

HYFORUM 2004 – Clean Energies for the 21st Century

25 -28 May 2004, Beijing, P.R. China

Reinhold Wurster

Daily Use of Hydrogen in Road Vehicles
and their Refueling Infrastructure:
Safety, Codes and Regulations



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Ottobrunn



- ① **Hydrogen Vehicles and their Refueling Infrastructure**
- ② **Safety Implications of Hydrogen Use in Road Transport**
- ③ **Why Harmonized Regulations and Standards ?**
- ④ **Globally Harmonized Vehicle Approval**
- ⑤ **Recommendations**

Hydrogen Vehicles and their Refueling Infrastructure

Infrastructure for Fleet Demonstration Activities



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Munich
35 MPa CGH₂ and LH₂
since 1999



Luxemburg - CUTE
35 MPa CGH₂
since Sept. 2003



Reykjavik - ECTOS
35 MPa CGH₂
since April 2003



BVG/Total Berlin
LH₂ + 25 MPa CGH₂
since Nov 2002

Hydrogen Vehicles and their Refueling Infrastructure

Infrastructure for Fleet Demonstration Activities



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Stuttgart- CUTE
35 MPa CGH₂
since Sept. 2003



Barth/Germany
25 MPa CGH₂
since 2002



Dudenhofen/ Opel
LCGH₂ at 70 MPa
since March 2003

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Hydrogen Vehicles and their Refueling Infrastructure

Infrastructure for the Every Day Use of Passenger Cars



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Malmö
25/(35) MPa CGH₂
since Sept. 2003



CEP Berlin
LH₂ and 70 MPa CGH₂
public multi-fuel from fall 2004



H2MUC Munich
Public LH₂ since 1999



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Safety Implications of Hydrogen Use in Road Transport

Fires and explosions



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Behaviour is different to hydrocarbons

- wide limits of flammability and detonability
- ignition and detonation energies low
- non luminous flame.
- very buoyant - flammable cloud disperses rapidly.

For the safety case need to be able to estimate the consequences of a release

- how likely to ignite?
- how likely to detonate Vs deflagrate?
- what overpressures would be generated?
- what level of injury / structural damage / escalation is possible?

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Source: Shell in www.eihp.org



www.lbst.de

Safety Implications of Hydrogen Use in Road Transport

Accident with compressed gas hydrogen trailer in Germany, 2001



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A 7.5 t truck crashed into a tube trailer. Three valves were damaged, hydrogen escaped and was ignited. The fire burned the crashed truck and the driver, locked in the crashed driver's cabin was killed by the fire. For several hours the fire brigade had to cool the storage tubes with water in order to avoid their deformation. The motor way and the parallel train track had to be closed down for many hours. Nobody else was injured or killed in the accident.



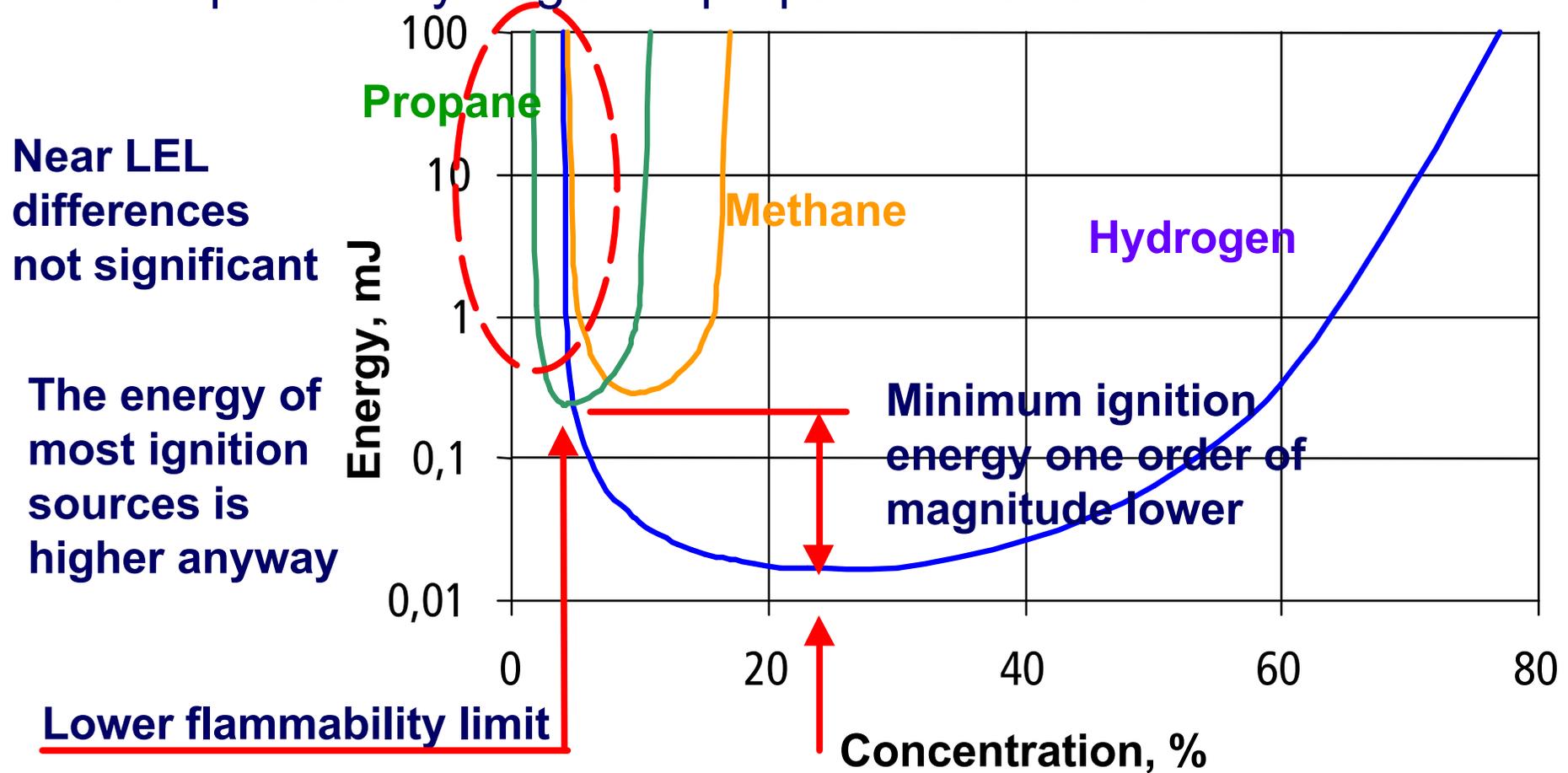
Safety Implications of Hydrogen Use in Road Transport

Flammability ranges and ignition energy



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Comparison hydrogen – propane - methane



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Source:
DWV in www.eihp.org

**Associated concentration
very high**

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Safety Implications of Hydrogen Use in Road Transport

Hydrogen explosions



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	Hydrogen	Methane	Propane
Detonability limits (vol. % in air)			
Lower limit (LDL)	11-18	6.3	3.1
Upper limit (UDL)	59	13.5	7
Maximum Laminar Burning velocity (m/s)	3.46	0.43	0.47

- Hydrogen more prone to detonate than hydrocarbons.
 - ⇒ Are there any credible retail scenarios in which hydrogen detonations could occur?

