Proceedings

of the Mid-Term Assessment Workshop of the

European Integrated Hydrogen Project - Phase II [EIHP2]

Proceedings
Volume 1
Morning Session

held at the European Commission's
CCAB - Centre Albert Borchette
Brussels, 02 October 2002

Morning Session - Topics

- 09:10: "Introduction by the European Commission " (W. Borthwick, DG Research)
- 09:30: "Refuelling Station - WP 2" (H. Andersen, Norsk Hydro)
- 09:50: "Refuelling Interfaces - WP 3" (F. Isorna, INTA)
- 10:10: "Vehicle" (D. Stoll, BMW)
- 10:40: *Coffee Break*
- 11:00: "Safety - WP 5" (D. Baraldi, EC-JRC)
- 11:20: "Intl. Links and Cluster Activities - WP 6" (M. Jones, BP)
- 11:40: "Clean Fuel Systems - Filling Stations for Natural Gas and Hydrogen" (W. Niessen, Ballast Nedam)
- 12:00: "Gas Storage Systems for Compressed Hydrogen" (S. Rau, Dynetek Europe
- 12:20: "H2 powered ICE and FC buses in public operations" (Ch. Gruber, MAN)
- 12:40: "Hydrogen Safety" (U. Schmidtchen, DWV and BAM)

EIHP2 Mid-Term Assessment Workshop

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Brussels, 2nd October 2002

EU Policy Elements Relevant to Transport

- Security of energy supply
- Climate Change
- Air quality
- Transport and Mobility
- Industrial Competitiveness

Driving forces beyond direct environmental considerations:

- **Longer-term, fundamental change needed**
  - **paradigm change to address climate change**
  - **fossil fuels are finite**
- **Need a common energy vector**
  - **Security of supply: diversify primary sources**
  - **Primary energy must eventually come from renewable sources, these are locally different**
- **Industrial policy:**
  - **who will supply the technology for a new global market ?**
  - **The prospect of an industrial revolution in terms of universal electrical end-use**
- **fuel cells and hydrogen are "cool"**

Hydrogen and electricity: key energy vectors of the future

Key issues for novel concepts:

Cost-effectiveness on a whole life cycle basis in achieving energy , air quality and noise targets

Improvements beyond Kyoto targets / environmental impact analysis

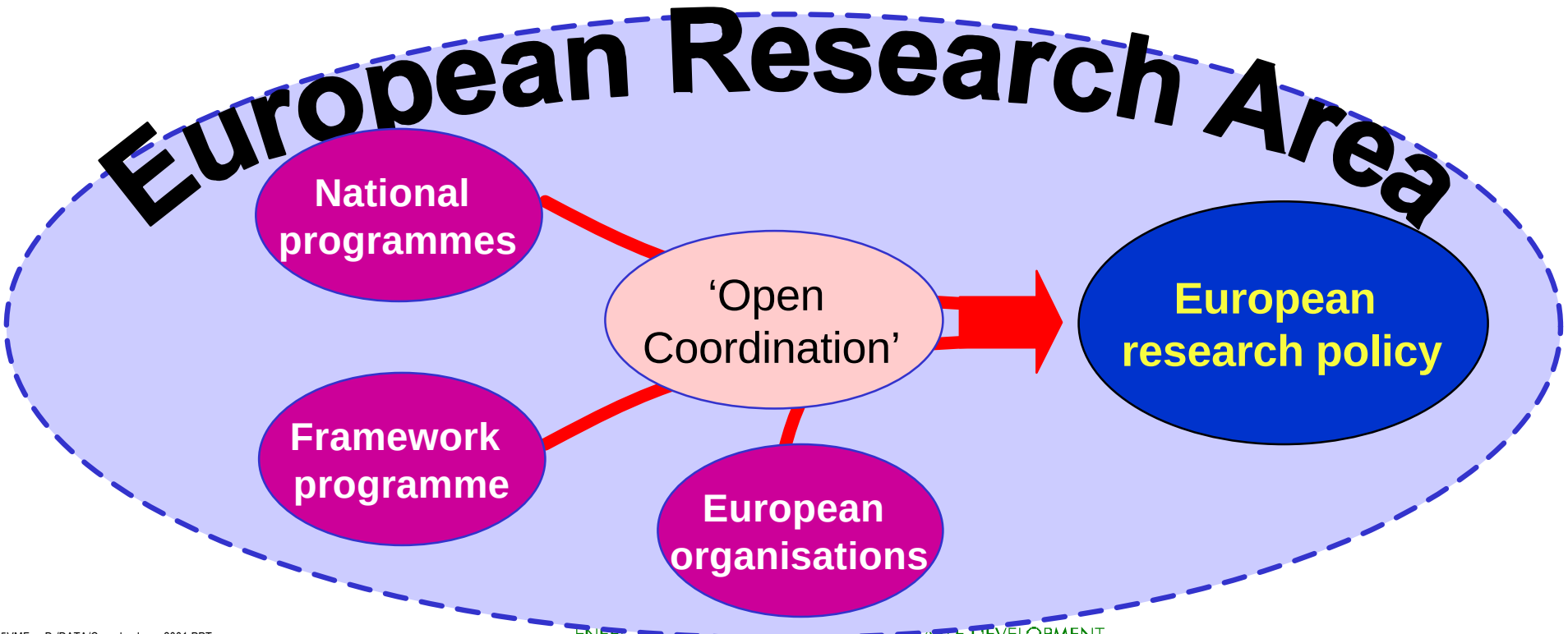
Compatibility with integration in new transport systems, intermodality / interoperability

Safety

Public acceptance

The European Research Area

- A blueprint for the future of research in Europe
- Broad support at the highest political, scientific and industrial levels
- Being implemented



Framework Programme 2002-2006
Schematic Structure of Objectives and Instruments

Networks of excellence	Integrated projects	"Article 169"

Block 1 : "Focussing and Integrating European Research" (incl. Intl. Cooperation and SMEs) (13.285M€)

1. Genomics and biotechnology for health (2.200M€)
2. Information Society technologies (3.600M€)
3. Nanotechnologies, intelligent materials and new production processes (1.300M€)
4. Aeronautics and space (1.075M€)
5. Food safety and health risks (685M€)
6. Sustainable development and global change (2.120M€)
7. Citizens and governance in the European knowledge-based society (225M€)
8. Anticipating the EU's Scientific and Technological needs (1.320M€)

Block 2 : "Structuring the European Research Area" (2.265M€)

1. Innovation
2. Human resources and mobility
3. Infrastructures
4. Science and society

Block 3 : "Strengthening the Foundations of the European Research Area" (330M€)

1. Opening up national programmes
2. Networking national programmes (benchmarking, mapping)

FP6 - A wider range of better differentiated instruments (1)

- Integrated projects
- Networks of excellence
- Article 169 *(joint implementation of national programmes)*
- As a "stairway of excellence"
  - ✓ specific targeted research projects
  - ✓ co-ordination actions
- Specific support actions

FP6 - 2002-2006

Focussing and integrating European Research

- Priority 6: "Sustainable Development, Global Change and Eco-systems"
- Sustainable Energy Systems (810 M€)
  - ✓ Sustainable Surface Transport (610 M€)
  - ✓ Global Change and Eco-systems (700 M€)

Energy RTD in FP6

➡Sustainable Energy Systems (810 Mio EURO)

- Reduction of greenhouse gases and pollutant emissions
- Security of energy supply
- Increased use of renewable energy
- Achieve enhanced competitiveness of European industry

FP6
Fuel Cells and Hydrogen

- Research will be implemented in Priority 6, in particular under the area "Sustainable Energy Systems"

- Budget in this area will most likely increase compared to previous programmes, depending on the quality of the proposals.

EUROPEAN RESEARCH 2002 at the crossroads

Conference to launch the 6th Framework Programme for Research

BRUSSELS , 11-12-13 NOVEMBER 2002

ENERGY, ENVIRONMENT AND SUSTAINABLE DEVELOPMENT

Events

- Plenary sessions
- Sessions on rules for participation
- “Participants’ forum”
- Project presentations
- Exhibition
- Press

Information

- **http://europa.eu.int/comm/research/conferences/2002**

- European Commission / Directorate General for Research, Information and Communication Unit:

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Mid – Term Assessment Workshop

Work Package 2: Refueling Station

Brussels
02 October 2002

Presentation by
Henrik Andersen
Norsk Hydro ASA

WP2: Main Objectives and Partners

- Provide inputs for regulatory activities on an EU and global level to facilitate harmonised procedures for approval of hydrogen refuelling infrastructure
- Develop hydrogen specific indutrial codes of practise for
  - Safe design and operation
  - Periodic inspection
- Identify components to be harmonised

WP2: Partner Experience

- Operation
  - 300-400 years of accumulated H2 experience from own facilities
  - Will be responsible for more than 10 operating H2 filling stations within 2 years
- Design
  - Will have provided more than 10 H2 filling stations within 2 years

WP 2: Deliverables

- List of existing standards, codes and regulations for conventional fuels and hydrogen
- Document describing required station components to be harmonised
- Procedure or protocol for maintenance and inspection
- Procedure that allows introduction of hydrogen refuelling stations

Sub-task 2.1: List of existing C&S

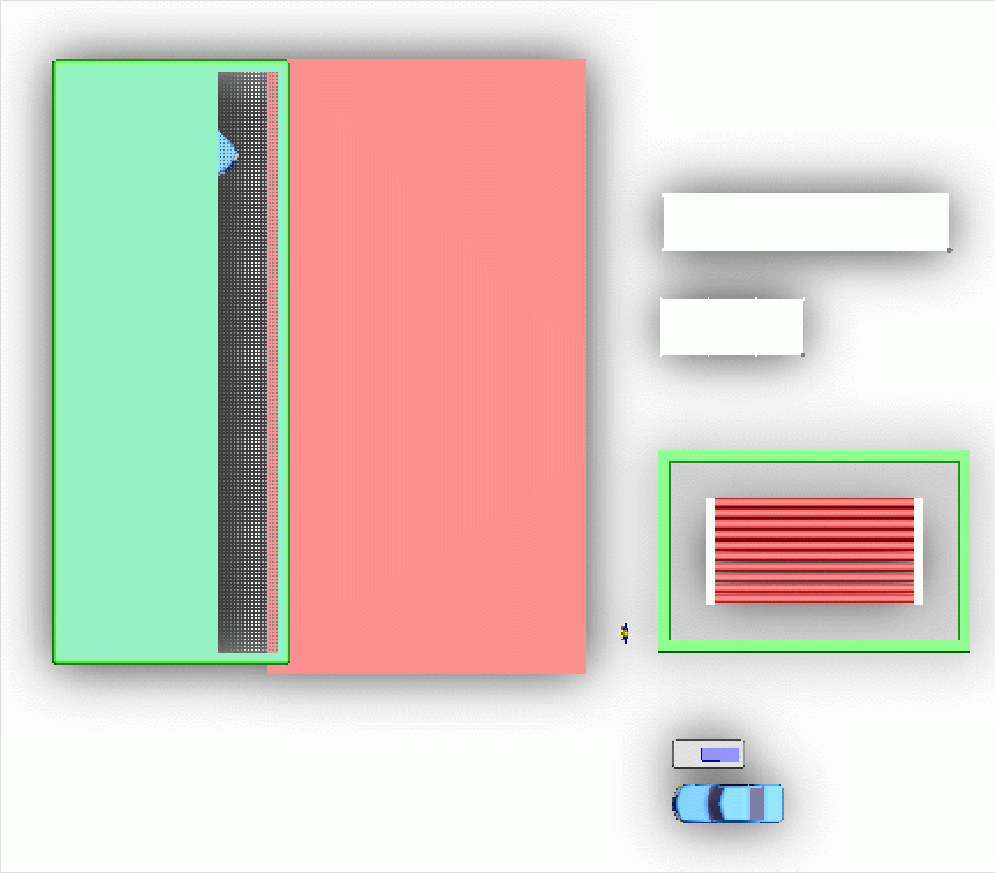
Original list of 190 C&S

- ISO
  - ISO TC 197 (Hydrogen)
  - ISO 15500 (CNG)
- EN
- NFPA
- EIGA
- National
  - CPR (Dutch)
  - ASME, API
  - NORSOK (Norwegian)
  - TRG 4XX (German)
  - Etc

The most important C&S

- ISO 15916
- TRG 406
- NFPA 50A
- EIGA 15/96

Sub-task 2.2: Develop Requirement for H_2 Refuelling Station



Main Components:

Processing Unit

Compressor Module

CGH2 Storage

Dispenser

Sub-task 2.2: Develop Requirement for H_2 Refuelling Station

- Development of a ”code” for safe design and operation
  - First priority is CGH2 compressor, storage and dispenser system
  - On-site production and bulk delivery of hydrogen will be added later
  - Requirements for LH2 refuelling stations to be developed later
  - The ”code” can form a basis for an ISO standard
- Other groups (NHA, ISO etc) will be invited for input and discussion

Sub-task 2.2: Develop Requirement for H_2 Refuelling Station

- Safety Studies of different Generic refuelling concepts
  - Methanol Reforming – BP and Norsk Hydro
  - Natural Gas Reforming – Norsk Hydro
  - Ammonia splitting – Norsk Hydro
  - Water Electrolysis – Hydrogen Systems, Shell and Norsk Hydro
  - LH2 and CGH2 by pipeline and truck : Air Products and Air Liquide
- Rapid Risk Ranking
- HAZOP of water-electrolysis
- QRA
- Assessment of safety distances

- Technology to be presented in the WP 2 afternoon session

Sub-task 2.3: Components to be harmonised

- On-going work :
  - ISO 22734 (WD) : Water-Electrolysis
  - ISO TC 197 N238 : Fuel-processor (Fossil fuels, eg NG)
  - Etc
  - WP 2 will only monitor
  - EIHP members already participates in TC of ISO
- Only connector seems feasible to harmonised
- Hydrogen technology on a refuelling station is new technology and standards can create barriers for improvement in the future
- Standards should as start be based on general safety requirements

Workshop Time Schedule WP2

- 14:10 h: Challenges in development of a infrastructure in Europe – Experience from CUTE (BP)
- 14:30 h: Hydrogen filling station based on water-electrolysis – Hydrogen Systems
- 14:50 h: Hydrogen filling station based on NG reforming - Norsk Hydro
- 15:10 h: Liquid hydrogen filling station - Air Liquid
- 15:30 h: Gaseous hydrogen filling station – APCI
- 15:50 h: Hydrogen Vehicle refuelling stations – Shell
- 16:10 h: General discussion and formulation of conclusions/ findings

Mid-Term Assessment Workshop

Brussels
02 October 2002

Presentation by
Fernando Isorna (INTA)
WP3-Refuelling Interfaces

WP3 Refuelling interfaces: Partners

WP3 Refuelling interfaces: Introduction

WP3 consortium will develop requirements for new draft standards of the refuelling interface "vehicle-refuelling station". This directly applies to the receptacle (vehicle based) and the nozzle (refuelling station based) and will have to take into consideration also items such as optimum storage pressure for CGH_2 storage and prerequisites of CGH_2 and LH_2 refuelling procedures. Validation of the interfaces shall ensure compliance with the elaborated standard and functional operability. Standardised on-board storage pressure(s) will be vital to the safe and commercially viable introduction of CGH_2.

WP3 Refuelling interfaces. Objectives

- Identification of optimised storage pressure for CGH_2.
- Approval of CGH_2 and LH_2 connectors (German approval for LH_2 connector).
- Development of refuelling procedures (CGH_2 and LH_2).
- Development of recommendations for the requirements needed for international standardisation of refuelling interfaces (CGH_2 and LH_2).

Sub-task 3.1 “Identification of optimum on-board storage pressure for CGH2”:

Sub-task 3.2 “Remaining CGH2 Activities”.

