the requirements of the draft CGH_2 regulation and to identify necessary changes.

The validation of the CGH_2 draft done by DaimlerChrysler dealt with part II of the CGH_2 draft that details the installation of a hydrogen onboard storage system into a vehicle. The suppliers have done the validation of the specific components. Since there are no type approved hydrogen components in existence, the validation was conducted assuming that type approved hydrogen components would be available.

The project was run using a two steps approach. Each chapter of part II of the CGH_2 draft was looked at and DaimlerChrysler experts made a proposal on a technical solution. The proposed solution was then discussed and agreed upon with the technical service (TUV Rhineland) and implemented in a F-Cell vehicle:



If this process resulted in a contradiction to the draft regulation, it was mentioned under comments with a proposal for amending. These comments for amending were sent to the EIHP WP 4.4 leader for distributing and transferring to the ad hoc working group of GRPE.

The vehicle type approval for the F-Cell vehicle is based on the vehicle description, the description of the hydrogen storage system, the safety concept, the component approval, the confirmation of the vehicle manufacturer that the vehicle complies with the relevant regulations (based on testing, results of crash tests, simulations and calculations) and the visual inspection and engineering evaluation by TUV Rhineland.

1.2.2.3.6 Safety valve (WP 4.5)

Air Liquide and CEA have conducted a safety study on hydrogen release through the safety devices of the LH_2 tank system in case of vehicle rollover under fire.

The goal of the study is to check whether the current rules for safety valves sizing which are taken from the industry (for example CGA) can be applied to LH_2 mobile tanks installed on a vehicle. Those scenarios usually describe either vacuum loss or fire, but the tank rollover + vacuum loss + fire scenario is not describe in the current norms.

This scenario was considered by Air Liquide and its project partners as being the most severe one.

The Air Liquide EIHP tank geometry was modelled using a CEA simulation code SIDONHY developed for diphasic hydrogen flow modelisation in rocket engines. The flow of Hydrogen in case of an accident has been modelled by the CEA taking into account the physical characteristics of the EIHP LH_2 tank.

A separated report has been issued by CEA validating the safety valve calculations made by Air Liquide, and calculating the discharge time of the LH_2 tank when submitted to the rollover + fire scenario.

The emptying flow rates and duration were published and could be used in order to calculate safety distances in case of a LH_2 vehicle crash.

1.2.2.4 WP 5 – Safety

WP5.1 Review of Available Safety Data

In WP5.1 a state of the art review of existing safety data of hydrogen and other fuels reached the conclusion that a ranking of the relative safety of different fuels will depend on each specific application and potential accident scenario. The reason for this is that some aspects of hydrogen (e.g. buoyancy and ability to disperse) are favourable for hydrogen as compared to other fuels, whilst on the other hand for a given size of flammable cloud, the faster burning velocity of hydrogen would tend to indicate larger explosion overpressures compared to other fuels.

WP5.2 Risk Analysis of Refuelling Infrastructure

- Development of a methodology, Rapid Risk Ranking (RRR) and application of RRR to different re-fuelling station concepts. Risk reducing measures were also identified as a part of the analyses. (Several reports and D5.2-WP5.2)

- Development of Acceptance criteria for hydrogen re-fuelling station risk analysis (Report and D 5.2-WP5.2).
- The Quantitative Risk Acceptance criteria and the Rapid Risk Ranking Methodology were published in a scientific paper prepared jointly by DNV and NH, and presented at the 1st European Hydrogen Energy Conference (1EHEC) in Grenoble, France in September 2003. The main results from the RRR studies were presented as a poster (prepared jointly by NH and DNV) at the 1EHEC.
- Recommendations for standards and codes of hydrogen re-fuelling stations (D5.2-WP5.2). Recommendations and mitigation measures were provided as inputs to the draft documents for ECE regulations on vehicles with LH_2 and CGH_2 onboard storage systems and to draft standard documents on *Gaseous Hydrogen Vehicle Refuelling Stations* for submission to ISO TC197 WG 11.