HOWEVER

- Buoyancy and rapid dispersion of hydrogen limits size of flammable gas clouds

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Source: Shell in www.eihp.org



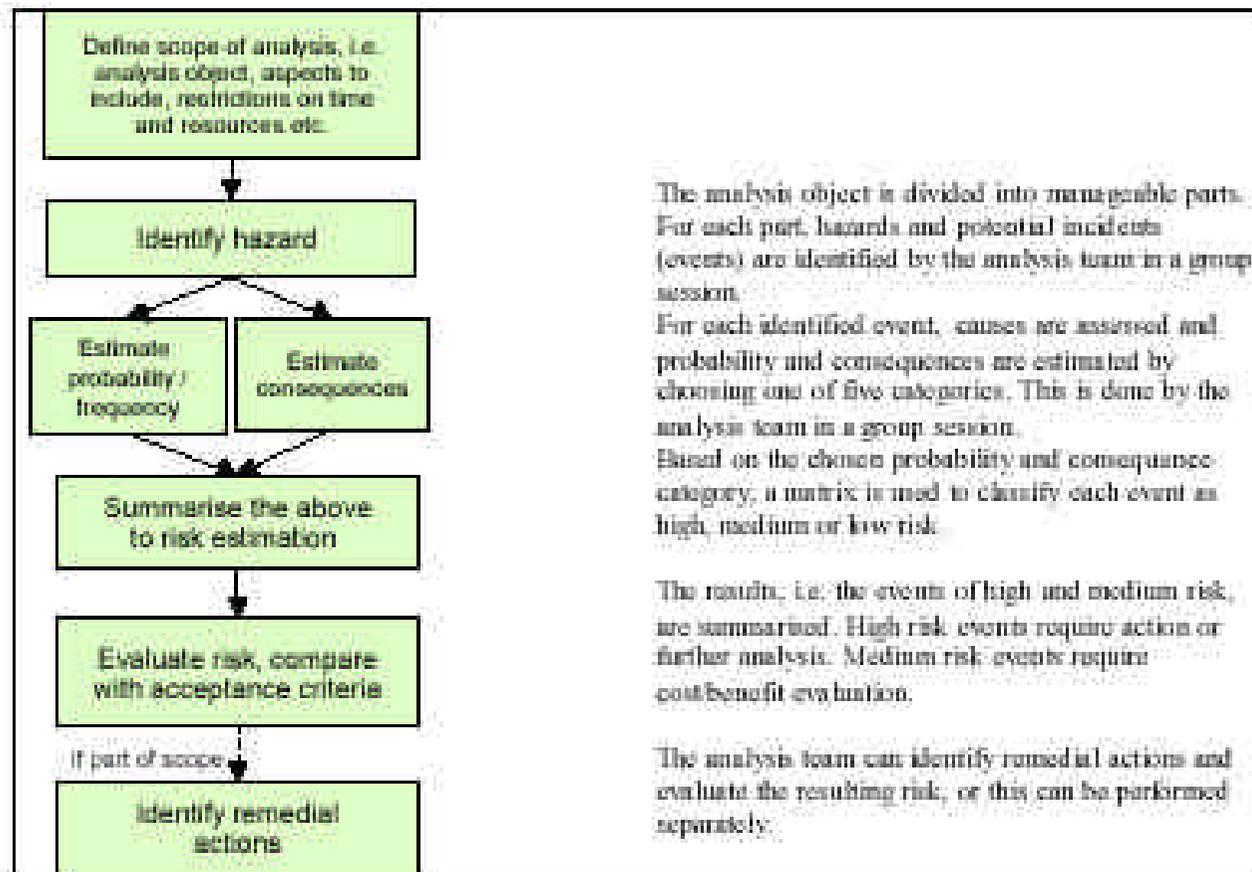
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Rapid Risk Ranking Methodology



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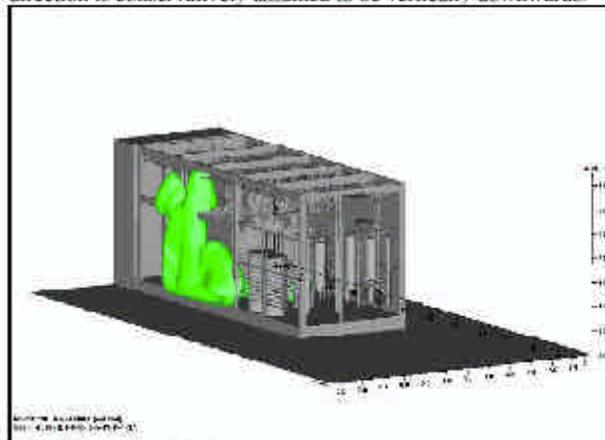
Safety Implications of Hydrogen Use in Road Transport

CFD simulation of high pressure leaks in confined areas

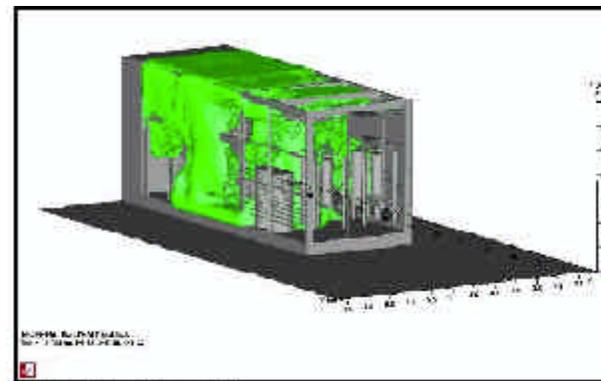


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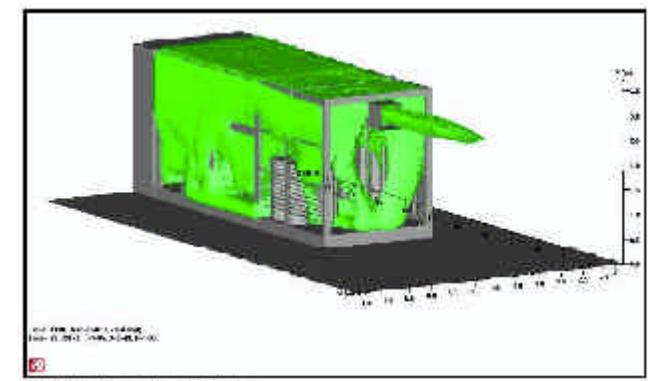
Figure 4 “Snapshot” of hydrogen gas cloud, showing the gas envelope with H₂-concentration in air > 1/2 LFL (2 vol%), at three different timesteps. Release rate 10 g/s, sonic velocity. Ventilation capacity 300 volume changes per hour. Release position is about 1.5 m above ground level, halfway between the end walls and close to one of the sidewalls. Release direction is conservatively assumed to be vertically downwards.



a) 4 s after release start



b) 10 s after release start



c) 20 s after release start

High pressure leaks in confined areas

If high pressure hydrogen releases occur in a confined area (e.g. inside a container for compression or inside a confined storage area) impulse and buoyancy effects will influence on the dispersion. The confinement will trap the gas, the gas jet will impinge on walls, floor or other objects present, and lose velocity, and thus the impulse will be reduced. There may be special conditions related to the flow pattern inside the confined area, dependent of ventilation, extents and position of obstacles etc., that may lead to accumulation of hydrogen at lower levels. However, the released gas will usually rise to the ceiling.

The gas will accumulate, and large flammable gas envelopes may be created, if no measures are taken for shutdown of release or effective dilution and removal of the gas. A release scenario showing a 10 g/s release of hydrogen inside a process container of 40 m³ is illustrated in figure 4. The calculations, carried out with the CFD code FLACS, ref. [12], indicate that even large ventilation rates (300 volume changes per hour) will have limited

11 effect on releases of this size.