Sub-task 3.3 “Development of LH2 refuelling procedures”:

WP3 Refuelling interfaces. Sub-task 3.1 Progress of work

- **Existing studies to identify the optimum on-board storage pressure for CGH2.**
- **Identified issues that may cause difficulties with the introduction of very high pressure hydrogen systems, however, no insurmountable problems were identified (valves, fittings, temperature rise during refilling, metering systems, flexible components, material/design fatigue problems, sealing of non-metallic components, etc.).**
- **Studies on optimum on-board storage pressure for city buses, with the possibility of looking at passenger cars later. 200, 250, 350, 500, 600 & 700 bar (includes values proposed in the SAE draft refilling connector standard).**

WP3 Refuelling interfaces. Sub-task 3.1 Progress of work

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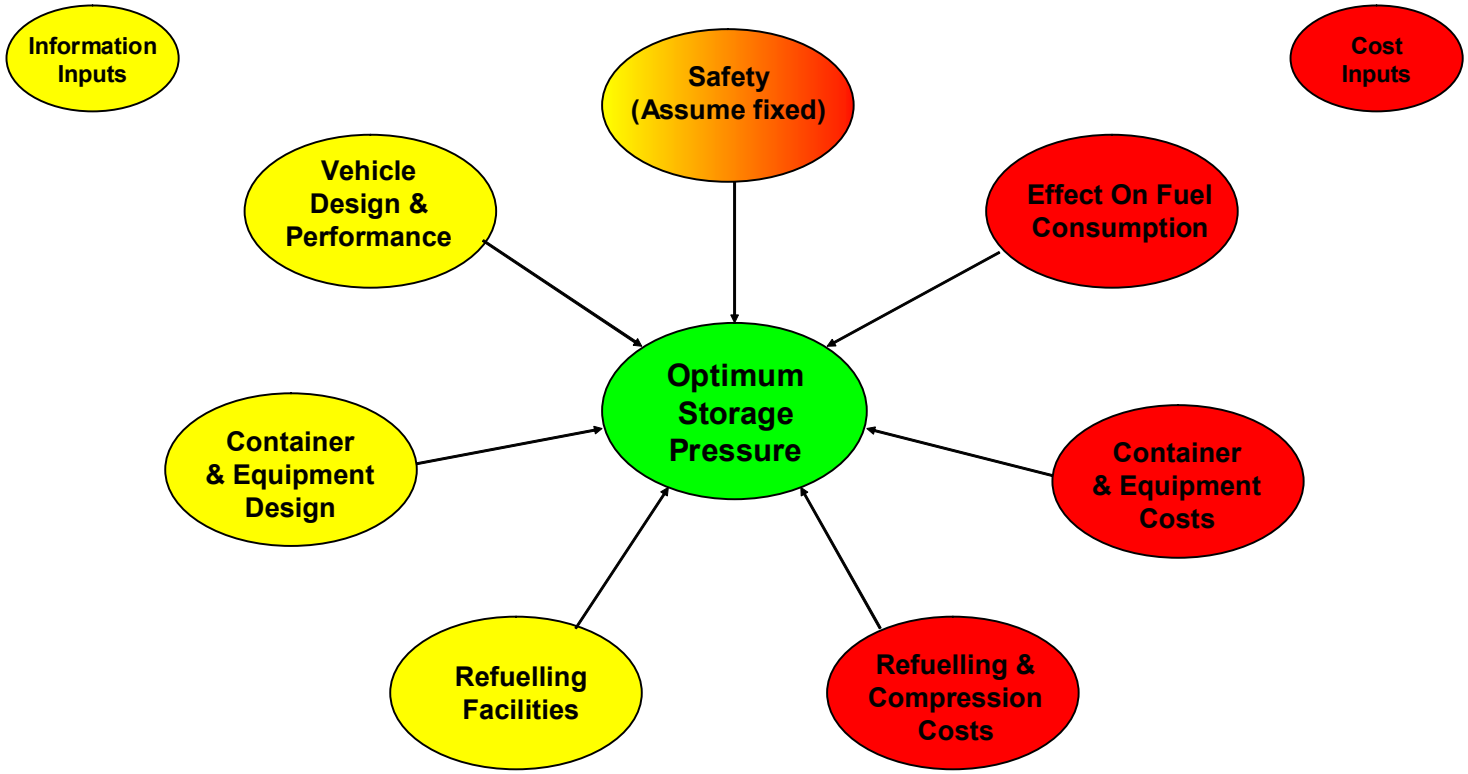
- **Studies on optimum on-board storage pressure for city buses, with the possibility of looking at passenger cars later. 200, 250, 350, 500, 600 & 700 bar (includes values proposed in the SAE draft refilling connector standard).**

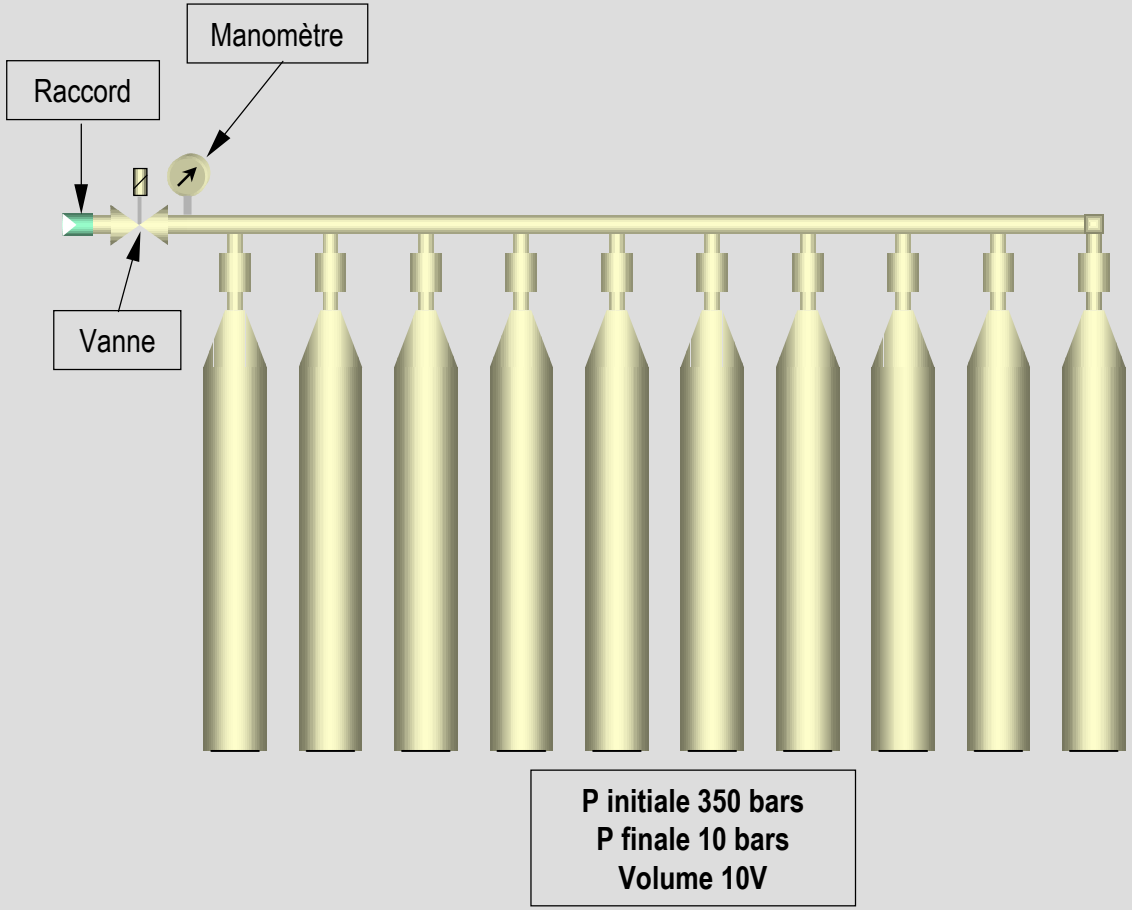
WP3 Refuelling interfaces



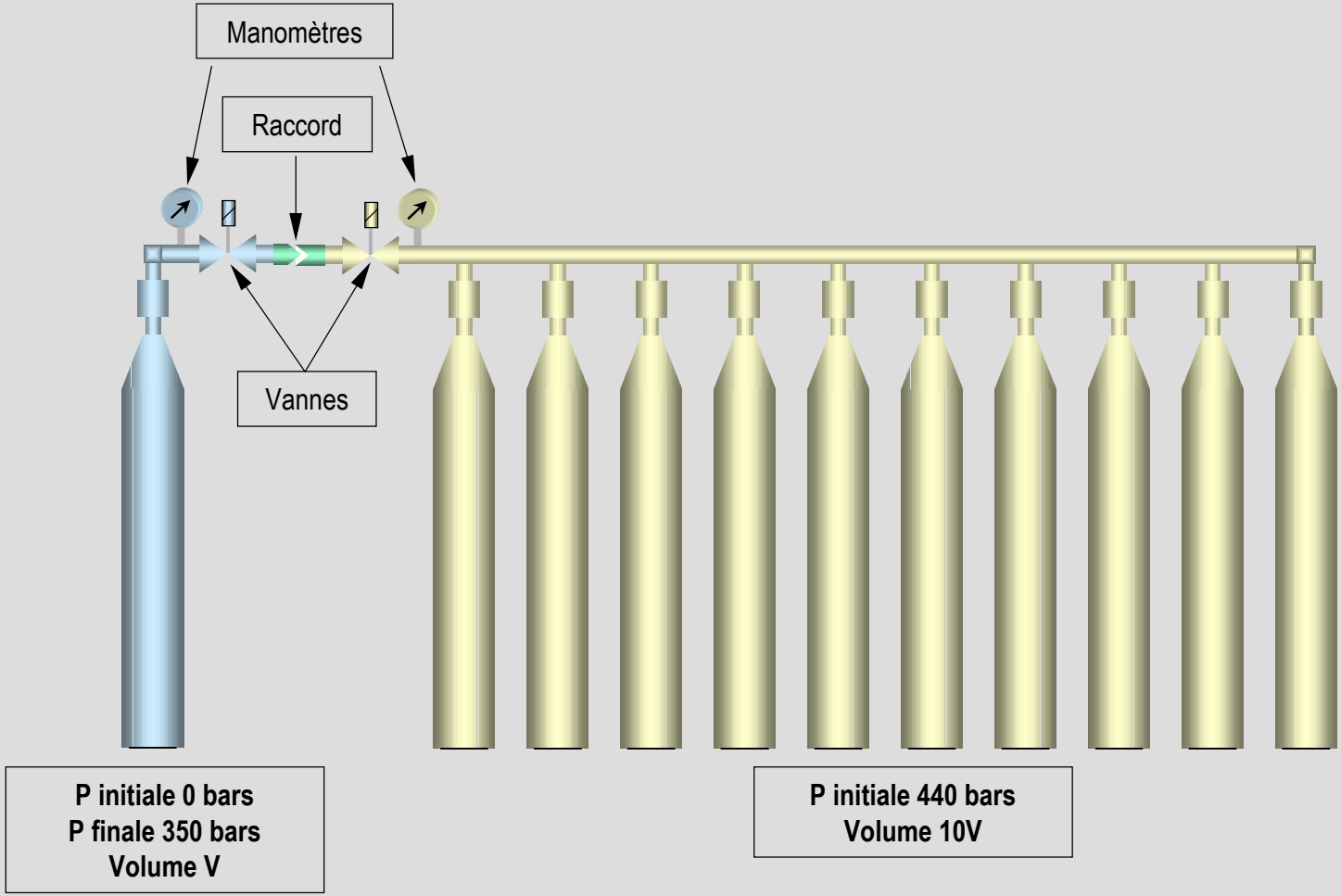
WP3 Refuelling interfaces. Subtask 3.2 Progress of work

- Carried out the development of experiments of fuelling tanks in order to supply data useful to propose a refuelling procedure.
- Experiments to be performed: Two experiments will be performed. The objective is to simulate as well as possible a real hydrogen refuelling.
- The first experiment is a preliminary experiment consisting of the depressurising of an hydrogen reservoir at 350 bar through the CMV08 STAUBLI connector (Figure 1). End of year 2002.
- The second experiment is an hydrogen transfer from a tank pressurized at 440 bar to a smaller tank initially empty through the STAUBLI connector (Figure 2). June 2003.

WP3 Refuelling interfaces: H_2 depressurising experiment



WP3 Refuelling interfaces: Hydrogen transfer experiment

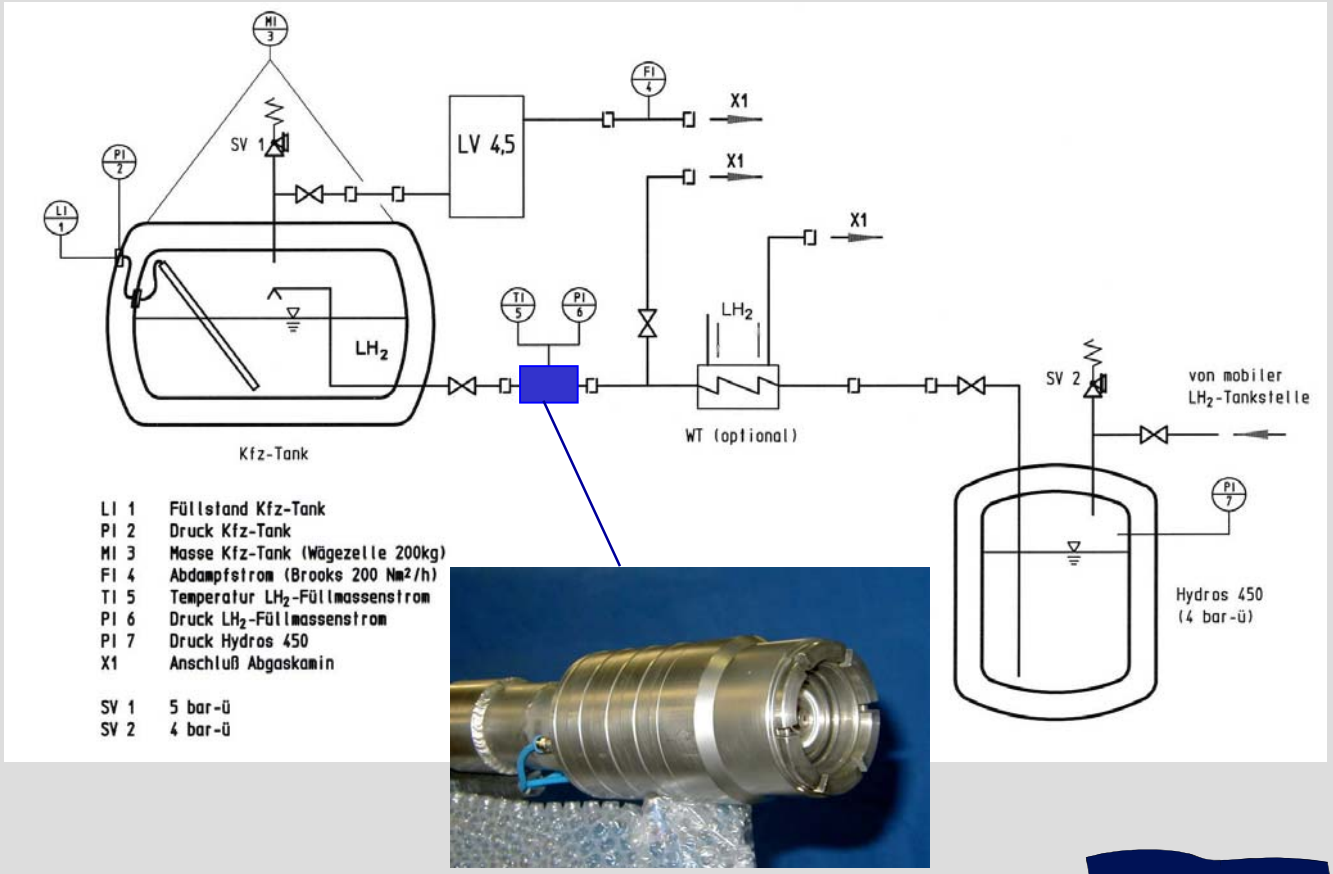


WP3 Refuelling interfaces. Subtask 3.3 Progress of work

- Requirements for the refuelling procedure for LH2 vehicles from the point of view of a vehicle manufacturer was made, discussed and updated. Possible refuelling concepts have been identified.
- Test procedures for LH2 couplings have been discussed. A new coupling for liquid hydrogen was manufactured and first cryogenic tests with liquid nitrogen have been carried out. A test stand for refuelling tests with liquid hydrogen is already finished.

Test of Clean Break Coupling with Liquid Hydrogen

- suitability of CBC for LH2
- simulation of a filling pump (subcooled liquid)
- data for different fuelling procedures
- recommendations for standardisation



WP3 Refuelling interfaces. Expected deliverables

CGH2:

Results of experiments performed at CEA.

Draft of recommendations on requirements for Int. Standards for interfaces equipment to standardization committees (as e.g. ISO TC 197).

Definition of refuelling procedures.

Proposal of identified optimum on-board storage pressure.

LH2:

Results of different refuelling tests (LN2 and LH2).

Definition of refuelling procedures.

Draft of recommendations on requirements for Int. Standards for interfaces equipment to standardization committees (as e.g. ISO TC 197).