WP 5.3 - Safety Study For CGH_2 Commercial Vehicles

When comparing the inner city and tunnel environments, a similar release of hydrogen is significantly more severe in a tunnel, and the energy available in the flammable cloud is greater and remains for a longer period in tunnels.

When comparing hydrogen and natural gas releases, for the cases and environments investigated and within the limits of the assumptions, it appears that without additional mitigating measures hydrogen is more hazardous than natural gas.

The work has proven CFD modeling techniques to be a useful tool for investigating the release of hydrogen in real world situations. It also underlines the importance and benefits of performing safety studies for hydrogen applications, in order to be able to understand, and therefore, minimise and control the consequences of accidental hydrogen releases to within acceptable levels.

As a result of the work undertaken in Sub-task 5.3 the following recommendations are made for further research:

i) The effect of the fuel concentration range within a flammable cloud on the combustion regime

ii) The effects of wind on the dispersion and combustion of hydrogen.

iii) Hydrogen releases in tunnels must be investigated further to gain a better understanding of the release and ignition conditions that could result in fast deflagrations or detonations, including the effect of different tunnel characteristics.

iv) For PRD release strategies, a detailed risk analysis is necessary before any detailed recommendations can be made.

v) The model used for the maintenance garage should be developed further to allow firmer conclusions to be developed.

WP5.4 Simulation Code Validation

An extensive experimental programme was completed in order to improve the understanding and knowledge of gas combustion (hydrogen, methane and propane) in semi-confined and vented geometries. Critical conditions for strong flame acceleration and transition from deflagration to detonation in vented tubes and semi-confined geometry were identified. A code validation was performed against experimental data, evaluating the accuracy of the computational fluid dynamics code REACFLOW.

WP5.5 Comparative Study

The comparative study was performed using both information from the most recent literature and results that were obtained within EIHP2. Regarding safety, it was pointed out that there is a substantial lack of available data on the literature, especially concerning accident frequencies.

As it was already pointed out in WP5.1, some physical properties (such as a larger diffusion coefficient, a larger buoyancy) make hydrogen potentially safer than other fuels. On the other hands, because of other properties such as flammability limit and burning velocity a hydrogen accident could produce potentially more severe consequences. In WP5.2 and WP5.3, it was shown that the accident consequences depend strongly on the initial and boundary conditions. Therefore each scenario requires a separate analysis. For the worst-case scenarios that were considered in the analysis such as the combination of large hydrogen release rates in confined environments, mitigation and risk-reducing measures have to be developed.

Although the price of fuel-cell hydrogen vehicles will be larger than the price of conventional cars, if the cost of the environmental-health impact due to green-house gas emissions and air pollution is taken into account in the comparative well to wheel analysis, it will become competitive to run hydrogen driven vehicles compared to other fuels in the near future.

Finally hydrogen is a non-toxic gas, which makes it preferable over conventional fuels (Diesel or Gasoline).

1.2.2.5 WP 6 – International links

The intention of WP6 was to create and maintain international linkages both within the EU and externally, particularly within the US.

Through the activities of the partners in WP6 these aims have been achieved:

- Various US bodies including DoE and IHIG are now fully aware of the role and purpose of EIHP. This has been enabled by the unique ability of global companies to span regional divides
- Initial meetings with delegations from the Japanese Electric Vehicle Association and the Japanese Hydrogen Forum have provided a useful first view of the RC&S landscape in Japan
- Summaries of RC&S activities in Europe and the US have been produced and a preliminary high-level gap analysis of European C&S for hydrogen infrastructure has been carried out and shared with key stakeholder in the US

Some high level conclusions are stated here:

- The leadership of the DoE in the US has provided a much-needed framework for C&S activities in the US which is enabling a focused approach
- Japan is viewed as the most advanced and coordinated with respect to RC&S activities, driven by their desire to commercialise hydrogen vehicles in 2005
- EIHP2 is viewed as a significant strength within Europe by the US but the view still persists that its main function is to create competitive advantage

- Comparison of US and EU gap analyses for infrastructure C&S activities reveals a great deal of similarity in key areas requiring progress. This is a good basis for future international collaboration

1.2.3 Assessment of Results and Conclusions

The description of requirements for liquid hydrogen as a fuel has been brought further significantly by the work in the frame of the EIHP project. The discussions with different European partners guarantee an essential step for common understanding and European harmonisation of future regulations for liquid hydrogen vehicle systems.