Source:
DNV & Hydro in www.eihp.org

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Safety Implications of Hydrogen Use in Road Transport

CFD simulation of H₂-Air diffusion flame in tunnel



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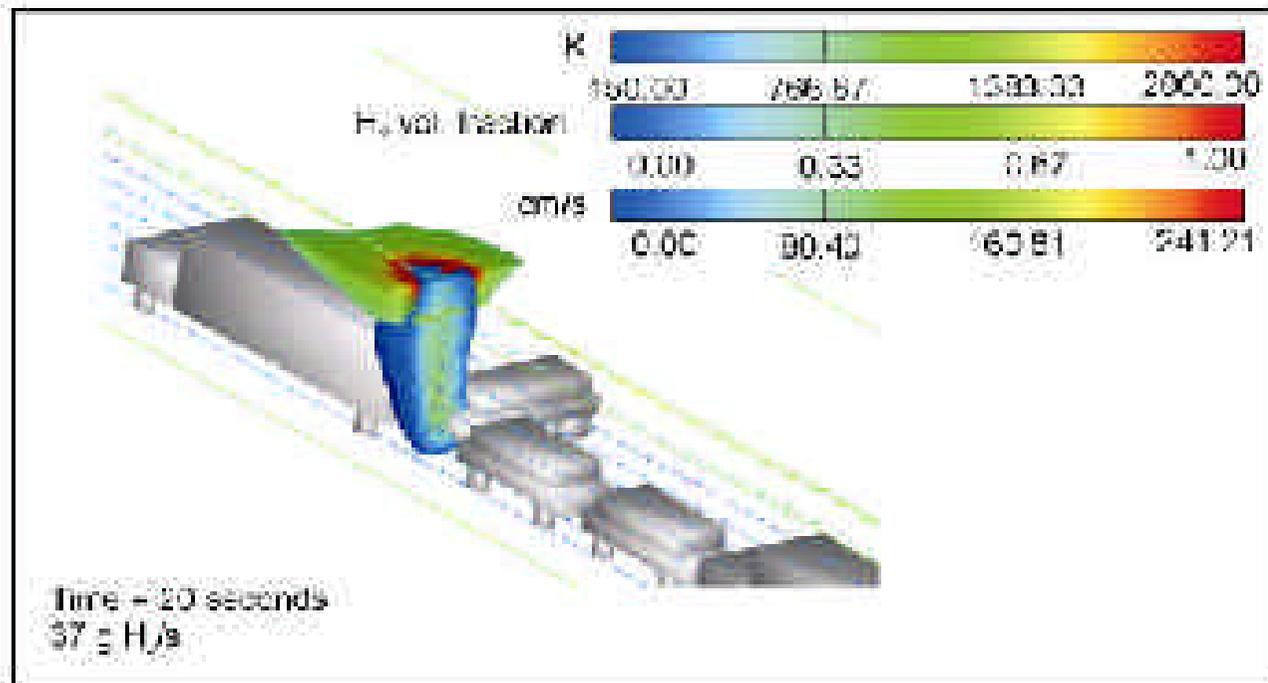


Fig. 4: Standing H₂-air diffusion flame in tunnel, case 2.2 with early ignition at 7.5 s.

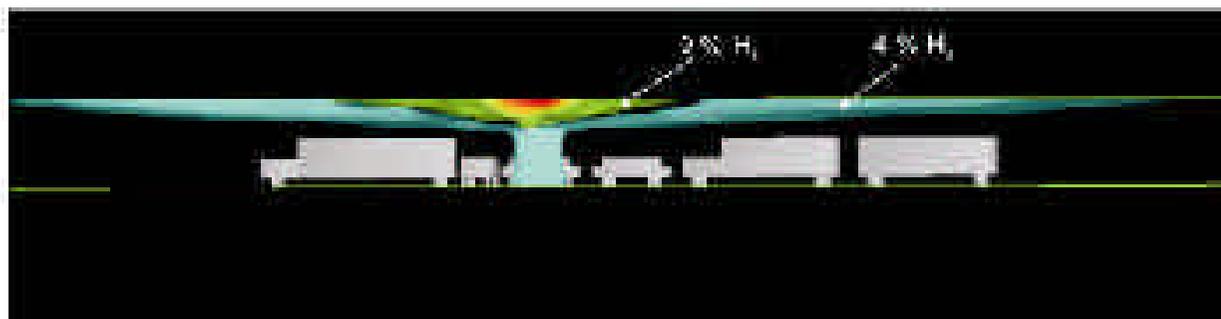


Fig. 1: Computed hydrogen distribution in the tunnel at the end of the H₂-release phase (900 s).

Source:
FZK
WHEC13 Beijing, 2000
in www.eihp.org

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Safety Implications of Hydrogen Use in Road Transport

Dispersion of hydrogen and propane



Propane

- is heavier than air
- remains near the ground
- fills basements, trenches etc.
- ignition risk!



Hydrogen

- is lighter than air
- rises up
- goes away from ignition sources
- disappears rapidly



These photos were made during experimental simulations of an accident with gas escape between buildings. The experiments were performed in the framework of the EQHHPP project by the Federal Institute for Materials Research and Testing (BAM), Berlin.

Safety Implications of Hydrogen Use in Road Transport

EQHHPP test of LH₂ vehicle onboard storage tanks



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BMW
LH₂ Vehicle
Tank Testing



- **Hydrogen rises rapidly**
 - **Correct, but:** diffusion makes it disperse **in all directions**. Including downwards, especially if it is trapped upwards (roof).
- **Hydrogen is light and disappears rapidly**
 - **Correct, but:** when cryogenic hydrogen escapes there is a **mixture cloud** consisting of hydrogen, air, and water; this is much **heavier** than hydrogen.
- **Underestimation of the risks is the start of an accident!**

Source:
BMW, 1994
in www.eihp.org

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Safety Implications of Hydrogen Use in Road Transport

Shell's jet release experiments at 2.5 MPa



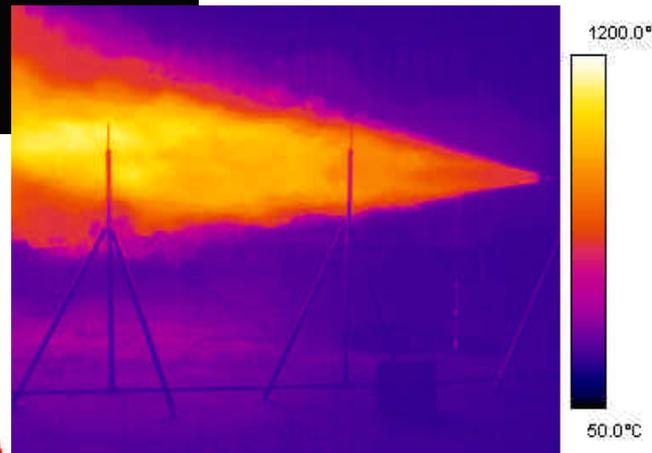
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hydrogen jet fire
invisible in daylight!



but visible at
night



IR thermal
image

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Source: Shell in www.eihp.org