Mid-Term Assessment Workshop

Brussels
02 October 2002

Presentation by
Dieter Stoll
BMW Group

WP 4 Vehicle – Objectives/State/Outlook

WP 4 Vehicle – Objectives/State/Outlook

Content:

- Motivation for the work package
- EIHP approach
- Deliverables, their Stati and Outlook
- Summary of targets

Motivation – Legal Situation in Europe, petrol vehicles

Sound Level
Emissions
Fuel tanks/rear protective device
Rear registration plate space
Steering effort
Door latches and hinges
Audible Warning

Rear visibility

Braking

Suppression (radio)

Diesel smoke

Interior fittings

Anti theft and immobiliser

Protective steering

Seat strength

Exterior projections

Speedometer and reverse gear

Plates (statutory)

Seat belt anchorages

Installation of lighting and
Light signalling device

Masses and dimensions
Safety glass
Tyres
Couplings
Frontal impact
side impact

Parking lamps

Seat belts

Forward vision

Identification of controls

Defrost/demist

Wash/wipe

Heating systems

Wheel guards

Head restraints

Fuel consumption

Engine power

Diesel emissions

Reversing lamps

Reflex reflectors
Position lamps
Direction indicators
Rear registration plate lamps
Head lamps
Front fog lamps
Towing hooks
Rear fog lamps

Motivation – Legal Situation in Europe, hydrogen vehicles

Sound Level **Emissions** **Fuel tanks/rear protective device** Rear registration plate space Steering effort Door latches and hinges Audible Warning

Rear visibility

Braking

Suppression (radio)

Diesel smoke

Interior fittings

Anti theft and immobiliser

Protective steering

Seat strength

Exterior projections

Speedometer and reverse gear

Plates (statutory)

Seat belt anchorages

Installation of lighting and Light signalling device

Masses and dimensions Safety glass Tyres Couplings **Frontal impact** **side impact**

Parking lamps

Seat belts

Forward vision

Identification of controls

Defrost/demist

Wash/wipe

Heating systems

Wheel guards

Head restraints

Fuel consumption

Engine power

Diesel emissions

Reversing lamps

Reflex reflectors Position lamps Direction indicators Rear registration plate lamps Head lamps Front fog lamps Towing hooks Rear fog lamps

List of directives/regulations to be amended

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 labelling	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)

Application for a Whole Vehicle Type Approval

TÜV for pressure vessels

Approval for high pressure parts and report

TÜV Automotive

Expertise

Application for approval (incl. exemption)

National approval authority

Report

EU-Commission

CATP

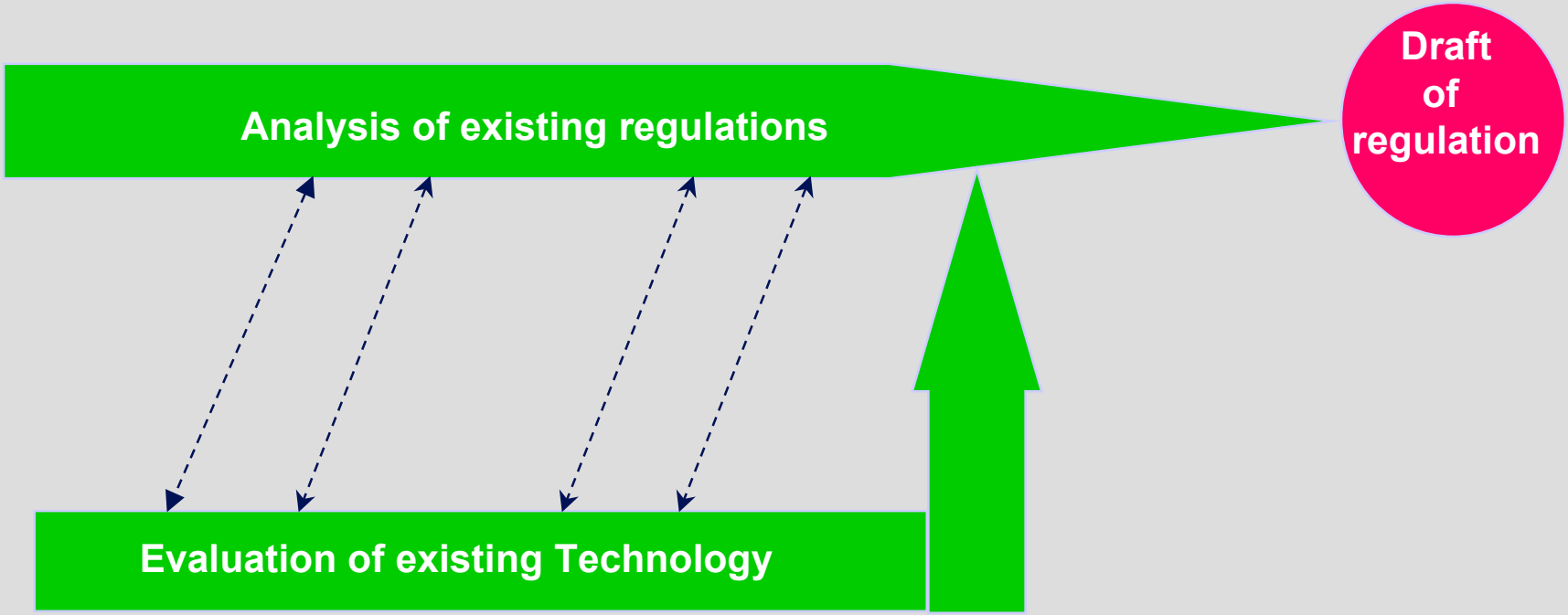
EU-Commission

Decision

National approval authority

WVTA restricted to 36 month

Dual Strategy



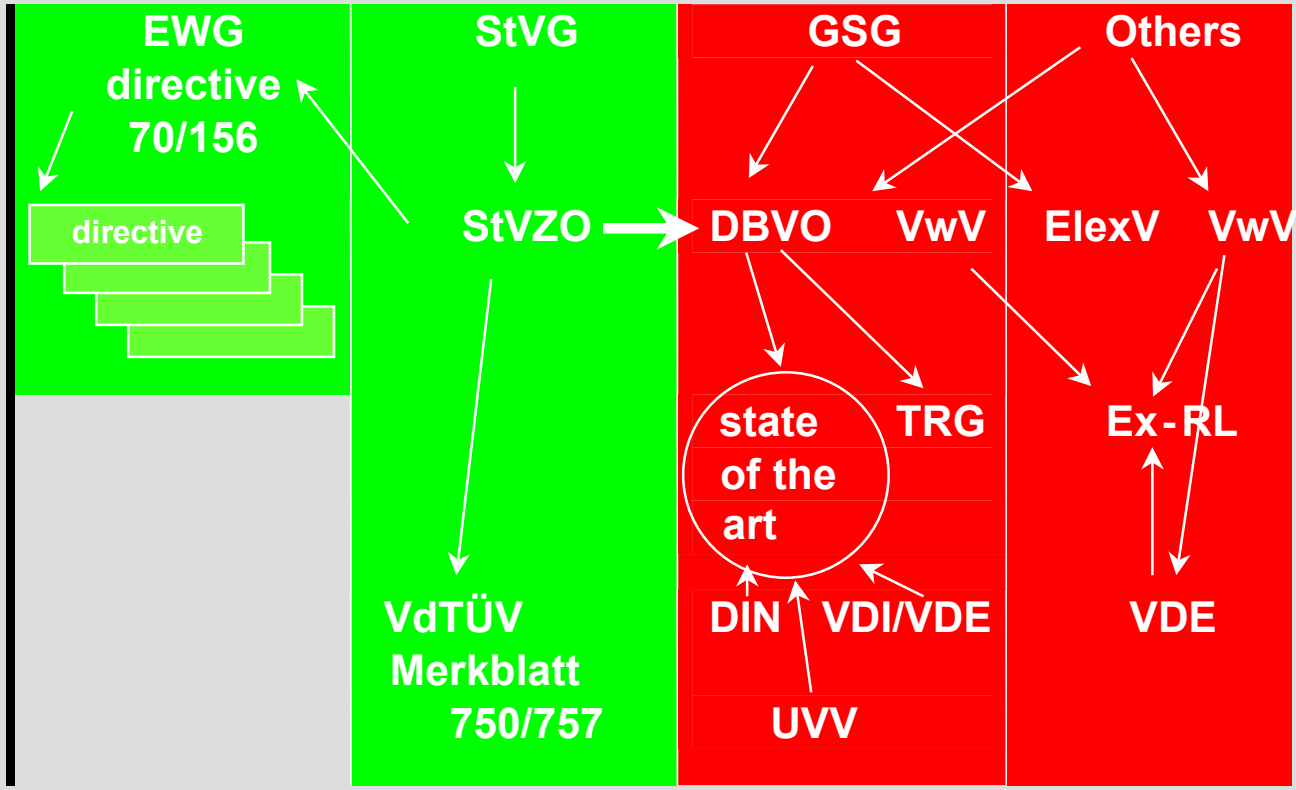
Results of the survey in Germany

Valid law

bylaws

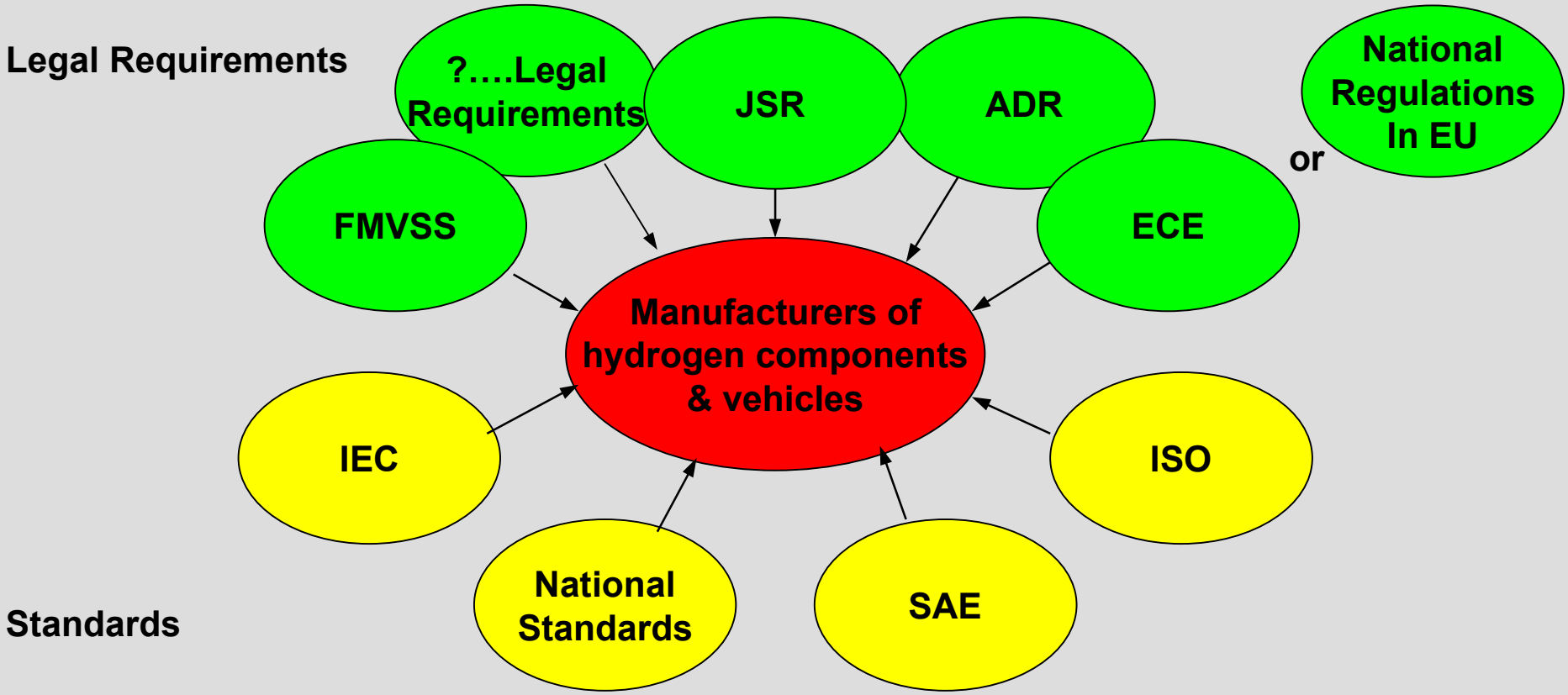
Codes of practise

Standards etc.

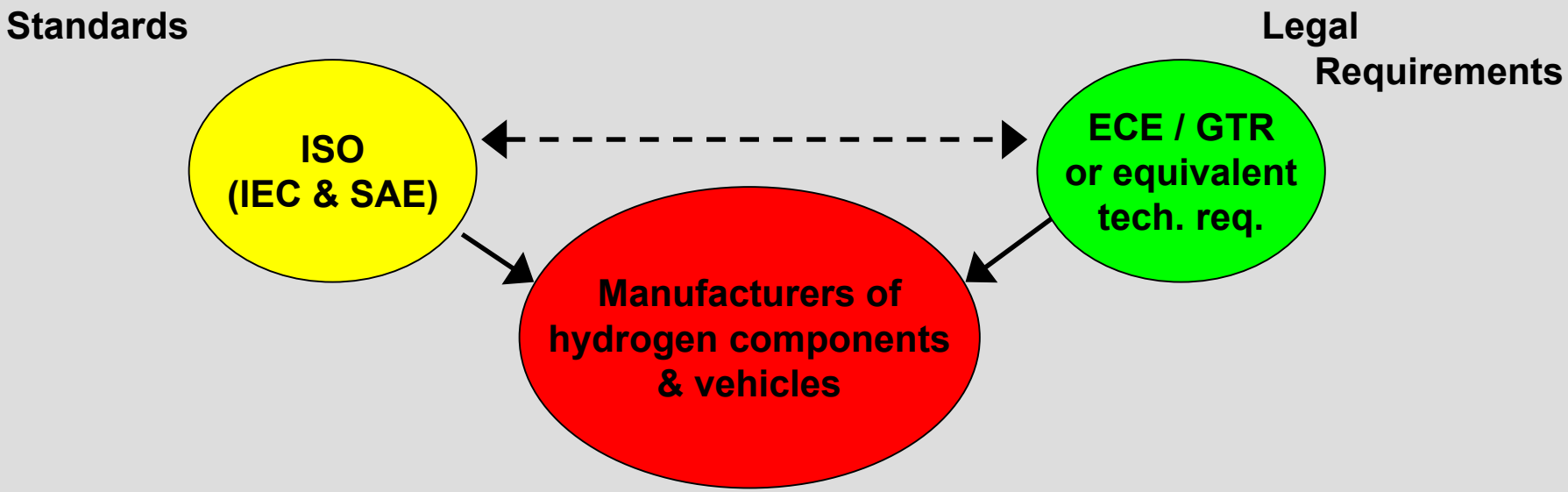


Results of the survey in USA

Codes and standards, undesirable situation



Codes and standards, desirable situation



Work package 4, deliverables, Stati and Outlook

1. **List of deficits in rules and regulations including proposals for modification**

   - **Rules and regulations are identified**
   - **Workload is distributed to partner**
   - **Drafts for modifications are under development**
   - **Agreed modifications will be forwarded to relevant committees**

2. Accepted ECE Regulation

- 2 draft regulations are elaborated
- Draft regulations are forwarded to ECE in Geneva
- GRPE ad hoc working group was formed
- Technical discussion with ISO in order to harmonize technical requirements

Work package 4, draft regulations

LH_2 vehicles

Proposal for a new draft regulation (Rev.12)

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**

CGH_2 vehicles

Proposal for a new draft regulation (Rev.9)

UNIFORM PROVISIONS CONCERNING THE APPROVAL OF:

I. **SPECIFIC COMPONENTS OF MOTOR VEHICLES USING COMPRESSED GASEOUS HYDROGEN**

II. **VEHICLES WITH REGARD TO THE INSTALLATION OF SPECIFIC COMPONENTS FOR THE USE OF COMPRESSED GASEOUS HYDROGEN**

Work package 4, deliverables, Stati and Outlook

3. Global Technical Regulation for Hydrogen fuelled vehicles in the global Registry

- Issue was discussed in GRPE
- Decision to prepare an ECE Regulation first

4. Draft for an amending directive to 96/96/EC

- Existing rules for periodic inspection where investigated
- First draft for an amending directive (LH2) exists
- Draft is currently checked by different partner and organisations outside EIHP

Work package 4, deliverables, Stati and Outlook

5. Approval for components and vehicles or an evaluation of necessary major modifications in existing components or vehicles
   - New components and vehicles are under development
   - Requirements from EIHP drafts are the basis for the development of new vehicles and components
   - Comments and proposals for modification are gathered from the design departments of vehicle manufacturers and suppliers
   - Draft regulations where improved continuously

6. Standard for calculation of safety valves for vehicle application

- Activities of this task have been redefined to issue a recommendation about what regulation to follow when sizing a safety valve for an on board application, as regulation exists and it is not useful to try to rewrite what is already existing

Work package 4, Summary of targets

- A legal framework must lead to planning reliability for car and component manufacturers as soon as possible
- Legal requirements and Standards should be on a global basis i.e. GTR‘s and ISO

European Integrated Hydrogen Project - Phase II

Mid – Term Assessment Workshop
Work Package 5: SAFETY

Brussels
02 October 2002

Presentation by
Daniele Baraldi
EC-JRC Institute for Energy

WP5: Objectives and Partners

- To assess the **safety of hydrogen** when used as a fuel in vehicles and the safety of the associated infrastructure.
- To perform a **comparative study of hydrogen** versus current vehicles fuels.
- To support the **safety issues** in the other work packages.

Overview of Work Package 5

- **Sub-task 5.1**: Review of existing safety data on hydrogen and comparative fuels. Partner: Shell.

- **Sub-task 5.2**: Risk analysis of re-fuelling infrastructure, including CFD simulations of gas dispersion and combustion. Partners: Det Norske Veritas, Norsk Hydro, NCSRDemokritos, EC-JRC.