WP4 - UNECE Draft Regulations and GTR Process:

Although the draft ECE regulations for LH_2 and CGH_2 have wide international acceptance from a technical point of view, they and are now awaiting political voting at UNECE WP.29 because of the philosophical objections of Japan and USA. Neither an ECE regulation nor a GTR is available yet.

In this regard it is worth mentioning that already in May 2003 the LH_2 draft was discussed in GRPE's 46th session, but was not forwarded to WP.29 for political approval. In January 2004, GRPE in their 47th session again did not adopt the draft ECE regulations to WP.29.

On both occasions, the representatives of the USA and Japan objected to the draft regulations.

As requested by GRPE in May 2003, a road map has been developed on how to proceed with the introduction of GTR for hydrogen vehicles. This road map details three options out of which two are supported:

The USA and Japan favour option 1, which suggests abandoning the draft ECE regulations and immediately starting working on GTRs.

The EC, Canada, Germany, the Netherlands, Norway, ISO and the European Automotive Industry are in favor of option 3, which would put into force the two draft ECE regulations as an interim measure in parallel with an immediate start of work on GTR. In doing so, a regulatory framework for the approval of hydrogen-fuelled vehicles using ECE regulations would be in place latest in 2006 when it is needed by the industry.

The conclusion is that work on GTR should start as soon as possible since everybody will benefit from GTR. For time reasons however, an interim solution is needed at the latest by 2006. Therefore, the draft ECE regulations should be adopted by WP.29. In the event that there is not a positive political vote in WP29, both the LH_2 and the CGH_2 draft should be converted into EC directives with the highest priority.

WP5.1 - Review of Available Safety Data

The relative safety of different fuels will depend on each specific application and potential accident scenario. The reason for this is that some aspects of hydrogen (e.g. buoyancy and ability to disperse) are favourable for hydrogen as compared to other fuels, whilst on the other hand for a given size of flammable cloud, the faster burning velocity of hydrogen would tend to indicate larger explosion overpressures compared to other fuels.

WP5.2 Risk Analysis of Refuelling Infrastructure

Results from the risk assessment studies were used as input to safety recommendations to be included in standards. Recommendations for risk mitigation measures were suggested and communicated to WP2, but the effect of the measures were not quantified. This should be examined further at a later stage.

Despite the overall good WP performance, the study could not cover all the gaps in hydrogen safety because of the limited available time and resources. The still existing gaps in hydrogen safety were identified at the end of the deliverables.

The failure frequencies used for quantification of the probability of accident scenarios were based on available failure frequencies from large-scale industrial installations offshore. These data may not be relevant for small-scale hydrogen installations with a public interface, related to equipment dimensions, the physical environment, operation, inspection and maintenance routines. More realistic failure frequencies therefore need to be established.

Transport of hydrogen or hazardous feed stock (ammonia, natural gas and methanol) should also be examined to include the complete risk contributions related to use of hydrogen as a transport fuel compared to petrol.