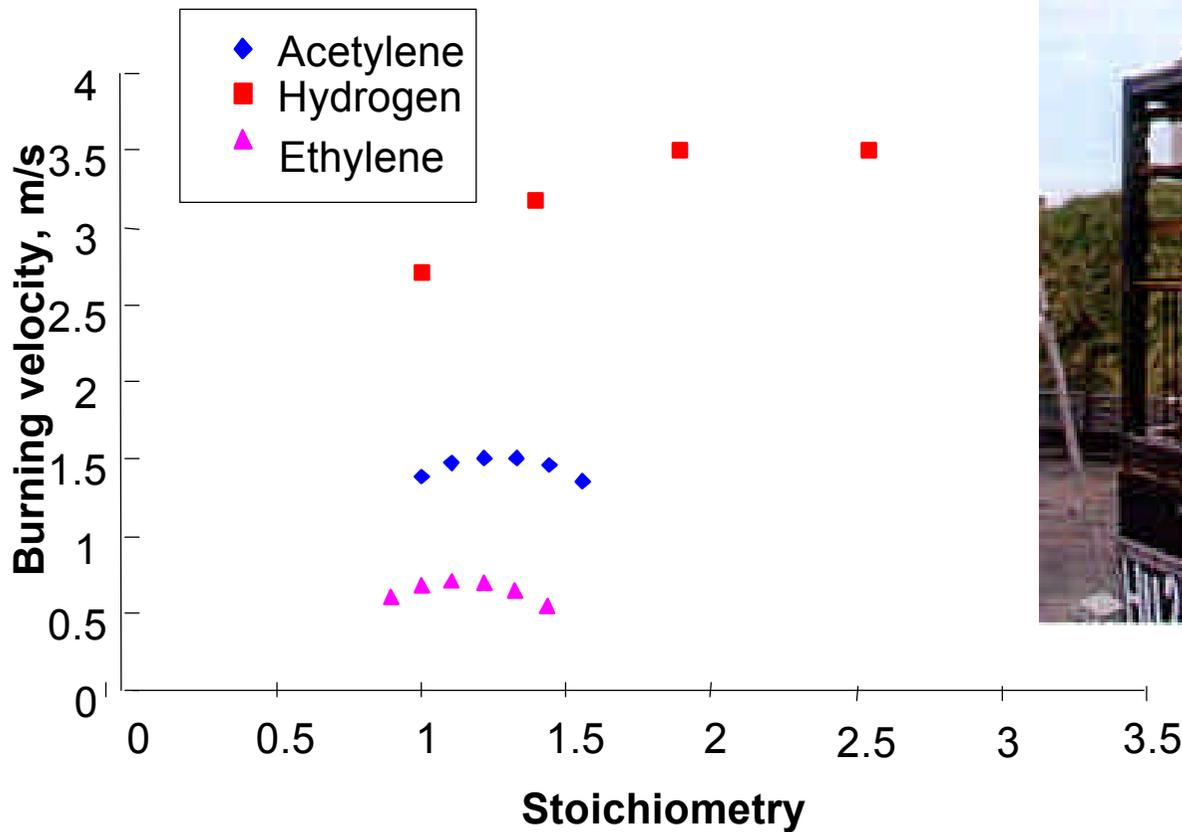
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Safety Implications of Hydrogen Use in Road Transport

Shell's comparison of small scale unconfined explosions



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Comparison of literature burning velocities suggests hydrogen explosions could be more severe than acetylene

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Source: Shell in www.eihp.org



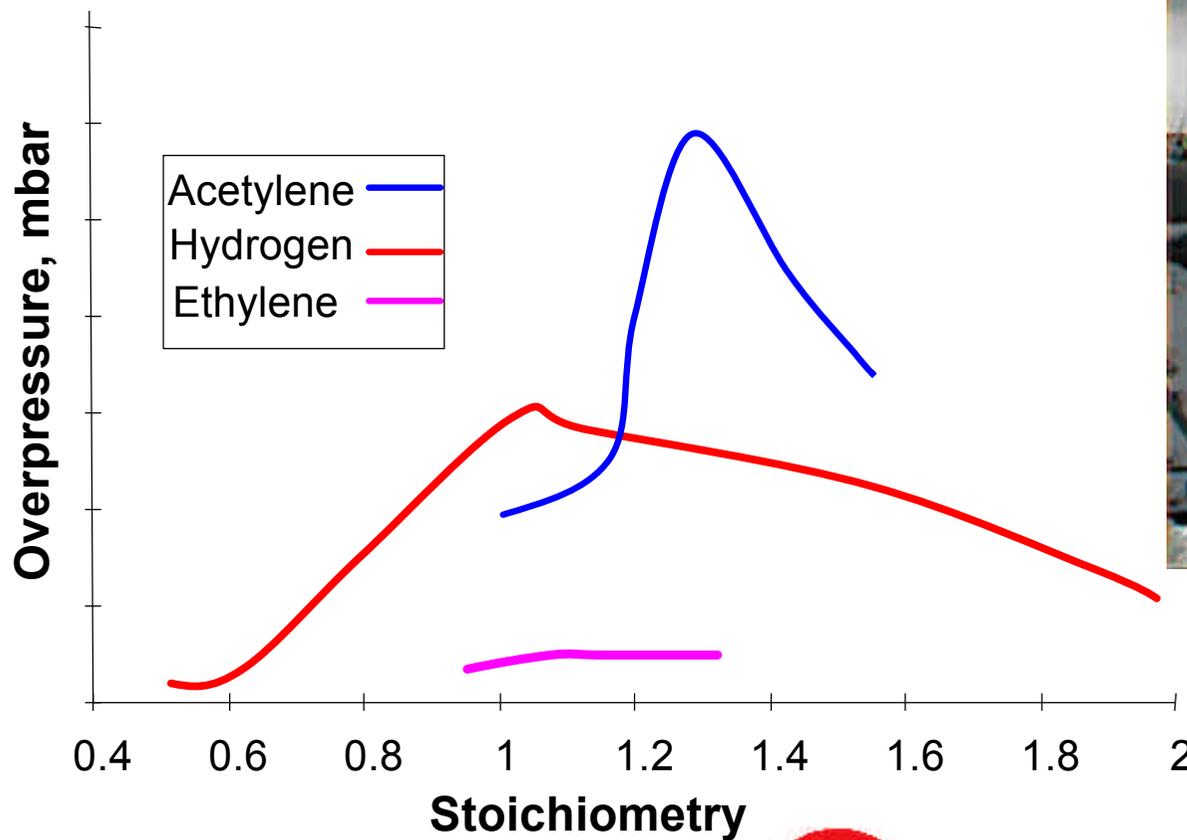
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Safety Implications of Hydrogen Use in Road Transport

Shell's comparison of small scale unconfined explosions



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Hydrogen explosion actually milder than acetylene at length scales investigated.

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Source: Shell in www.eihp.org



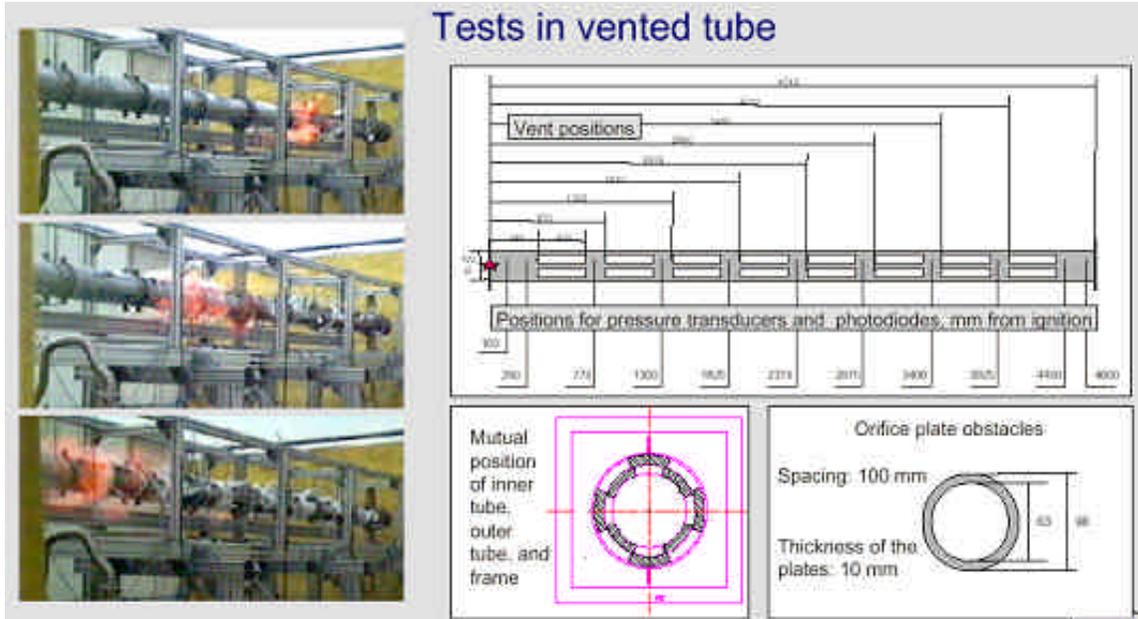
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Safety Implications of Hydrogen Use in Road Transport