- **Sub-task 5.3**: Safety study of CGH2 vehicles. Partners: Volvo Technology Corporation, NCSRDemokritos, Raufoss, EC-JRC.

- **Sub-task 5.4:** Experimental test programme. Partner**:** FZKarlsruhe.

- **Sub-task 5.5**: Comparative study of risk to health, safety and environment. Partners: Det Norske Veritas and EC-JRC.

Sub-task 5.1: Review of Hydrogen Safety Data.

Compilation of Existing Safety Data on Hydrogen and Comparative Fuels

Shell made a compilation of existing data on the safety of hydrogen and comparative fuels. The report reviewed the influence of the various physical properties of the fuels which may have an impact on safety, such as for instance: propensity to leak, flammability, ignition characteristic, sensitivity to detonation …

Factors making hydrogen safer

- Propensity to dissipate quickly.
- Relatively high LFL
- Low energy density

Factors making hydrogen less safe

- Wide flammable range.
- Low ignition energy
- Small quenching gap
- Propensity to detonate

Compilation of Existing Safety Data on Hydrogen and Comparative Fuels

- **Conclusion:**

concerning the explosion hazard, hydrogen can be safer than conventional fuels in some situations and more hazardous in others. The relative safety of hydrogen compared to other fuels must take into consideration the particular circumstances of its accidental release.

For the introduction of hydrogen as a retail fuel, quantitative risk assessment over the whole supply chain as well as the vehicle is needed.

Sub-task 5.2: Risk analysis of re-fuelling infrastructure

- NH and DNV have been performing a **HAZOP** of a re-fuelling station concept based on water electrolysis in order to identify cases for the Quantitative Risk Analysis (QRA).

- **CFD simulations** of accident consequences (gas dispersion and combustion) related to re-fuelling infrastructure by NH, NCSRDemokritos and EC-JRC.

- Development of **Rapid Risk Ranking (RRR) methodology** for H2 re-fuelling station concepts by NH and DNV .

- **RRR of re-fuelling stations** based on H2 production by water electrolysis, ammonia splitting, methanol steam reforming, CGH2 supplied by truck or pipeline and LH2 supplied by truck, natural gas reforming (NH and DNV).

- Development of **acceptance criteria** for H2 re-fuelling station concepts (NH and DNV).

Sub-task 5.3: Safety Study of CGH_2 Vehicles.

- Develop an understanding of the dispersion and combustion of hydrogen in **realistic accident scenarios**.The following scenarios have been selected for **CFD calculations** :

NCRSD dispersion calculation

- Tunnels checks
- 1983 Stockholm Accident
- Bus accident in an inner city environment
- CNG
- Maintenance garage
- Fire.

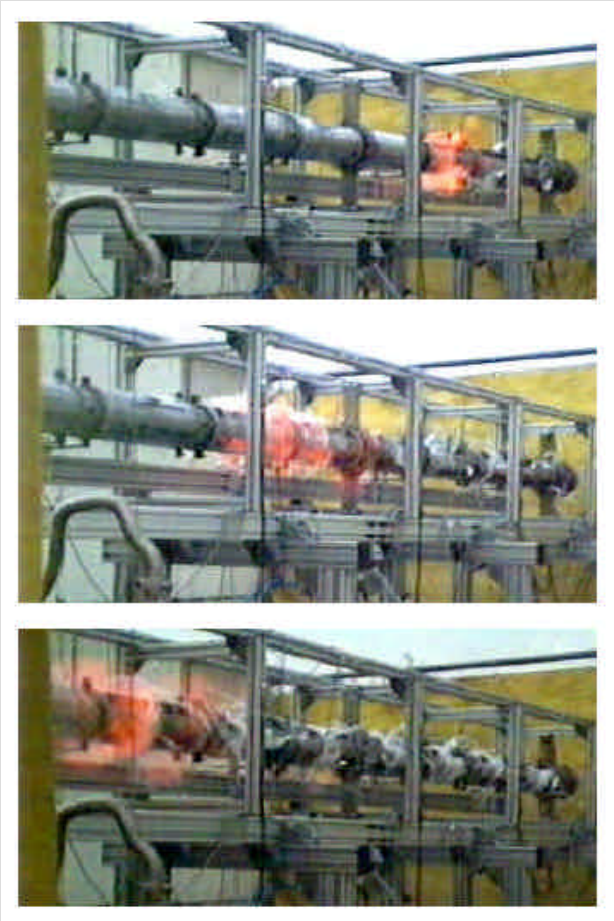
- Modelling of accident scenarios to form the basis of a consequence analysis to be used in a **wider safety study** of commercial vehicles (urban buses).

- Assist developing **safe components and systems** for use with hydrogen.

- Provide input to the continuing development of the **draft ECE regulation** for the use of CGH_2 in vehicles.

- Provide an **informed basis** for discussion with the authorities and public regarding the introduction of hydrogen as a commercial vehicle fuel.

Sub-task 5.4: Experimental Test Programme



- FZK has been performing **experiments** of gas combustion. Objectives of the tests include:
  - Study of **critical conditions** for strong Flame Acceleration and DDT in vented tubes and semi-confined geometry;
  - **Comparison** of explosion properties of hydrogen and typical hydrocarbon fuels in semi-confined geometry ;
  - Generation of the data necessary for **validation** of computer codes for simulation of gaseous explosions in semi-confined geometry.

- In the experiments fuel type, concentrations and geometrical configurations are varied in a way which covers **relevant scenarios**.

Sub-task 5.5: Comparative study of Risk to HSE

- DNV and EC-JRC will conduct an **overall comparative study of risk to Health, Safety and Environment** (HSE) associated to hydrogen and other fuels. The investigation will include the results from sub-task 5.2 and 5.3.

- Work to be undertaken in the **third year** of the project.

Workshop Time Schedule WP5 SAFETY

- **14.10** Structure of Hydrogen Safety Problems – FZK`s Proposal for the 6th Framework Programme: HySafe Integrated Project (*Sergey Dorofeev*, FZK)
- **14:30** Properties of Hydrogen in Comparison with Other Fuels (*Jan Maarten Teuben*, Shell – Subtask 5.1).
- **14:50** Release Scenarios and Modeling of Hydrogen Mixing and Combustion (*Alexander Venetsanos*, NCSRD – Subtask 5.3).
- **15.10** Evaluation of Hazards Associated with Hydrogen Combustion - Achievements and Issues (*S. Dorofeev,* FZK – Subtask 5.4).
- **15.30** Risk analysis - Problems and Issues (*Harald Rikheim*, DNV - Subtask 5.2, 5.5).
- **15:50** H2-Accident Mitigation Techniques (*Berry Sanders*, TNO).
- **16:10** General Discussion and Conclusions.

Mid-Term Workshop Meeting

Brussels
02 October 2002

WP6
Presentation by
Dr M D Jones
BP

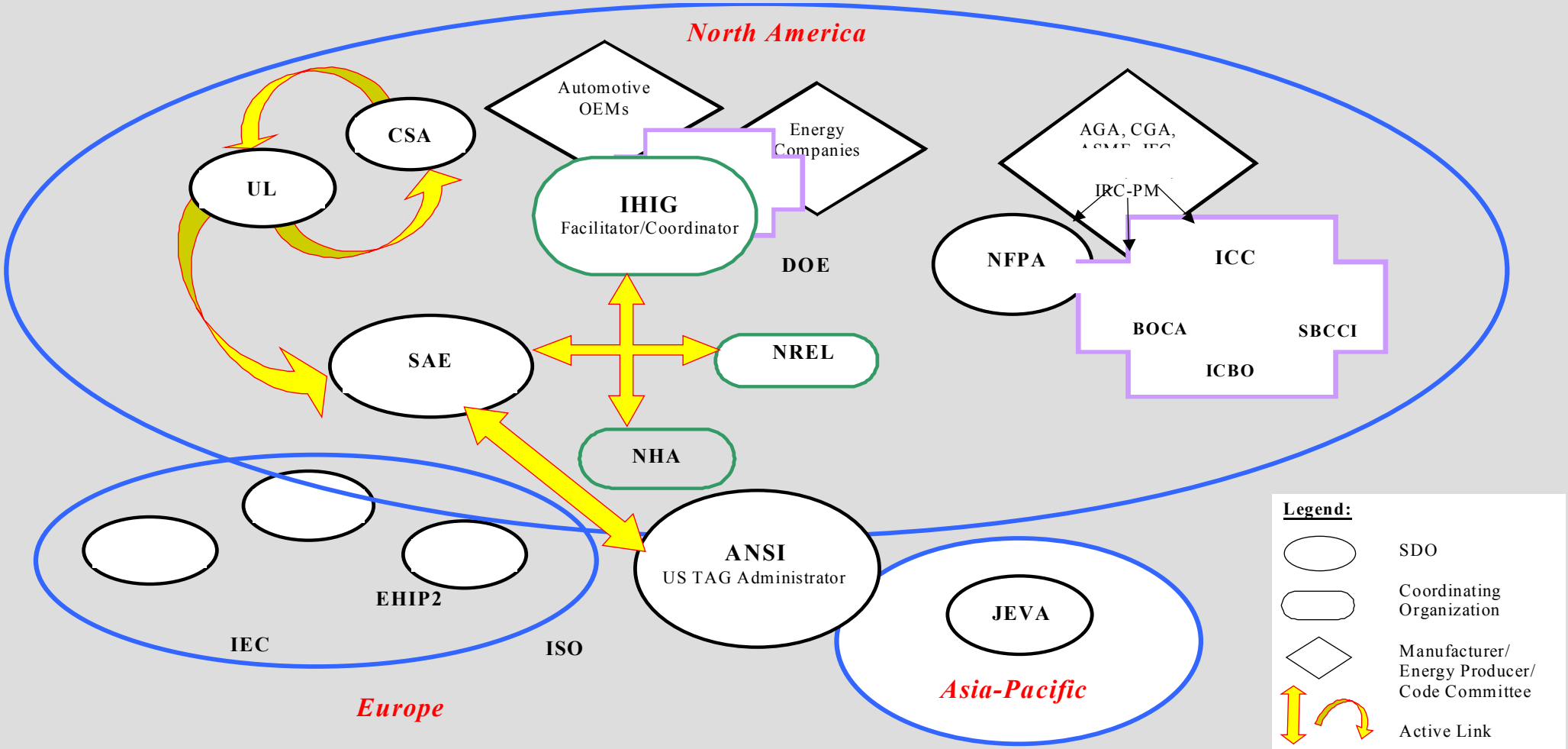
WP6 International Links and Cluster Activities

- Partners: BP, Shell, CEA, DaimlerChrysler, Ford.
- Aim is that there are Global codes, standards and regulations applicable to the transportation industry and refuelling infrastructure
- Key that we establish and maintain links on codes and standards initiatives Worldwide.
- Exchange information with ISO, CaFCP, NHA, SAE, DOE etc.

Deliverables:

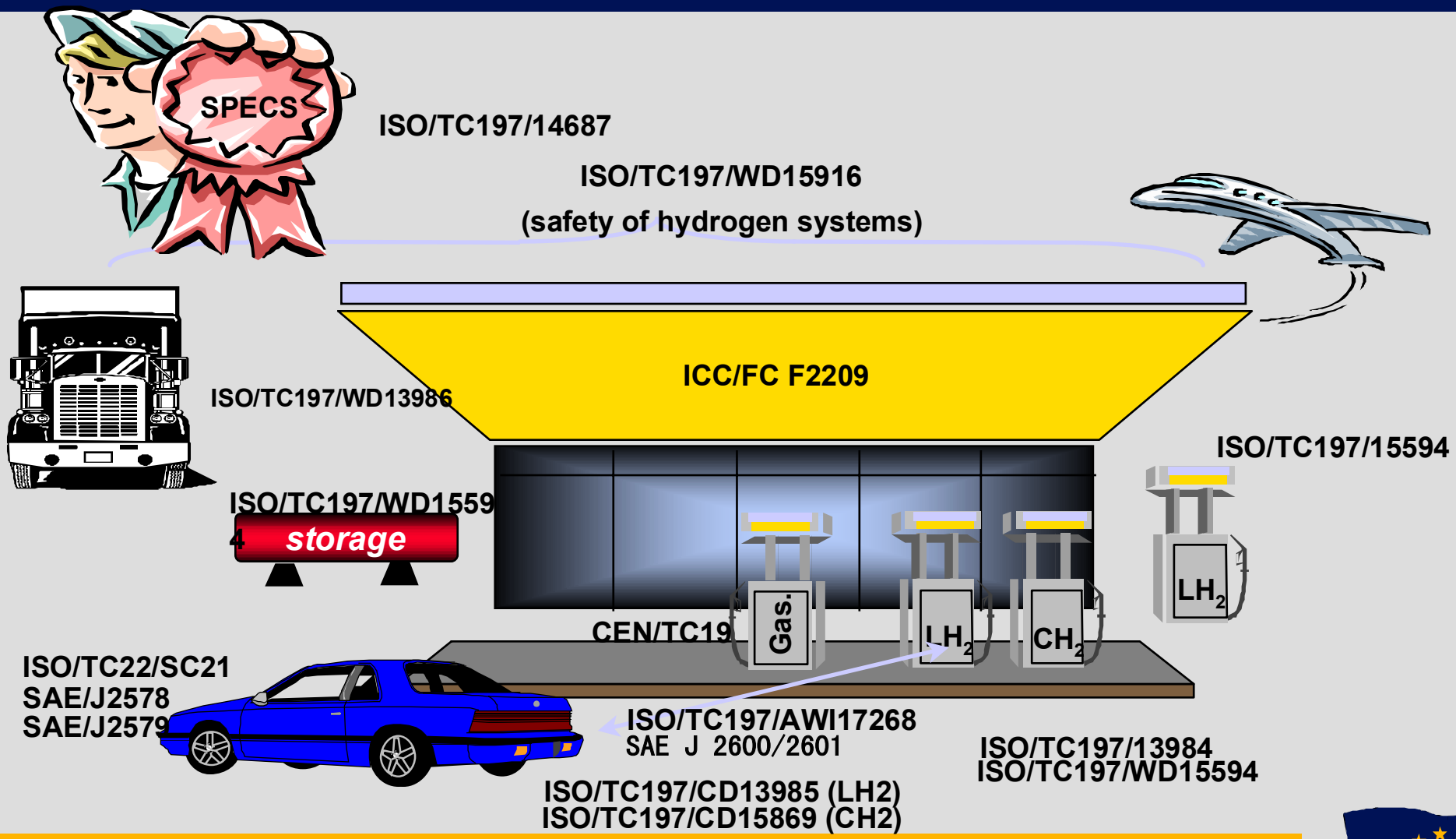
- Briefing notes on the latest codes and standards developments worldwide
- Briefing notes on developments in ISOTC197
- Link to codes and standards activities globally.
- Establish process for information sharing on C+S

Complex Codes and Strandards Developments (IHIG view)



Hydrogen Codes & Standards Relational Roadmap

Complex Codes and Strandards Developments (IHIG view)



WP6 Establish links to major organisations developing codes

- WP6 companies involved already internationally in C+S developments in US and Japan.
  - eg. BP and Shell in IHIG, NHA, TES, CaFCP etc.
  - eg. Ford and DC in CaFCP, SAE, etc.

- Established contacts to ISO TC 22 SC 21, IEC TC 105, SAE FCC Interface Working Group, FCCJ (via DC Japan), EVAA, Hydro Quebec, CaFCP, NHA & DOE and TES, etc.

- EIHP2 outline has been presented to:
  SAE Full Committee Meeting,
  NHA annual meeting 2001.
  IHIG activity developing codes and standards.

- Links established between EIHP and ISO and NHA on C+S.

WP6 International Links and Cluster Activities

- EIHP has the opportunity to become the platform for addressing issues relating to C+S for hydrogen across Europe.
- Briefing notes produced by both BP and Shell on the international C+S activities relevant to refuelling stations and associated buildings.
- Briefing notes issued on ISO TC197 and SAE developments.
- Review of the principle organisations developing Codes and standards has been completed and details published on the internal EIHP web site.

WP 6.4 Workshops with target groups

- CEA is participating to the ISO/TC197 standardization committee on hydrogen technology. CEA has the chairmanship of the corresponding French AFNOR mirror committee.

- CEA has been attending to the following meetings:
  ISO/TC197 2001 plenary meeting : Paris (France) 25/10/2001
  ISO/TC197 2002 plenary meeting : Montréal (Canada) 13-14/06/2002

- BP and Shell participated in work shops in US on IHIG and US DOE codes and standards.

WP6.4 Information of Target Groups via Workshops/Internet

- Produced list of C+S activities and contacts globally.
- EIHP will produce a presentation for downloading and use by EIHP partners for external use and available on web site.
- Aim is that there is an information package (continuously updated)
- Work Package leaders will produce summary reports of EIHP output for dissemination to external C+S groups.

WP 6 is establishing the links, has identified the contacts. The communication of results to these groups must be from the individual WP leaders.