To get a comparison of the societal risks involved with hydrogen refuelling stations and conventional refuelling stations the production of petrol should also be considered. A safety risk analysis of societal risk should cover all the way from "well to wheel".
Assessments of consequences of hydrogen leaks need further validation for hydrogen:

- Based on the results from the CFD simulations obtained in this work, it is suggested that future work (beyond the limits of EIHP-2) should concentrate in a more systematic approach. As several demonstration hydrogen-refuelling stations are currently under construction or commissioning, real refuelling station layouts should be used. More than one predictive tool should also be applied, in order to capture variations in predicted risks, due to different modelling approaches.
- It is suggested that the simplified approach to estimate ignition probabilities used in this report are further developed in future studies. Preferably, future work should also include more detailed evaluations of how exposure of flammable gas clouds affect likelihood of ignition for different, relevant categories of ignition sources.
- Based on the results from the combustion simulations it is suggested that future work can include a parametric study on the how the position of the ignition point affects the overpressure generated by the explosion.
- More extensive validation work has to be carried out in order to allow drawing quantitative conclusions from the gas dispersion and combustion computations.

The most serious consequence of a large fire impinging on a hydrogen storage tank is escalation to a Boiling Liquid Expanding Vapour Explosion (BLEVE) for liquefied hydrogen systems. As it is uncertain to what degree a BLEVE is a relevant scenario for liquid hydrogen tanks, and the resources available were insufficient to assess this in detail in this work, the authors recommend this to be considered in future hydrogen safety initiatives (e.g. HySafe).

Issues related to LH_2 were not covered as well as CGH_2 in the study, and it is likely that this will be needed, e.g. as a input to the development of a code for LH_2 refuelling installations.

WP5.3 Safety Studies of CGH_2 Vehicles

In WP5.3 the numerical simulation of various hydrogen release scenarios for commercial vehicles was performed. The work has proven CFD modelling techniques to be a useful tool for investigating the release of hydrogen in real world situations. It also underlines the importance and benefits of performing safety studies for hydrogen applications, in order to be able to understand, and therefore, minimise and control the consequences of accidental hydrogen releases to within acceptable levels.

WP5.4 Simulation Code Validation

The extensive experimental combustion programme established a database for numerical code validation. Moreover criteria for flame acceleration and for transition from deflagration to detonation were identified on the basis of the experimental data. Those results and the validated numerical codes are instrumental in improving gas-combustion understanding and in providing useful information in order to help designing safer vehicles and infrastructures. For future work, it would be useful to perform similar experiments with non-uniform mixtures and in real-scale size configurations in order to complete the experimental database and the subsequent validation process.

WP5.5 Comparative Study

Hydrogen has been compared to other fuels like methane and gas oil. Due to its different physical properties hydrogen behaves much different when it is released during an accident. Also the following consequences depend very much on the initial and boundary conditions. Therefore every accident scenario requires a separate analysis. For the worst-case scenarios (large release rates in confined environments) it was shown that mitigation measures have to be applied.

Hydrogen is non-toxic and therefore preferable to gas oil, but special care must be taken when handling cold liquid hydrogen.

When hydrogen is used as a fuel no greenhouse gases are released directly into the environment especially when hydrogen is produced from renewable energy. If the indirect costs of conventional fuels due to air pollution and the release of greenhouse gases are taken into account hydrogen becomes also a cost competitive fuel. For the end-user hydrogen driven vehicles will become more expensive than today's vehicles but within an acceptable range. Therefore hydrogen is one possibility to guarantee our mobility in the future.

1.2.4 Glossary

CGH_2	Compressed Gaseous Hydrogen
EC	European Commission
ECE	Economic Commission for Europe, a UN organisation (also UN-ECE)
EIHP	European Integrated Hydrogen Project
FMEA	Failure Modes and Effects Analysis
GRPE	Working Party on Pollution and Energy, WP.29 of UN-ECE
GTR	Global Technical Regulation
IEC	International Electrotechnical Commission

ISO	International Organisation for Standardisation
LH_2	Liquid Hydrogen
PET	Partially Vented Explosion Tubes
Rev.	Revision number of the EIHP Draft ECE Regulation documents
RRR	Rapid Risk Ranking
SAE	Society of Automotive Engineers
TC	Technical Committee (e.g. of ISO or IEC)
WHEC	World Hydrogen Energy Conference
WP.29	Working Party 29 of UN-ECE