EIHP2 combustion tests in semi-confined and vented tubes [FZK]



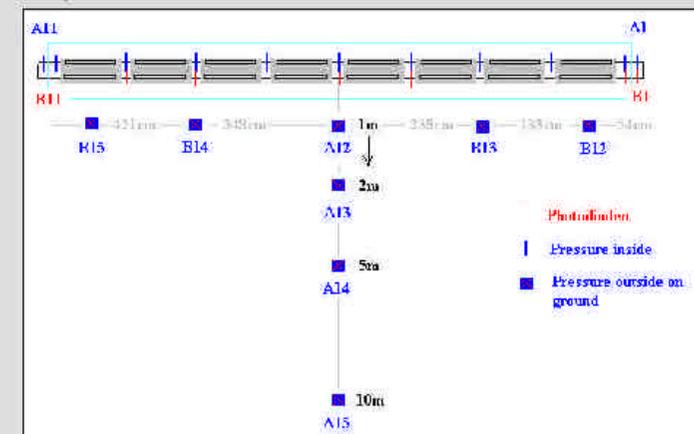
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Tests in semi-confined geometry



Positions for pressure transducers and photodiodes. Top view.



Source: FZK in www.eihp.org

Safety Implications of Hydrogen Use in Road Transport

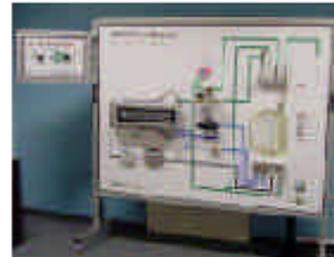
Challenges to be solved for a manufacturer of H₂ road vehicles



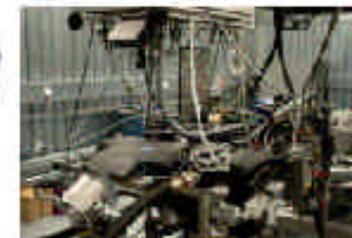
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Test Fleet Service



Employee Training



Test Rigs



Test Areas



H₂-Filling Stations

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Source:
BMW
18MAR2004

Why Harmonized Regulations, Codes and Standards ?

Challenges to be solved for safe operation H₂ vehicles on public roads



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Vehicle
licensing



Filling Station



Parking,
Garaging



Tunnels



Data Transmission



Emergency
Services



Accidents



Repairs/maintenance



Service

Source:
BMW
in www.eihp.org

Why Harmonized Regulations, Codes and Standards ?



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International Regulations, EU Directives, and Standards

- Legal Requirements and Regulations are ranked above standards
- UN Global Technical Regulation [1998 Agreement] 1st priority
 UNECE Regulation [1958 Agreement] 2nd priority
 EEC Directives 3rd priority
 National Directives and Regulations 4th priority
- Important directives regarding stationary hydrogen technologies and infrastructure systems are:
 - ATEX directives
 - PED (Pressurised Equipment Directive)
 - EMC (electromagnetic compatibility) directive
 - The Machinery Safety Directive
 - SEVESO II (large amounts of haz. mat.)
 - Transport of dangerous goods by road
 - UN IMO
- Standards (ISO, IEC, CEN, SAE)

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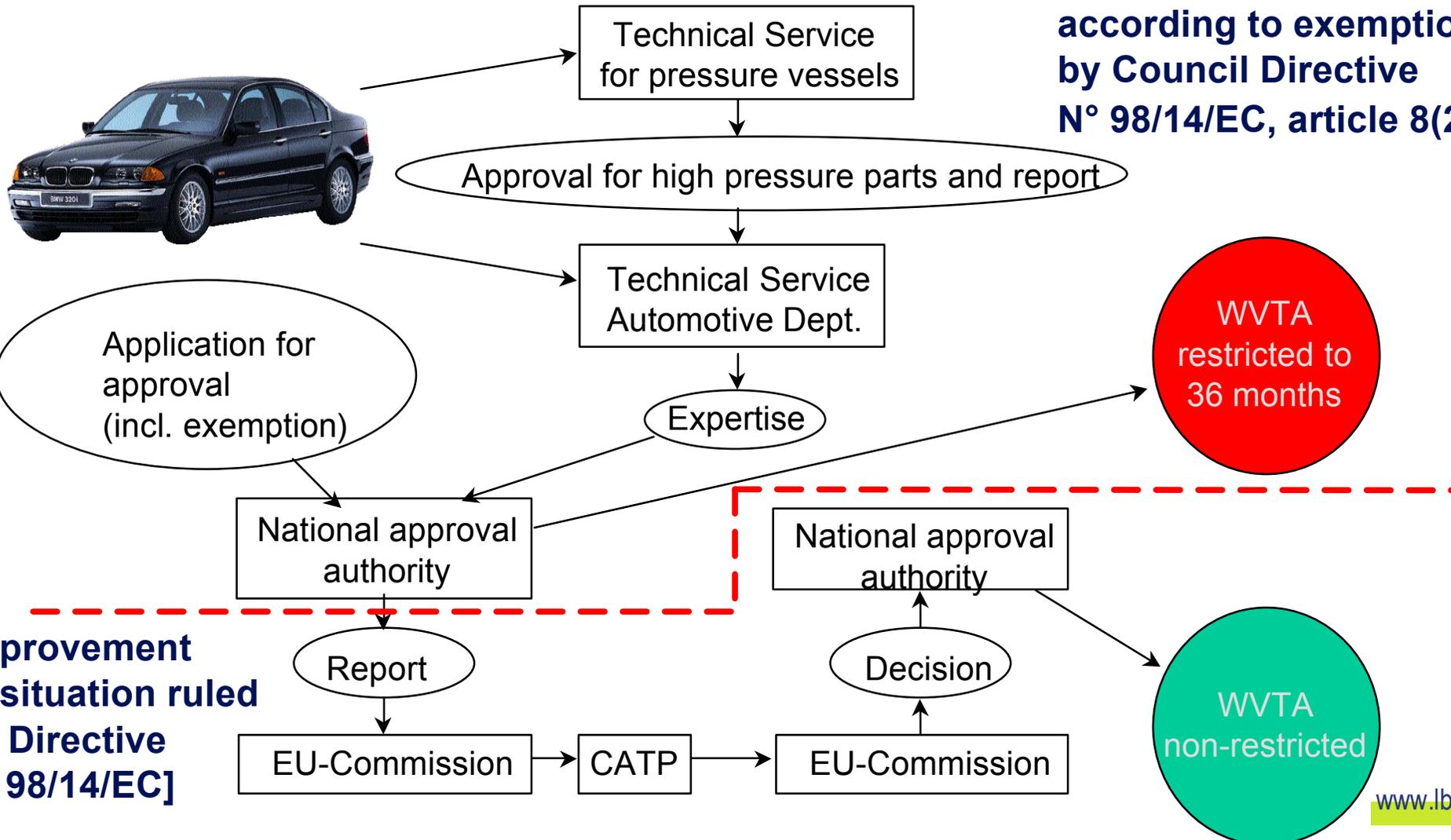
Why Harmonized Regulations, Codes and Standards ?

Harmonized Frame for Europe - or the EEC Directive



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[Current process according to exemption by Council Directive N° 98/14/EC, article 8(2)c]



[Improvement of situation ruled by Directive N° 98/14/EC]

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Why Harmonized Regulations, Codes and Standards ?