VANDENBORRE HYDROGEN SYSTEMS

Ballast Nedam International Product Management

TEESING

CFS CLEAN FUEL SYSTEMS

Presentation EIHP2 MTA-Workshop

Nijverheidsstraat 48c
B-2260 Oevel
Belgium
Tel. +32 (14) 462110
Fax +32 (14) 462111

P.O. Box 280
4140 AG Leerdam
The Netherlands
Tel. +31 (345) 639250
Fax +31 (345) 639207

P.O. Box 16
2280 AA Rijswijk
The Netherlands
Tel. +31 (70) 4130795
Fax +31 (70) 4130728

Ballast Nedam - International Product Management

Vandenborre Hydrogen Systems

Teesing

Clean Fuel Systems

A co- operation between BNIPM and Vandenborre

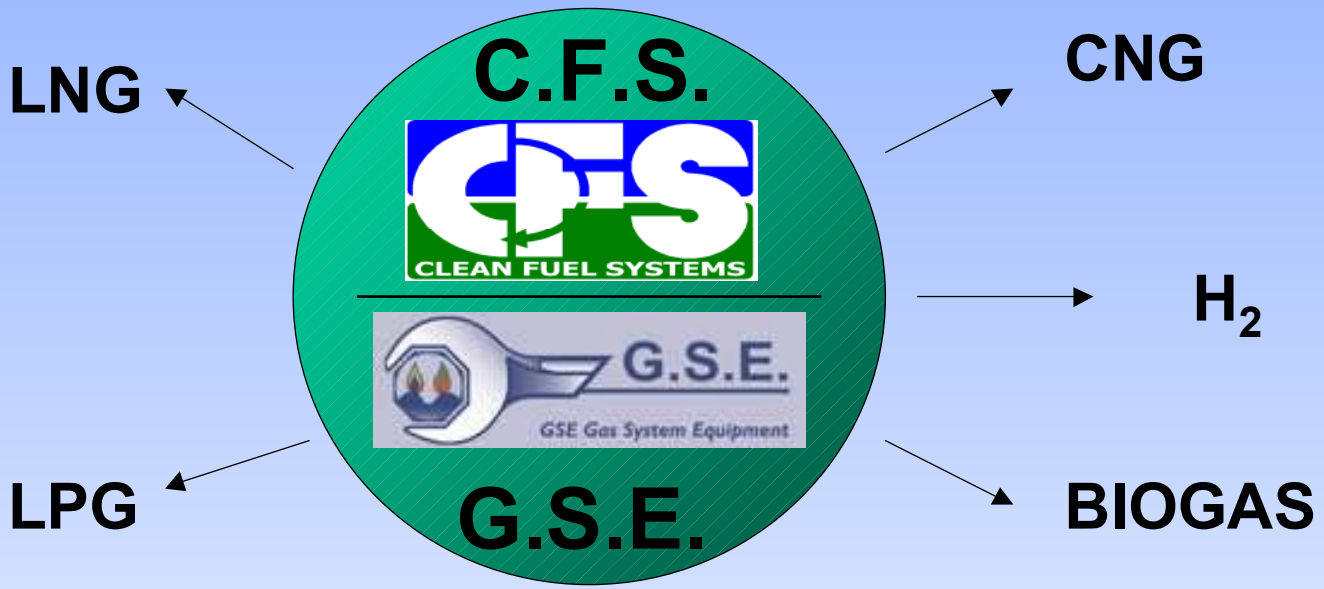
Gas System Equipment

A co- operation between BNIPM and Teesing

VANDENBORRE HYDROGEN SYSTEMS

Ballast Nedam International Product Management

TEESING



Introduction Ballast Nedam NV

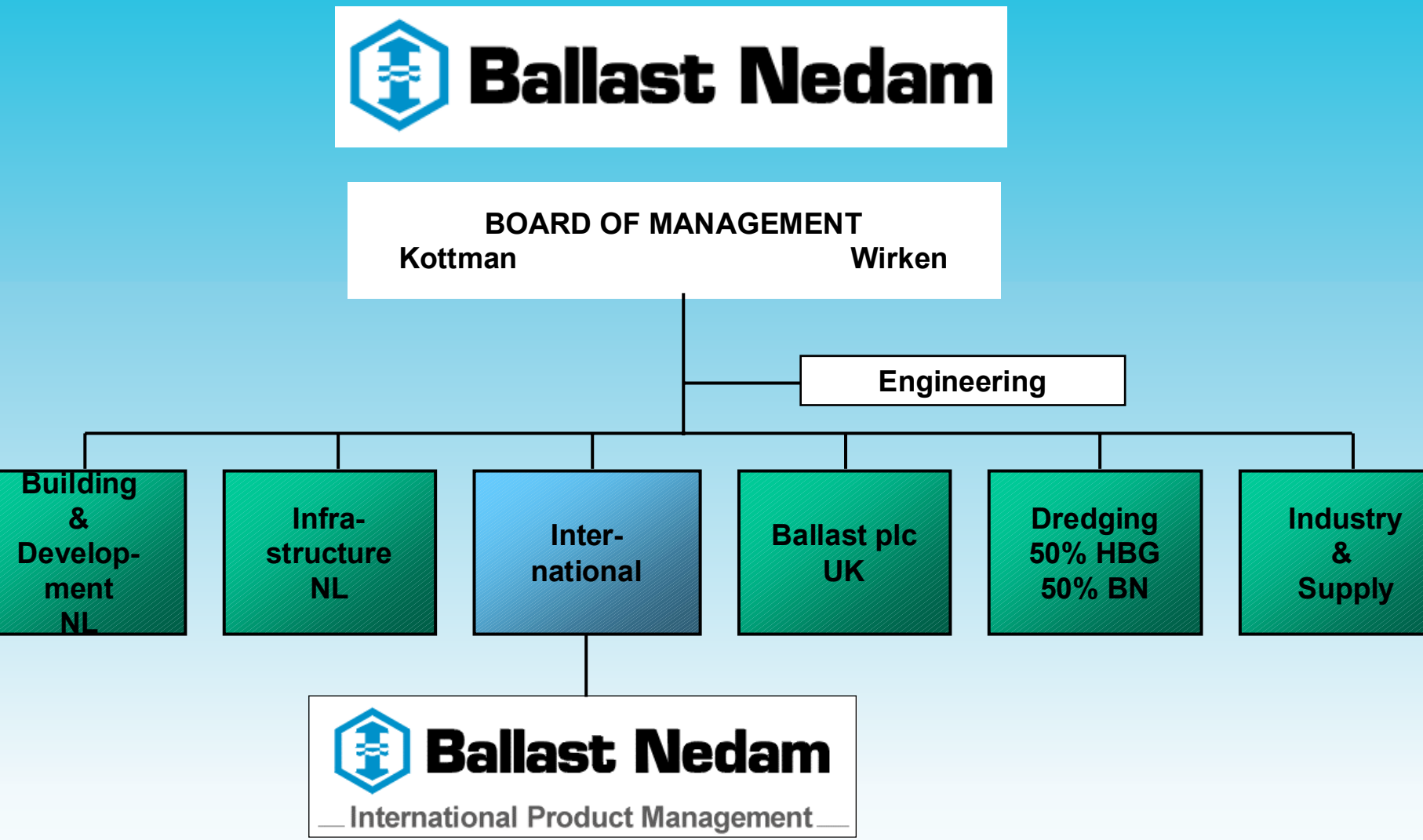
Ballast Nedam

A contractor which can offer a combination of skills in general building, civil/marine engineering and dredging by participating in all phases of a project - from concept to completion (i.e. feasibility studies, financing, investments, design, engineering, procurement, construction, operation and maintenance)

International Market

Europe, Southeast Asia, the Caribbean and the Middle East

Ranks among the forty leading European construction companies


Ballast Nedam
BOARD OF MANAGEMENT
Kottman
Wirken
Engineering
Building & Develop-ment NL
Infra-structure NL
Inter-national
Ballast plc UK
Dredging 50% HBG 50% BN
Industry & Supply
Ballast Nedam
International Product Management

Ballast Nedam

Geographical Spread

Introduction Ballast Nedam International Product Management

Ballast Nedam

International Product Management

European oriented organisation with a Central Knowledge Centre in the Netherlands

One central point of contact for all disciplines and activities

Knowledge of local legal and administrative requirements

Execution with own and experienced local building contractors

Specialized in design and construction of petrol and gas stations

Has build more than 200 Petrol stations all over Europe

Ballast Nedam

International Product Management

Projectmanagement and co-ordination at every desired level, in every phase and in every country

Feasibility and preparatory phase	Concepts Design Technical development
Executional phase	Realisation
Maintenance phase	Periodic maintenance Calamity service

Ballast Nedam

International Product Management

Ballast Nedam IPM

Your partner in total development

Introduction Automotive Fuelling Technology

Ballast Nedam

International Product Management

Automotive Fuelling Technology

Projectmanagement for all disciplines during the complete life cycle of a Fuel Supply Centre:

- Civil technique
- Builders works
- Installation technique
- Environmental technology
- Maintenance
- Fuelling Technology

Ballast Nedam

International Product Management

Installation technique

Ballast Nedam

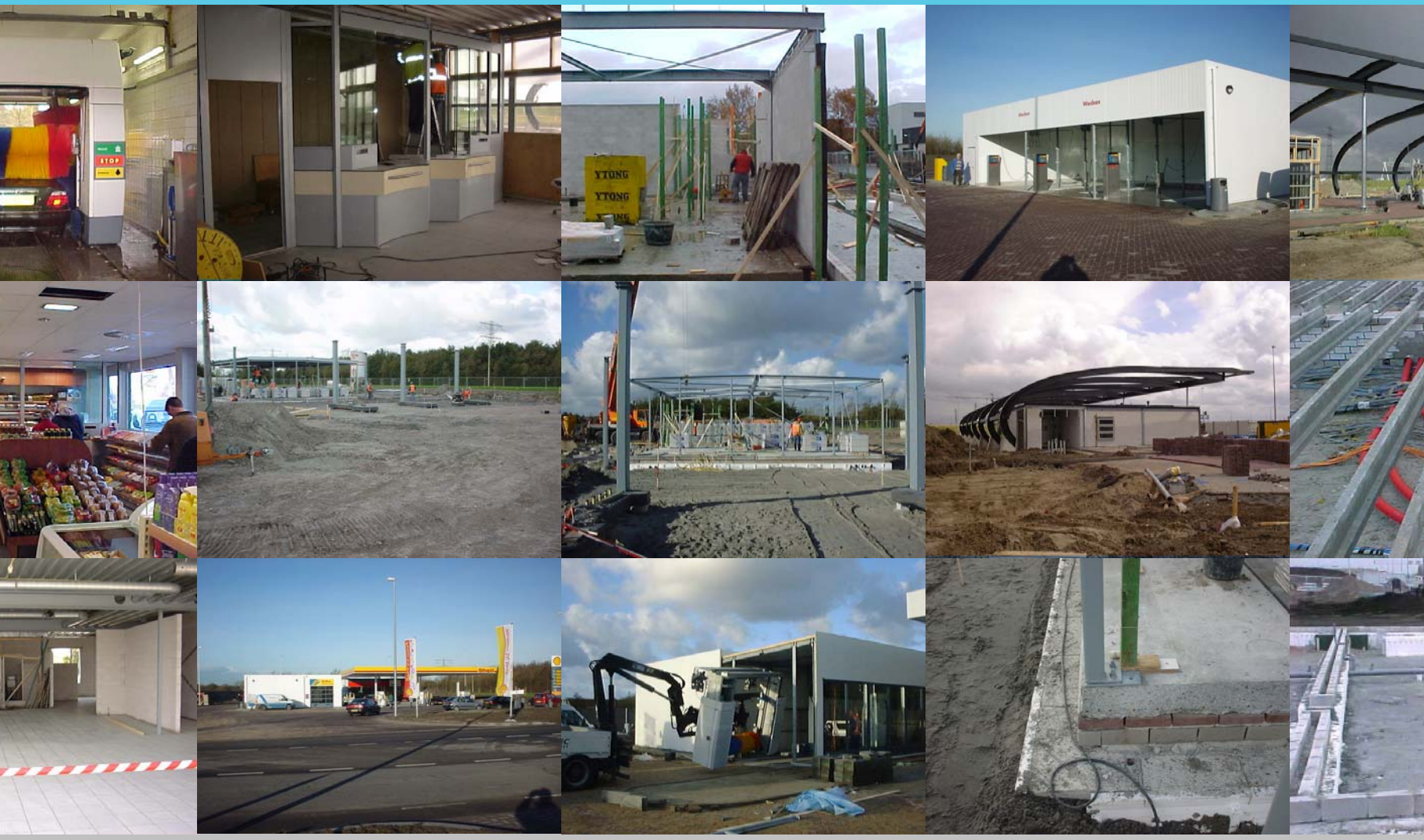
International Product Management

Civil technique

Ballast Nedam

International Product Management

Builders works



Ballast Nedam

International Product Management

Environmental technology

Ballast Nedam
International Product Management

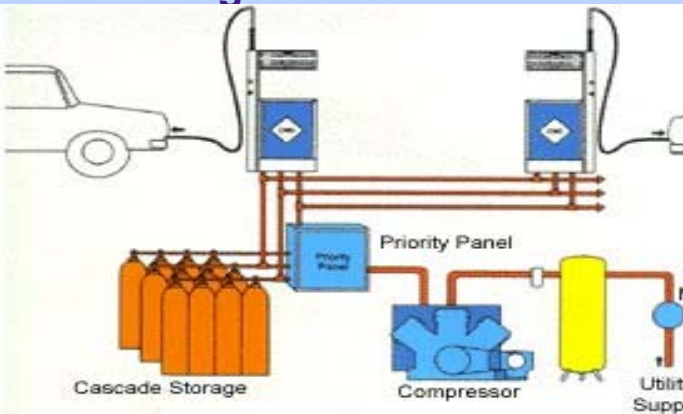
FuellingTechnology

Complete Service

- Pre-bid assistance in sizing station, station design and site selection
- Assist in obtaining permitting and regulatory approvals
- Supervise and install, test and assist in a station's early operations
- Monitor station's performance and status remotely
- Servicing stations

From Design to Commissioning

Availability of staff experienced in all aspects of station design.
We can set up the design and functional specifications for the station as well as provide installation, commissioning and training.



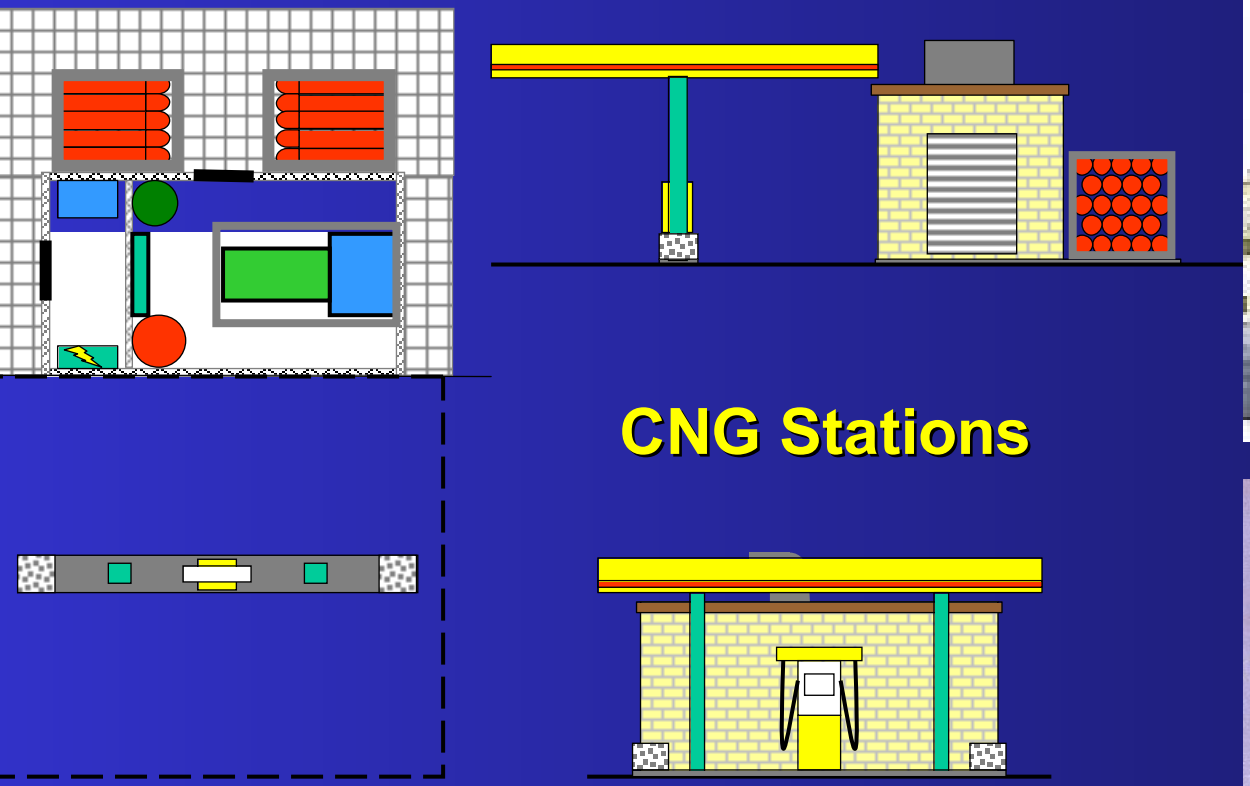
Ballast Nedam

International Product Management

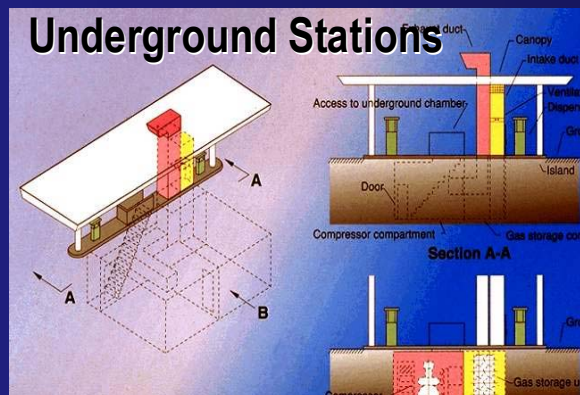
Fuelling Technology

Total Solutions

BNIPM can provide a wide variety of stations, from small compact stations to large custom stations. The stations will be designed with a modular approach so that components can be quickly installed and serviced.
If required, the stations can be designed for easy upgrade in the future.