Two Pathways to Present a Proposal for a Regulation in Europe
For the Whole Vehicle Type Approval of (H₂) Road Vehicles

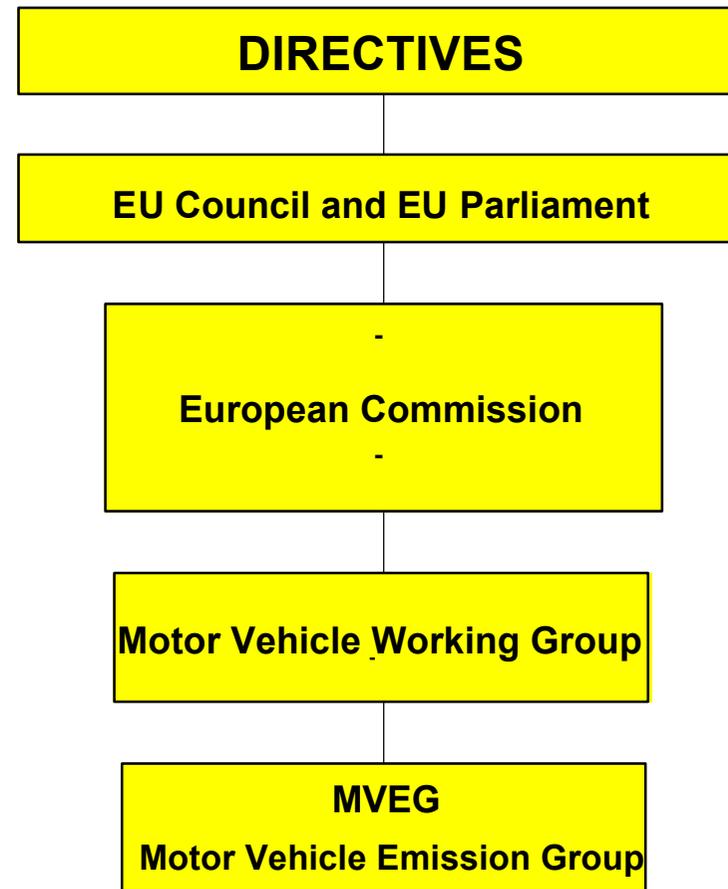


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UN-ECE



EC



23 **Voluntary** (Valid for: EU, Jap., Aus.)

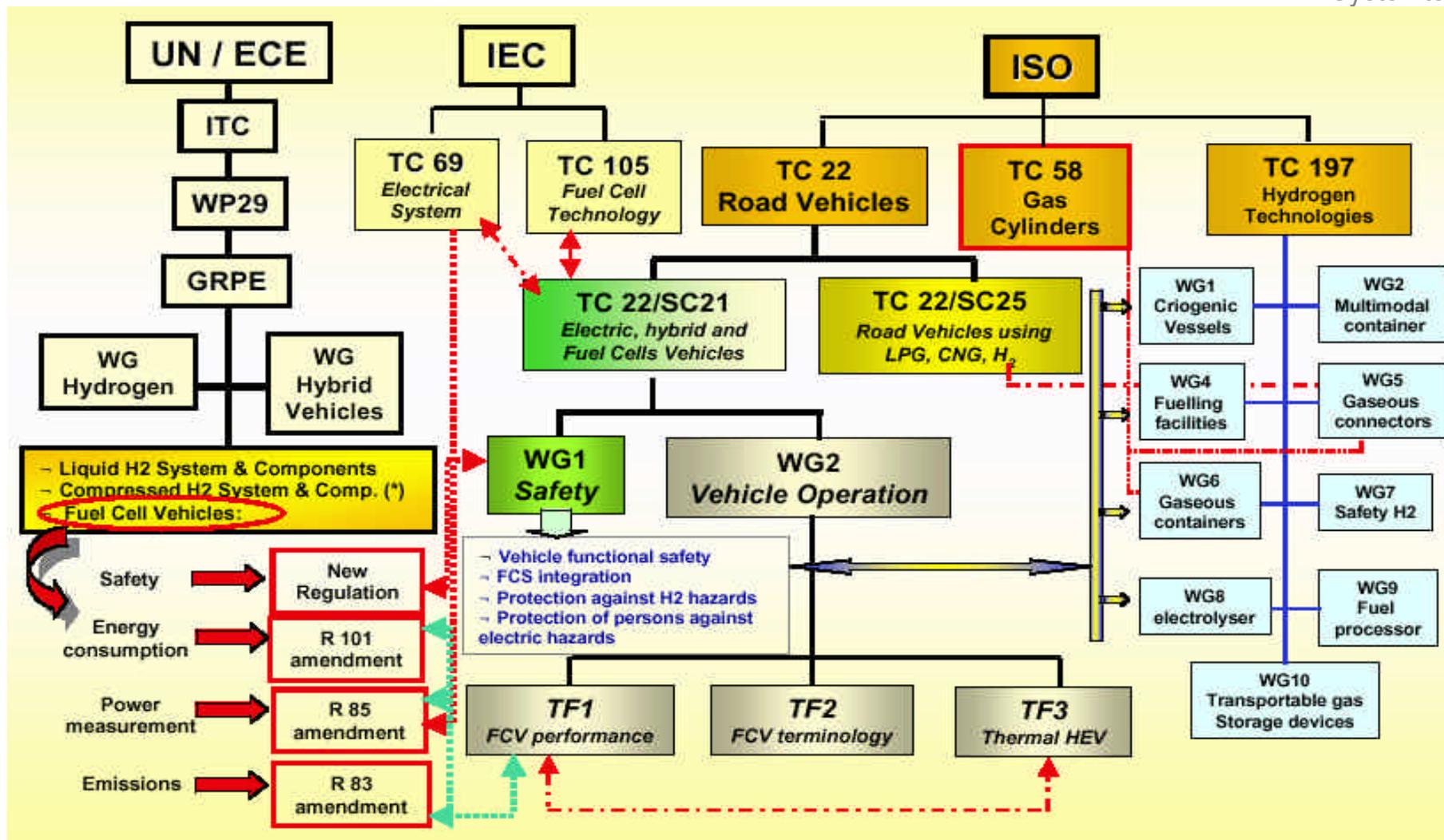
Binding for WVTA (Valid for: EU)