CNG Stations

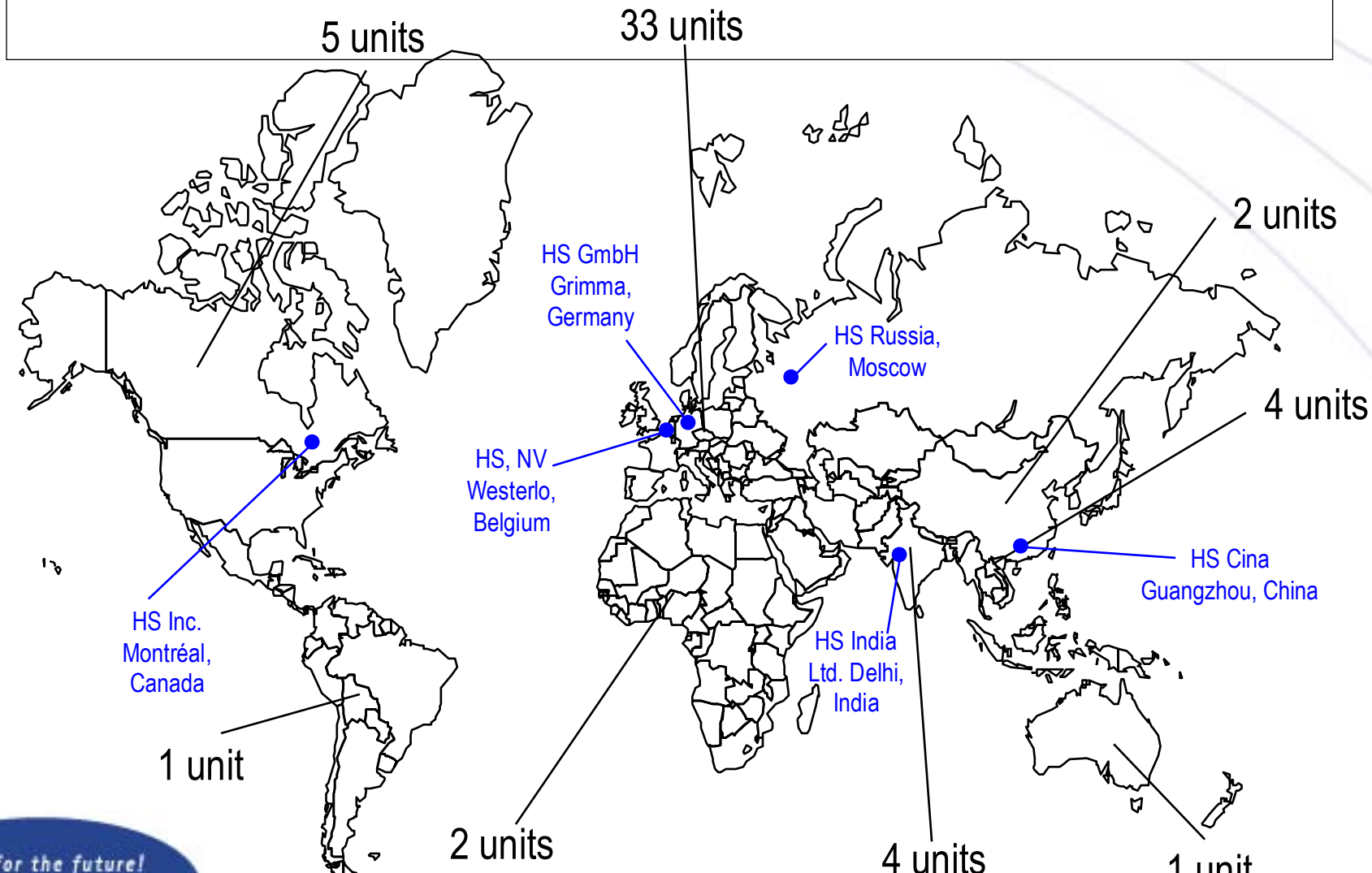


Introduction Vandenborre

Company's background

- 2000 : **Strategic partnerships**
- 1999 : **Commercial take off**
- 1998 : **Cost effective redesign**
- 1987-1998: **World wide field experience**
- 1985-1987: **Laboratory prototype IMET®**
- 1977-1985: **R&D of components**

Worldwide locations



Delivered IMET® units

Total	> 70
Industrial applications	> 50
Gas suppliers	26 IMET® units
CUTE Project	2 Conformed orders
Installed industrial capacity	More then 1.000Nm³/h

Registered cumulated Industrial produced hydrogen last 3 years exceeds 5.000.000Nm³

Introduction Teesing

Teesing B.V. company profile

TEESING

Teesing B.V. is a technical wholesale company, established in 1952.

- Teesing B.V. is a supplier of fittings, valves, tubing and assemblies for industrial applications in 4 sectors, viz.: pneumatics, hydraulics, instrumentation and transport of media.
- Teesing B.V. is mainly working with Swiss, German, English, Irish, French, Belgian, Taiwanese, Japanese and American manufacturers.
- Factories represented are:

  Gressel (SERTO), Rectus, Snap-tite, Furon, BEE, Bollin, ***WEH***, Alcon, Rehau, Hyup Dong, Nitta Moore, KM Europe Metal and Selfa Valves & Fittings.

Since its establishment in 1952, one of Teesing B.V.'s main objectives has always been to offer its customers a complete range of state of the art quality products. Gradually its various initiatives and activities have been laid down in a quality control system in accordance with the international ISO-9002 standard.

WEH®

TEESING

Teesing is a full representative o
WEH components

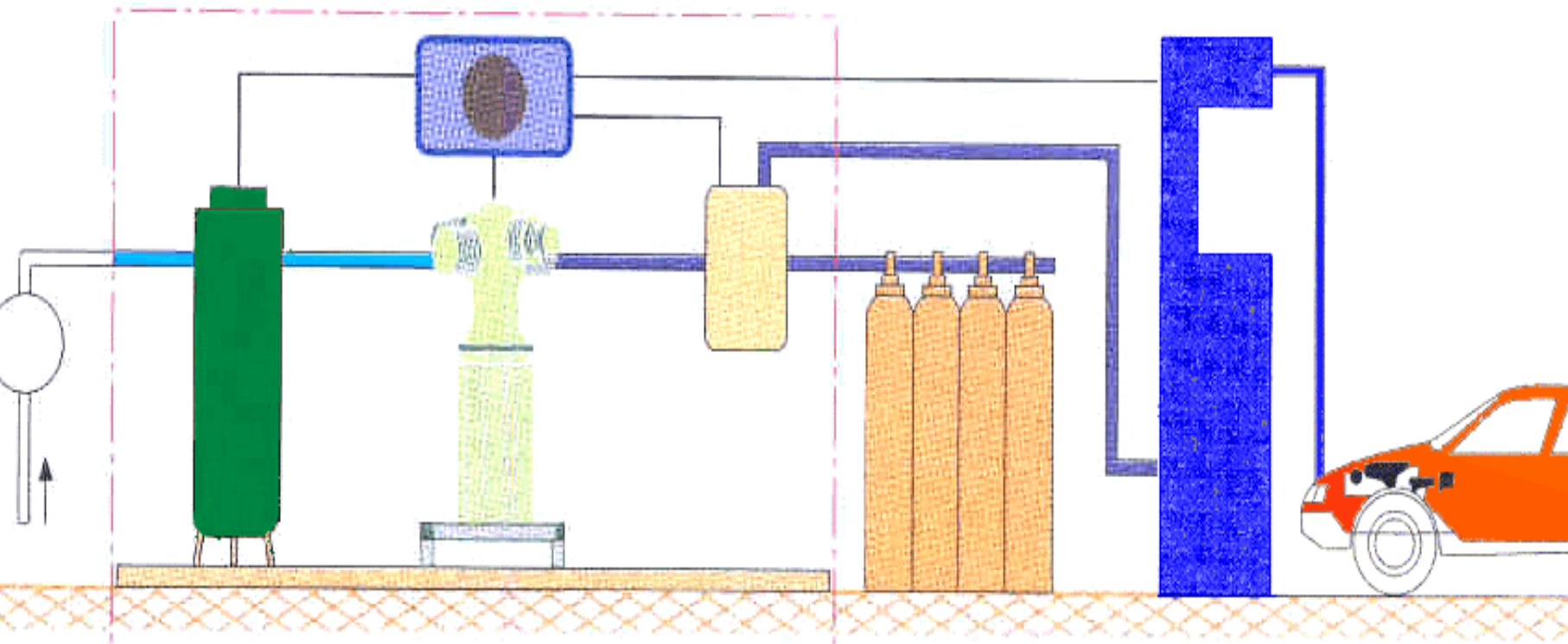
Continual developments of new applications from customers offer leadingedge technology in connection techniques.

As a result of this experience, WEH customers can always rely on well designed and fully developed solutions.

THE RIGHT CONNECTION

Products

The system



SUPPLY:
GASNETWORK
IMET (Hydrogen)
STORAGE

DRYER
(If applicable)

COMPRESSOR

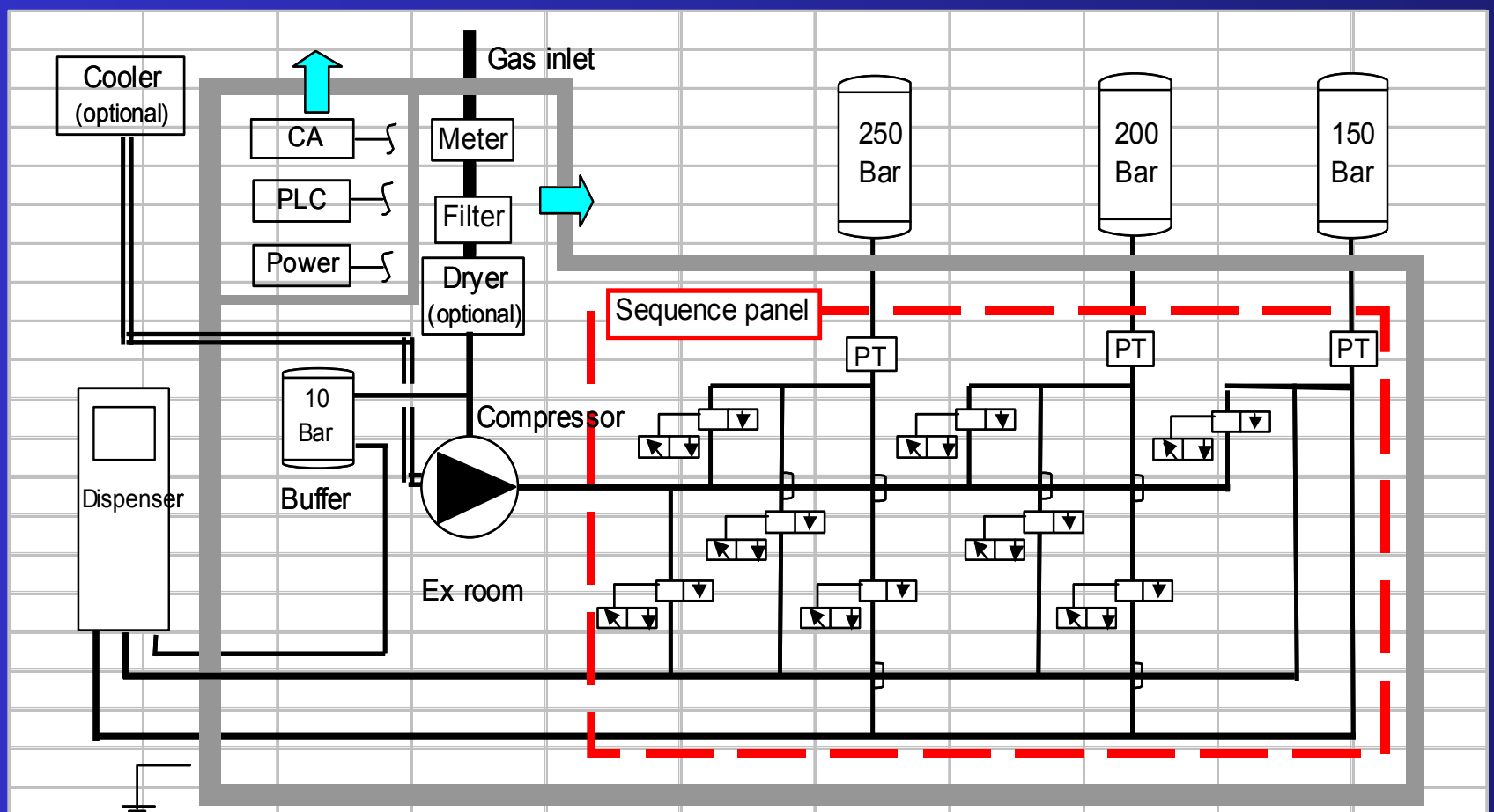
SEQUENCE PANEL

CASCADE STORAGE

DISPENSER

VEHICL

Simplified System Schedule (Cascade System)



Clean Fuel Systems Gas System Equipment

- Provider of systems and supplier of equipment, components and appendages for automotive fuelling stations:
  - CNG
  - Hydrogen
  - LPG
  - LNG (refer to Chart Nexgen)
  - Biogas

- Supplier of equipment, components and appendages for clean gas vehicles
  - Buses
  - Cars
  - Forklifts
  - Trucks

Equipment, Components and Appendages for Fuelling Stations

- Own developed Dispensers for CNG, LNG, Biogas, Hydrogen, LPG	CFS/GSE
- Compressors	Supplier as required
- Storage	Supplier as required
- Cryogenic storage	Chart/Nexgen
- Low Pressure Gas Separation Membrane	Cirmac
- Hydrogen electrolyser and treatment	Vandenborre/Hydrogen
- Cryogenic pump systems	Chart/Nexgen
- Filling hose assembly	Teesing/WEH
- High pressure switch valve	Teesing/WEH
- Fuelling nozzles	Teesing/WEH
- Own developed Sequence Panel	CFS/GSE
- Stainless steel high pressure fittings, valves and tubing	Teesing
- Visualisation	CFS

Equipment for Fuelling Stations

Hydraulic Compressor

Dispenser

Pay Terminal

Vessel Storage

Piston Compressor

Integral Dispenser

Cylinder Storage

Components and Appendages for Fuelling Stations

Sequence panel

Air Compressor

Check valve

Air operated control valve

Filling nozzle

Filling hose assembly

Own developed Dispensers

Mass flow meter

Filling hose assembly

Breakaway coupling

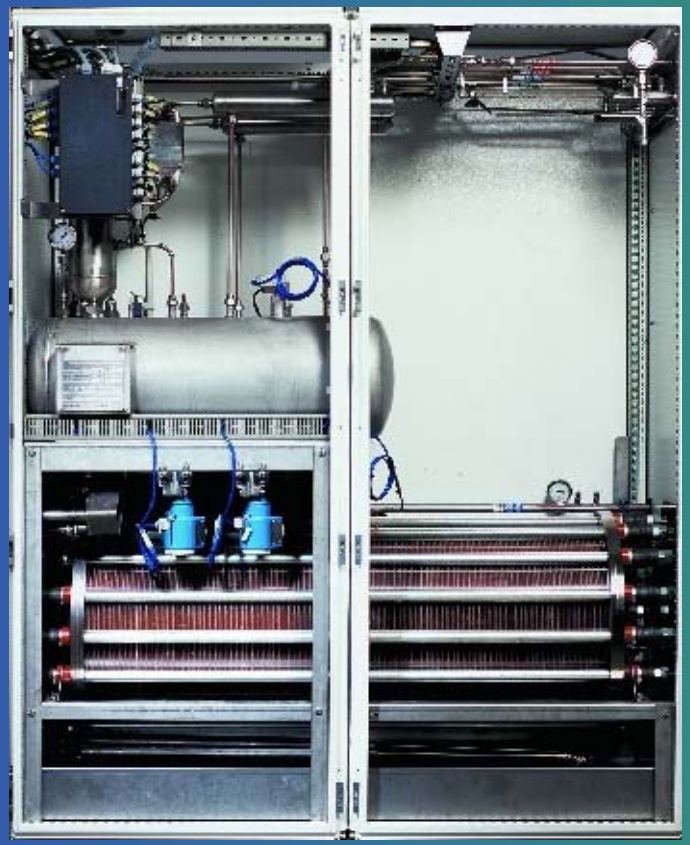
Air operated control valve

ELECTROLYSER

- The electroliser turns water into hydrogen
- In a compressor high pressure will be realised
- Clarify upto 99,9%
- Volume depended bulkstorage
- Customer fills with a standard dispenser

Hydrogen Electrolyser and Treatment equipment

RO unit



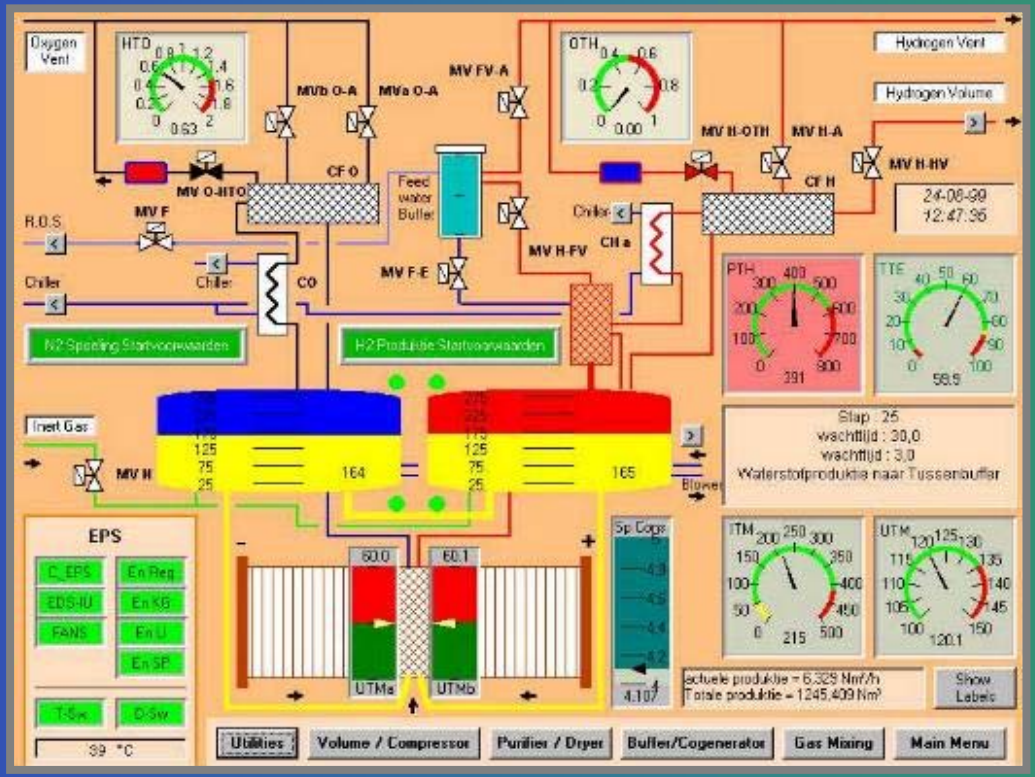
IMET

Dryer

Closed loop cooling

Chiller

Visualisation



The visualisation runs on a standard PC, which can be located in a seperated room.

This offers an overview of the process from a long distance and a faster diagnosis of the events.

The communication between the PC and the microprocessor can be done via Ethernet, serial connection or by modem

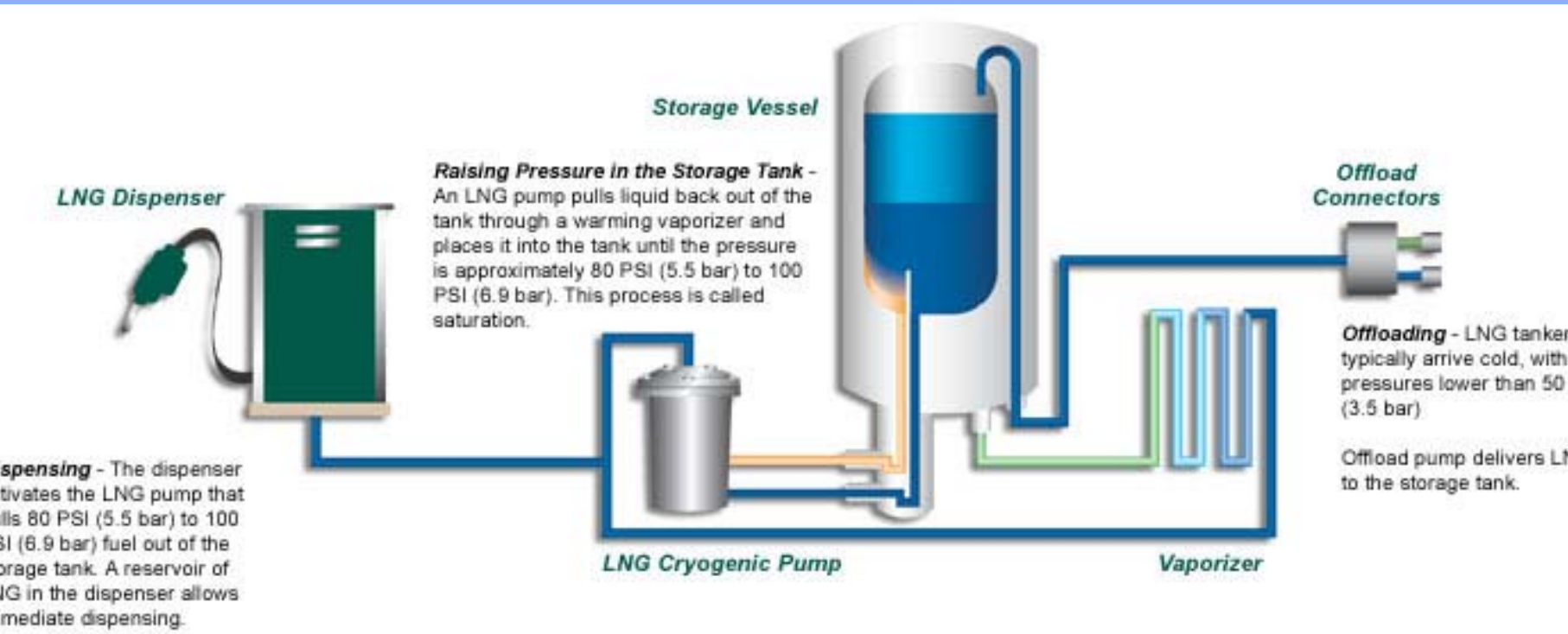
Containerised technique

CHART

NEXGEN FUELING.
A division of Chart Industries

G.S.E

LNG is natural gas in its liquid form. In the LNG market segment, Chart's NexGen Fueling division provides all the equipment needed for a LNG fueled fleet – from the liquefier to the on-board fueling system. LNG vehicles produce far less pollution than those fueled by conventional diesel and gasoline.



Equipment, Components and Appendages for clean gas vehicles

- Retrofit conversion kits for CNG
- High pressure systems and pressure reducers for commercial CNG vehicles
- Receptacles NGV_1 and NGV_2 (Teesing/WEH)
- High pressure cylinder valves
- Stainless steel high pressure fittings, valves and tubing (Teesing)
- Stainless steel pre-bend tubing (Teesing)

Equipment and Components for clean gas vehicles

High pressure cylinders

Retrofit conversion kits

Receptacles

Developments by CFS/GSE:

- One hose filling
- Vapor recovery system
- Underground storage
- Underground station
- Integrated dispenser
- Piston compressor for slow filling (China)
- State of the art sequence panel

Comparison between various fuels

Environmental

		Heavy metals	Noise	Possibility of soil pollution	Evaporation of emissions during fueling
Gasoline				severe	considerable
Diesel			noisier	severe	considerable
NG		None	quieter	none	less
Hydrogen		None	quieter	none	none
LPG		None		none	less

Safety

	Safety regulations and standards	Structural integrity of system	Danger from leaking tanks	Safety record	toxins	Fuel distribution
Gasoline	sufficient	sufficient	Fire and explosion hazard		toxic	By road
Diesel	sufficient	sufficient	Fire hazard	good	toxic	By road
NG	Good	Excellent, storage tanks are much stronger	Unlikely to occur NG is lighter than air	excellent	none	By pipeline, safest way of transport
Hydrogen	Will follow those for NG	Excellent, storage tanks are much stronger	Unlikely to occur H2 is lighter than air	Not yet proven	none	Locally produced
LPG	sufficient	sufficient	Fire and explosion hazard		toxic	By road

Safety standards and regulations

Aspects which will influence the design and construction of Refuelling stations

- Zone classification for hazardeous areas (IEC 60079)
- Fire safety (as per local requirements)
- Electrical safety (IEC regulations)
- Control (Senelec)
- Mechanical safety (Pressures, PED 97/23)
- Building regulations (as per local requirements)
- Compliance to CE
- Operational safety (as per local requirements)
- Specific regulations related to fuels

VANDENBORRE HYDROGEN SYSTEMS

Ballast Nedam International Product Management

TEESING

International regulations and standards specifically related to Alternative Fuels

	CNG	LNG	CH2	LH2
Gas supply	ISO 15403	NF EN 1160 PREN 1532 PREN 13645 EN 1473	ISO 14687 ISO WG 7 ISO WD 15916	ISO 14687 ISO WG 7 ISO WD 15916 ISO WG 2 ISO/WD 13986
Refuelling Station	PREN 13638 EN 13423	NFPA 59 A NFPA 497	ISO WG 4	WG 3 ISO WG 15594
Dispenser metering	Under construction by OIML			
Vehicle installation	Regulation 110 ISO 15501	NFPA 57 SAE 2323 SAE J2343		
Vehicle cylinder	ISO 11439	EN 1251 EN 1252 EN 12213 EN 12300 PREN 12456	ISO WG 6 ISO 15869	ISO WG 1 ISO 13984 ISO 13985
Vehicle refuelling coupling	ISO FDIS 14469	No standard available	ISO WG 5 ISO/AWI 17268	
Vehicle Components	ISO 15500	NF EN 12065 UNE EN 12066 UNE EN 12308 NF EN 12567 EN 1626 EN 1797 EN 12434		

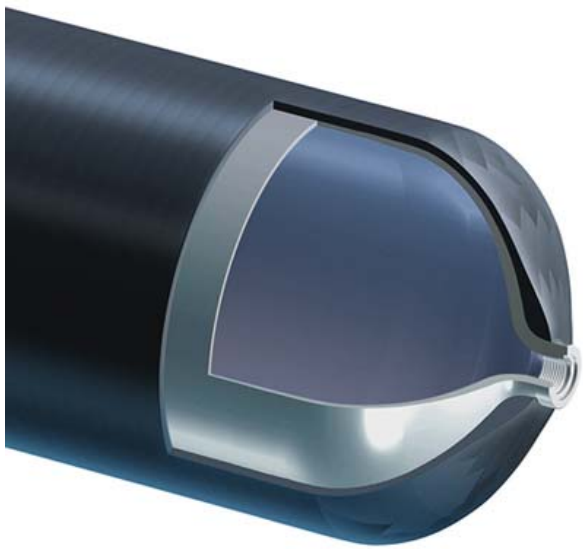
Dutch regulations and standards specifically related to Alternative Fuels

- CPR 17-1 indoor CNG fuelling stations
- CPR 17-3 outdoor CNG fuelling stations
- EN draft EU standard CNG stations
- These regulations can be used for H2 stations till 2004.
- New regulations will be drafted for LNG together with the ENGVA

Dynetek Europe GmbH

Advanced Lightweight Fuel Storage Systems ™

Gas Storage Systems for Compressed Hydrogen



- **Introduction**
- **Reasons for weight reduction**
- **Challenge today**
- **Challenge of the 700 bar step**

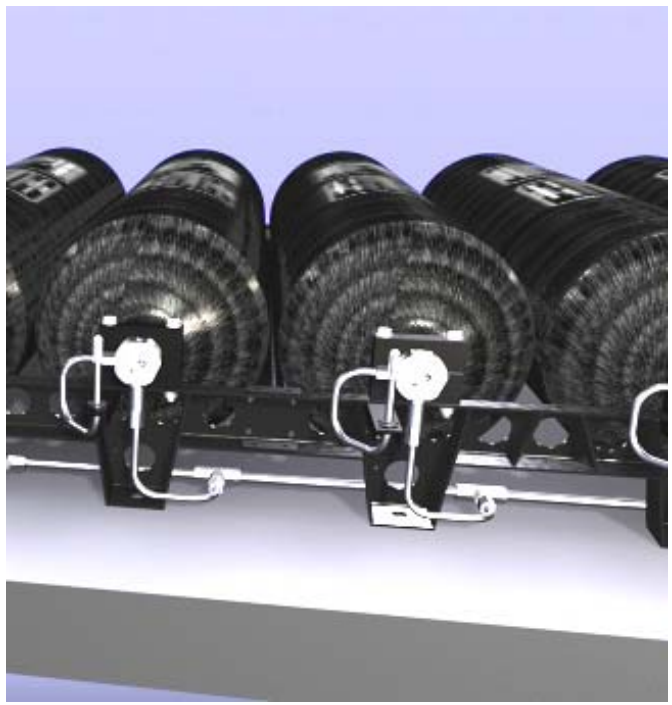
Steffen Rau
Dynetek Europe GmbH, Ratingen, Germany

EIHP Mid-Term Assessment Workshop, Brussels, 02 October 2002

Dynetek Products: Cylinders and Systems

Complete Systems (Drop-in place solutions)

- **Custom design entire system**
- **Custom design plumbing**



- **Design and manufacture**
  - **End-plugs**
  - **Brackets (belly and neck mounts)**
  - **Sub frames**
  - **Safety devices**
  - **Fittings**
  - **Roof covers**

Hydrogen Fuel Cell Vehicles on the Road

Dynetek

MAN TECHNOLOGIE

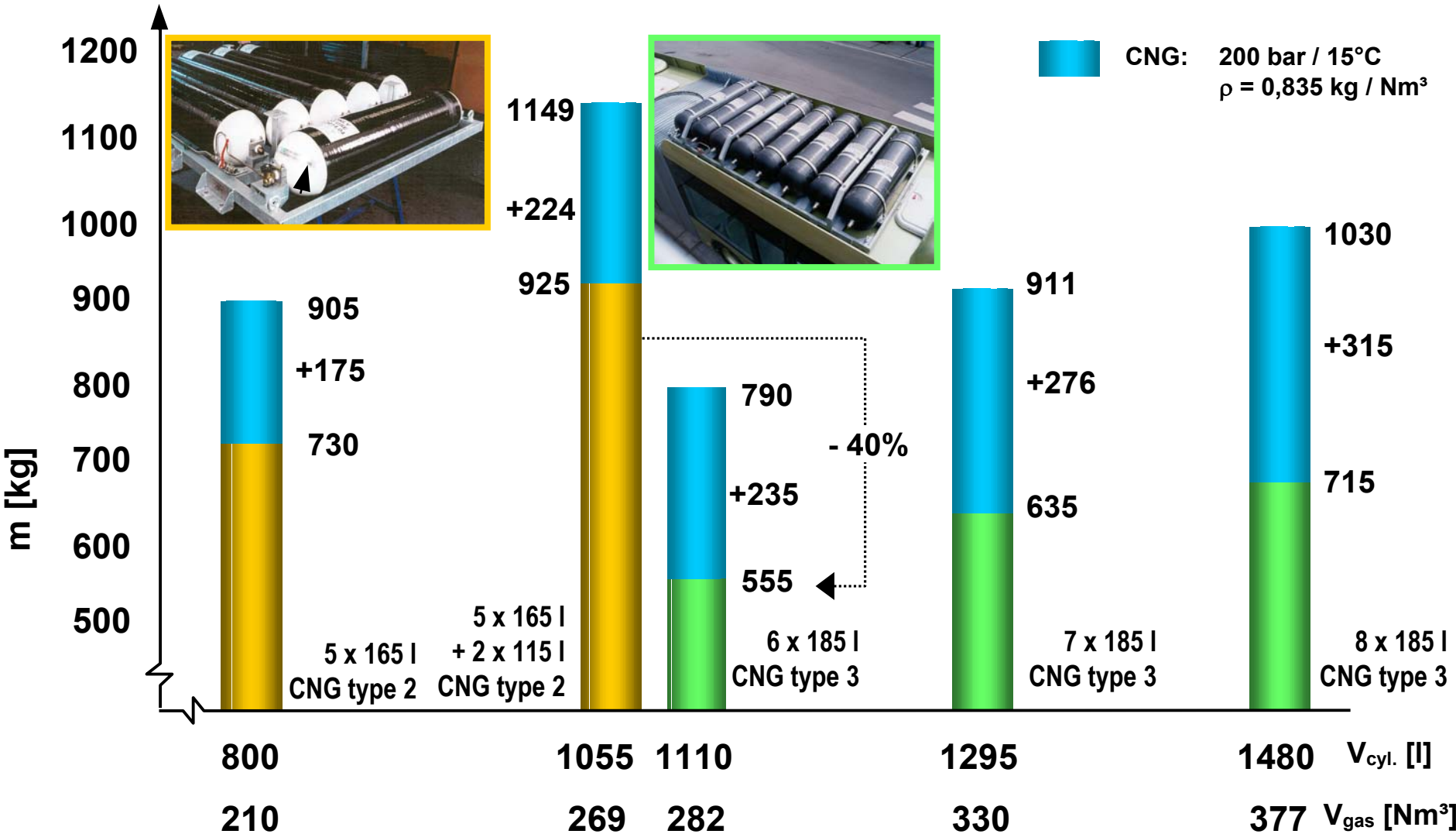
Hydrogen Storage System For Munich Airport Buses