Globally Harmonized Vehicle Approval

International Regulations & Standards Links for H2 & FC Vehicles



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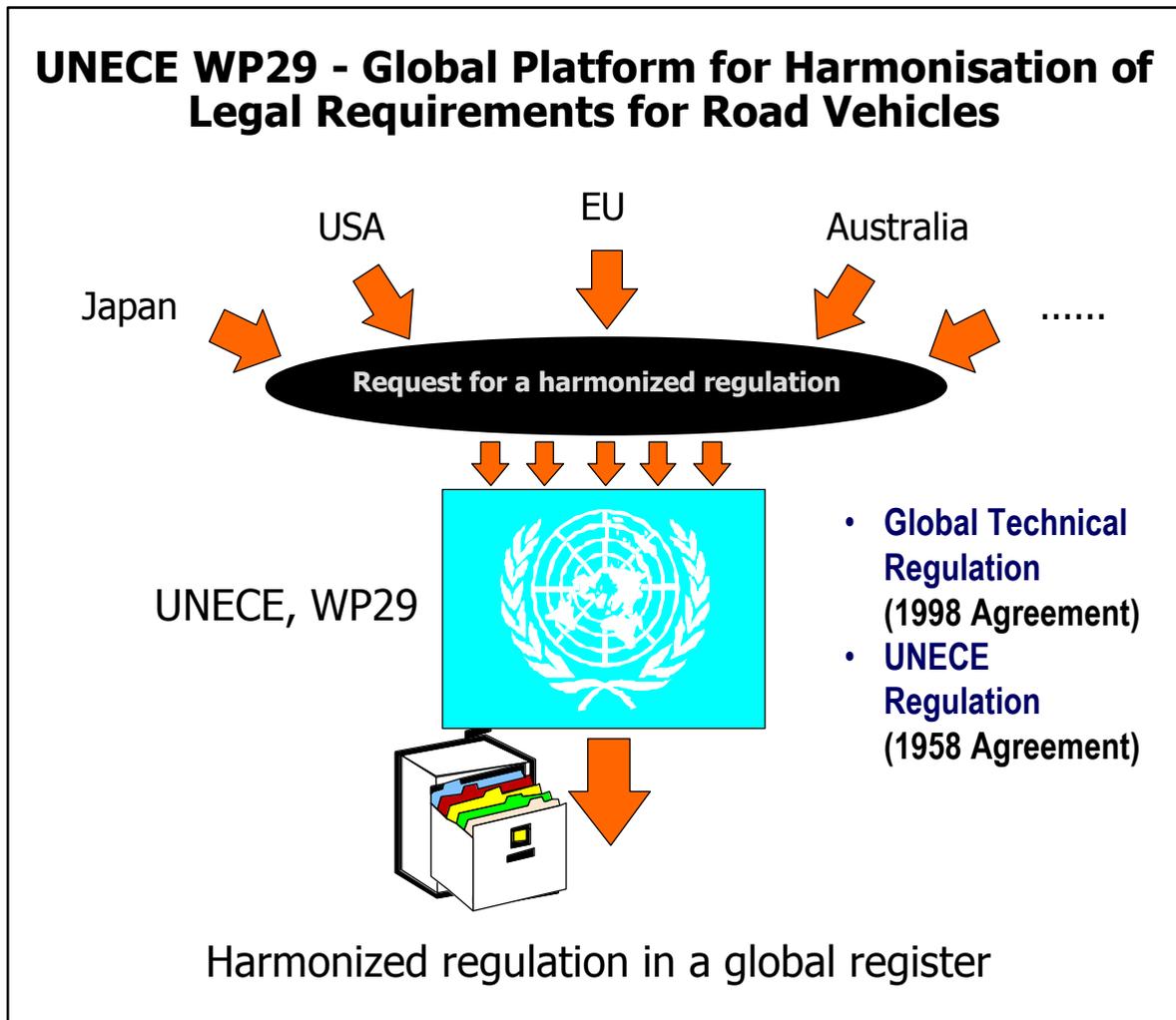
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Globally Harmonized Vehicle Approval

Global Platform for Harmonization of Regulations for Road Vehicles



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MEMBERS OF THE 1958 AGREEMENT:

[(E/ECE/324-E/ECE/TRANS/505/Rev.2)]

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

MEMBERS OF THE 1998 AGREEMENT:

[(E/ECE/TRANS/132 AND Corr.1)]

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, SPAIN

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Globally Harmonized Vehicle Approval

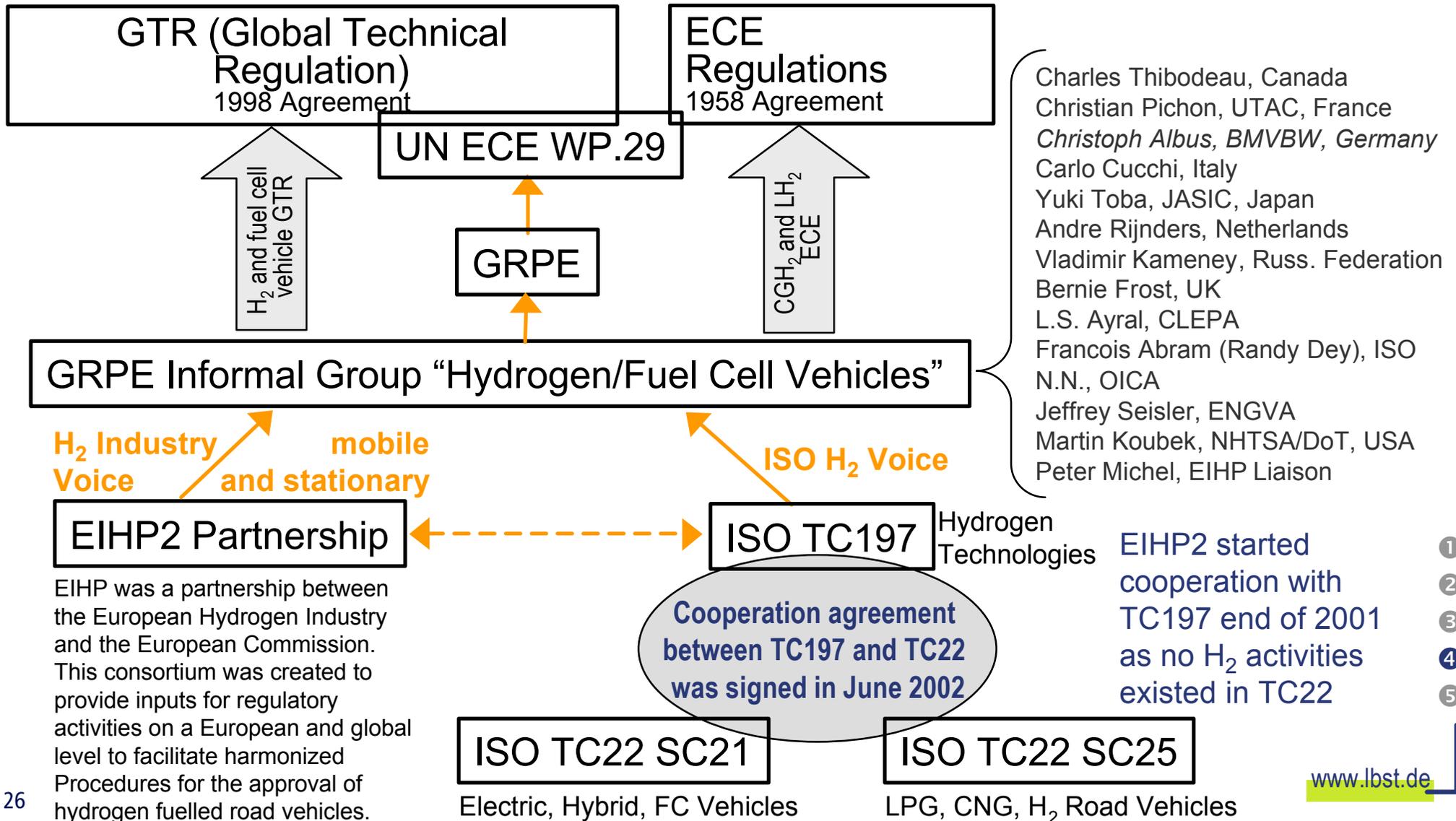
Global Cooperation Group for H₂ & FC Vehicles



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Target date for GTR: 2010

Target date for ECE: 2006



Globally Harmonized Standards

International standards and draft standards – ISO/TC197



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Published standards:

ISO 13984 Liquid hydrogen – Land vehicle fuelling system interface

ISO 14687 Hydrogen fuel – Product specification

Draft International Standards:

ISO/DIS 13985 Liquid hydrogen – Land vehicle fuel tanks

ISO/DIS 15869 Gaseous hydrogen and hydrogen blends – Land vehicle fuel tanks –

Part 1: General requirements

Part 2: Particular requirements for metal tanks

Part 3: Particular requirements for hoop wrapped composite tanks with metal liner

Part 4: Particular requirements for fully wrapped composite tanks with metal liner

Part 5: Particular requirements for fully wrapped composite tanks with non-metallic liner

ISO/DIS 17268 Gaseous hydrogen – Land vehicle filling connectors (based on SAE J2600)

ISO/ DIS 21009- 1 Liquid hydrogen storage

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Globally Harmonized Standards

International working draft and committee drafts, etc. – ISO/TC197

Working Drafts:

ISO/WD 22734 Hydrogen generators using water electrolysis process

ISO WD 13986 Tank containers for multimodal transportation of liquid hydrogen

Committee Drafts:

ISO/CD PAS 15594 Airport hydrogen fuelling facility

ISO/ CD 22734 Electrolyzer

ISO/CD 24490 Cryogenics pump

Draft Publicly Available Specification:

ISO/PRF TR 15916 Basic considerations for safety of hydrogen systems

Proposed New Work Items:

ISO/AWI 16110 Hydrogen generators using fuel processing technologies

ISO/AWI 16111 Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride

ISO/TC 197 NWIP N 253 Dispensing Unit

ISO/NP 20012 Gaseous hydrogen and hydrogen blends — Fuelling stations (Draft Technical Specification)



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BUT – Implementation of Stationary H₂&FC Equipment



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Local implementation will always have to follow also local requirements
Example: Europe

Normally the approval process takes several months and includes the following steps:

- Application for authorization
- Response from the authorities: A permission document with detailed description of all requirements
- Public hearing of the permission document
- Permission to build / establish the facilities
- Inspections of the established facilities, by Public Authorities / Notified Body
- Approval of the facilities and permission to operate

Licences, permits, and certificates :

- Building licence
- Environmental licence
- Operational licence
- CE certificates (which includes detailed documentation of the equipment)
- Third party inspection document / certificate

Authorities involved in the approval process are normally:

- Environment Authorities
- Fire and Explosion Authorities
- Municipal Building Authorities
- Civil Work Authorities

Important aspects regarding authority approval

- Relevant national regulations
- Risk analysis
 - knowledge about hydrogen safety related properties not yet fully explored
 - relevant operation and accident statistics missing or insufficient
- CE marking
 - dependent on risk analysis, testing and operation experience

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EIHP2 Working Draft – Gaseous Hydrogen Vehicle Refuelling Stations
EIGA Document IGC 15/96/E (gaseous Hydrogen Installations)

Documents assisting local implementation in Europe

www.lbst.de

Hazardous Areas and Zones

GASEOUS HYDROGEN VEHICLE REFUELLING STATIONS, EIHP2, WP2



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Hazardous areas are subdivided into zones as follows:

Zone 0: An area in which an explosive gas-air mixture is continuously present or present for long periods.

Zone 1: An area in which an explosive gas-air mixture is likely to occur in normal operation.

Zone 2: An area in which an explosive gas-air mixture is not likely to occur and if it does occur, will only exist for a short time.

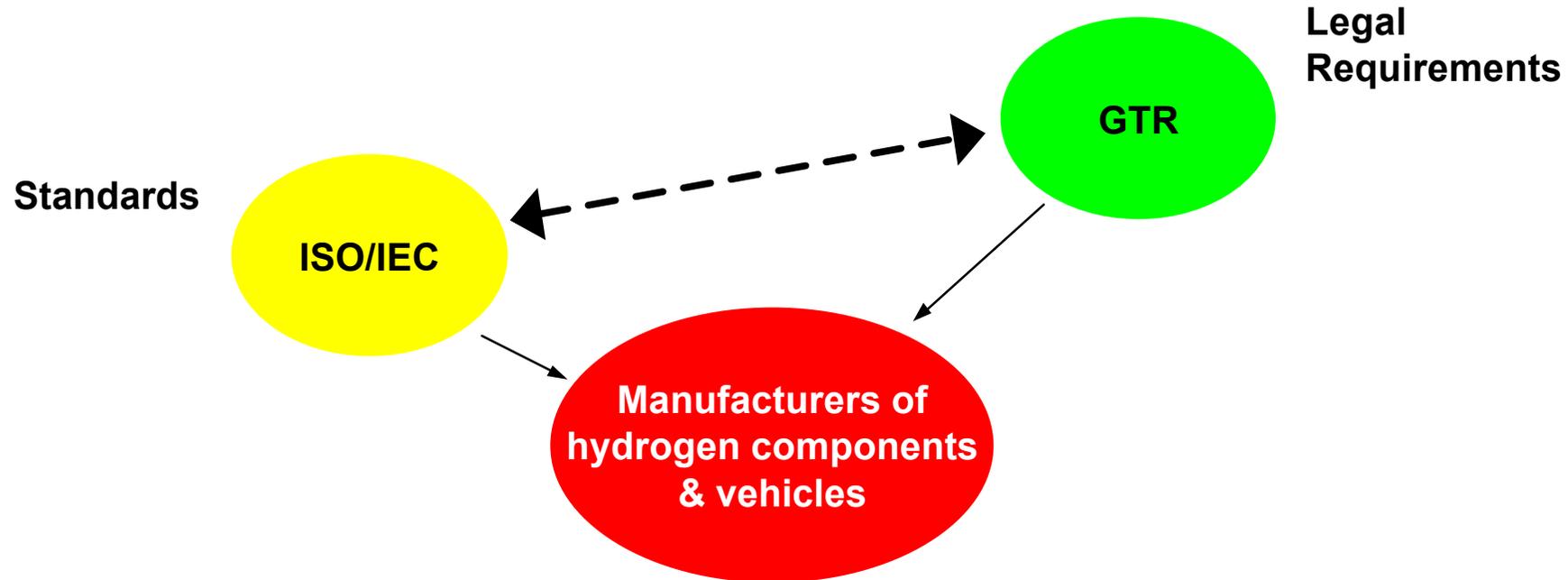
- Zone 0 does not occur in a gaseous hydrogen vehicle refuelling station.
- The area of zone 1 has to be permanently free of potential ignition sources (fire, "normal" electrical equipment, etc.). Electrical equipment installed in this area has to be certified to the appropriate hazardous area rating.
- The area of zone 2 has to be temporarily free of potential ignition sources (fire, "normal" electrical equipment, etc.), i.e. during the actual filling process. Electrical equipment installed in this area has to be certified to the appropriate hazardous area rating.
- The dispenser must not be located within the zone 1 area of the storage tanks or the compressor system.
- The dispenser must be located in such a way that vehicles approaching the dispenser must not enter into the zone 1 or zone 2 areas of the storage tanks or the compressor system.

Recommendations

Desirable Future Scenario For Regulations & Standards



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- Legal requirements should be created only where necessary
- GTRs should refer to available ISO/IEC standards

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Recommendations

Clear Vision of a Pathway to a GTR for H₂/FC Vehicles*



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Onboard storage-related issues ⇒ Two ECE Regulations under the 1958 Agreement (with limited lifetime) ⇒ **GTR** (to replace ECE Regs.)



Target date for a regulation 2006

Rest of H₂-Vehicle (FC, Safety in normal & crash conditions; Fuel Consumption; etc.)

Ⓟ Ⓟ Ⓟ Ⓟ

GTR under the 1998 Agreement (referencing ISO, IEC)

Target date for a regulation 2010

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* (still under discussion in the UNECE GRPE Informal Group on Hydrogen/Fuel Cell Vehicles)



ISO and IEC standards are required for:

- H₂ production equipment ⇒ ISO/TC 197
- Service stations ⇒ ISO/TC 197
- * Filling connectors ⇒ ISO/TC 197 and ISO/TC 22
- Fuel cells ⇒ IEC/TC 105
- * Onboard H₂/FC equipment ⇒ ISO/TC 197, ISO/TC 22 and IEC/TC105
- Others

* *For hydrogen, ISO/TC 197 will work with other TCs in joint working groups.*

Conclusions and Recommendations

How to successfully harmonize R&S globally ?



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- ⇒ do not re-invent the wheel
- ⇒ join forces internationally in the largest automotive markets (Europe, USA, Japan, China)
- ⇒ use existing regulatory and standardization bodies (UN, ISO, IEC) and participate more actively
- ⇒ try to avoid misunderstandings and misperceptions as early as possible
- ⇒ avoid duplications and contradictory/ inconsistent approaches
- ⇒ learn for local implementation also from similarities in requirements all over the world (e.g. fire authorities, environmental authorities) by informal international exchange between local experts

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Thank you for your attention!

For upcoming information please visit

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www.HyWays.de

- 1
- 2
- 3
- 4
- 5

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