System No:	0360	0390	Total
Service Pressure (psi):	3600	3600	3600
(bar)	250	250	250
Number of Cylinders:	6	9	15
Storage Volume (ltr):	1032	1548	2580
Total Cylinder Weight: (kg):	491	728	1219
Dimensions:			
Length (mm):	2715	3945	6660
Width (mm):	2160	2160	2160
Height (mm):	440	440	440

MAN Technologie
Munich,Germany

Comparison of weights of different CNG storage units

Dynetek

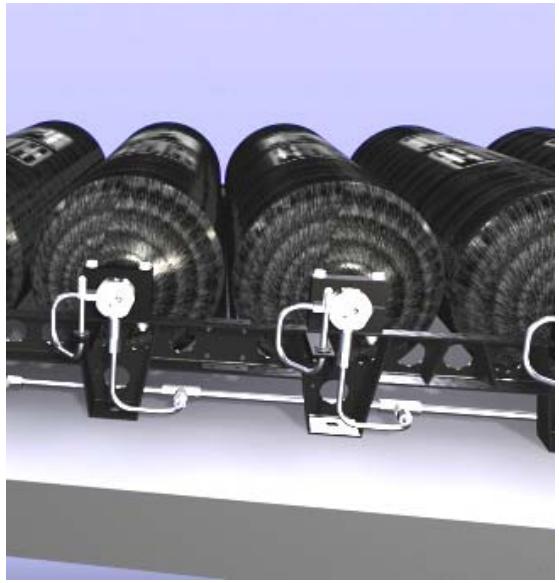


Urgent Demand for ECE-Standards

Dynetek

Cylinders and Components:
- **ISO/CD 15869:2001**
- **EIHP Rev. 9:2002**
- **national standards**

Components (valves, regulators, receptacles etc.):
- **…**



Periodic Requalification:

„ ... in accordance with the relevant regulations of the countries where the tank is used.“ (ISO/CD 15869:2001)

Gas cylinders - Inspection for requalification of high pressure cylinders and their installations, for the on-board storage of natural gas as a fuel for automotive vehicles
(ISO/CD 19078:2001)

Challenge of the 700 bar Step

Dynetek

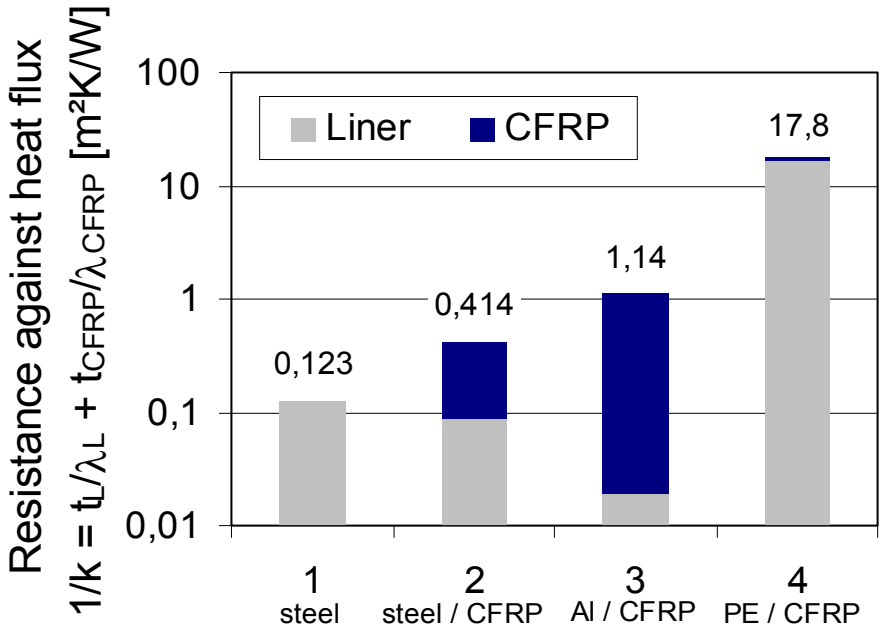
Cylinder Design

- thick wall effect
- liner material
- liner manufacturing technology
- fibre properties
- fast fill properties

Component Design

- “in-tank” solutions (port size, reliability)
- stability of PRD’s at high temperature and pressure
- stability of sealing materials at high temperature and pressure

Basis of Heat Flux in Different Cylinder Designs

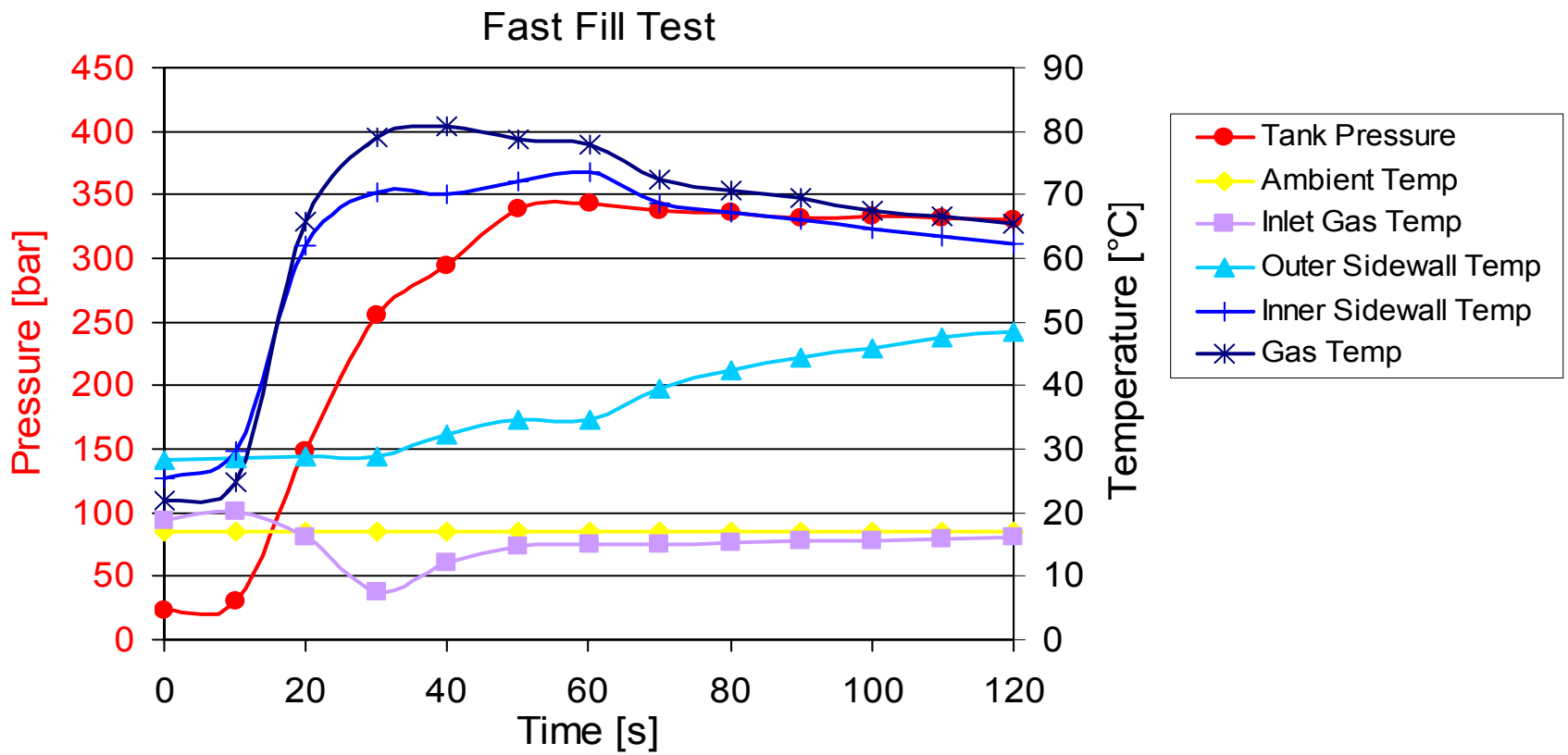


The material selection of the DyneCell cylinder shows much lower resistance against heat flux during fast filling compared to the fully wrapped cylinders with polymer liner. The gas cools down during fast filling by heat transfer to the outside surface as well as by heat absorption in the aluminium wall.

cyl. type (200 bar, D = 350 mm)	wall thickness		thermal conductivity	
	t_L [mm]	t_{CFRP} [mm]	λ_L [W/m²K]	λ_{CFRP} [W/m²K]
1	6,5	-	53	-
2	4,7	2,6	53	8
3	3,9	9	204	8
4	6	9	0,36	8

Source:
Tabellenbuch Metall; Verlag Europa-Lehrmittel Haan; 40 (1997)
Wärme- und Stoffübertragung by H. D. Baehr, K. Stephan; Springer Verlag Berlin; 3 (1998)
Die Kunststoffe und ihre Eigenschaften by H. Domininghaus; VDI Verlag Düsseldorf; 4 (1992)

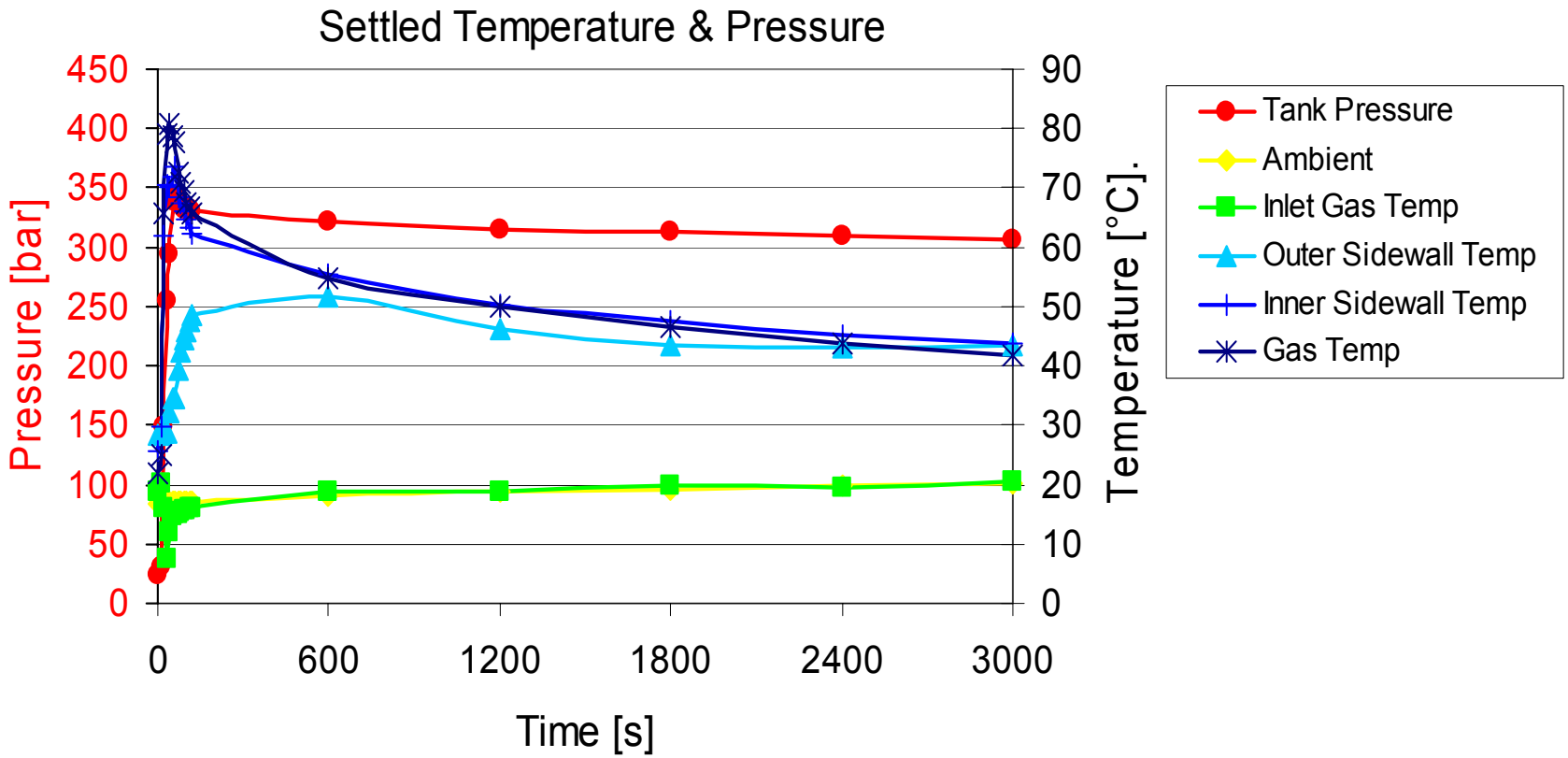
Test Results of Fast Fill Operations with Hydrogen



The results of this test point to the conclusion, that a 350 bar DyneCell cylinder for hydrogen can be filled to the maximum allowable filling pressure of 438 bar (125 %) within 2 minutes without exceeding the maximum allowable temperature of 85 °C.

Source: Fast Filling of Compressed Hydrogen Fuel Storage Cylinders by B. Jeary; 10th Canadian Hydrogen Conference; May 28-31, 2000; Québec City; Canada

Test Results of Fast Fill Operations with Hydrogen



When filling a cylinder up to 438 bar the temperature will be not more than the allowed maximum temperature of 82 °C.
Therefore, the cylinders can be refuelled to a filling pressure that corresponds with a settled pressure of 350 bar @ 15 °C and which is less then 438 bar.

Source: Fast Filling of Compressed Hydrogen Fuel Storage Cylinders by B. Jeary; 10th Canadian Hydrogen Conference; May 28-31, 2000; Québec City; Canada

Hydrogen Fuel Cell Vehicles on the Road

Hydrogen Fuel Cell Vehicles on the Road

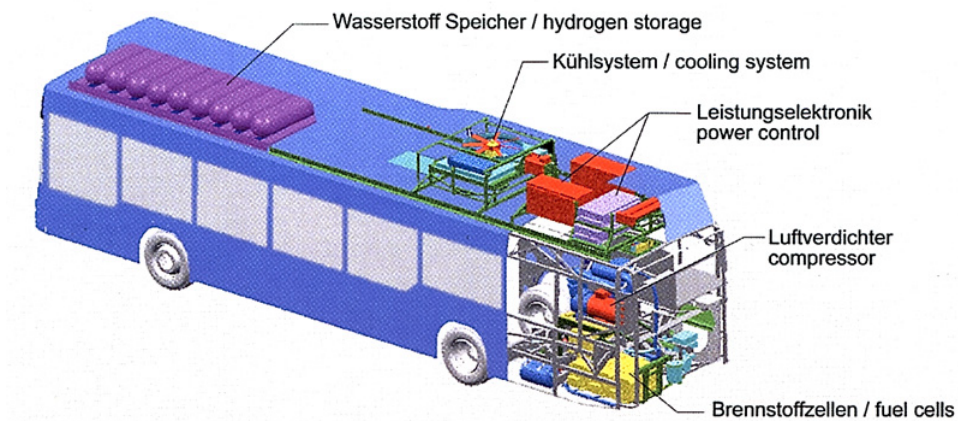
Dynetek

Hydrogen Fuel Cell Bus

Powered by Siemens' PEM Fuel Cell

MAN TECHNOLOGIE

Cylinders:	**DyneCell V170 x 9**
Volume w.c.:	**1,548 L**
Total Cylinder Weight:	**809 kg**
Service Pressure:	**3600psi/ 250bar**



Hydrogen Fuel Cell Vehicles on the Road

Dynetek

Ballard Power Systems
Vancouver – Chicago

Cylinders:	**DyneCell W316 x 8**
	DyneCell W210 x 1
Volume w.c.:	**2,738 L**
Total Cylinder Weight:	**809 kg**
Service Pressure:	**3600psi / 250bar**

EIHP Workshop in Brussels

2nd of October 2002

Hydrogen powered ICE and FC buses in public operations

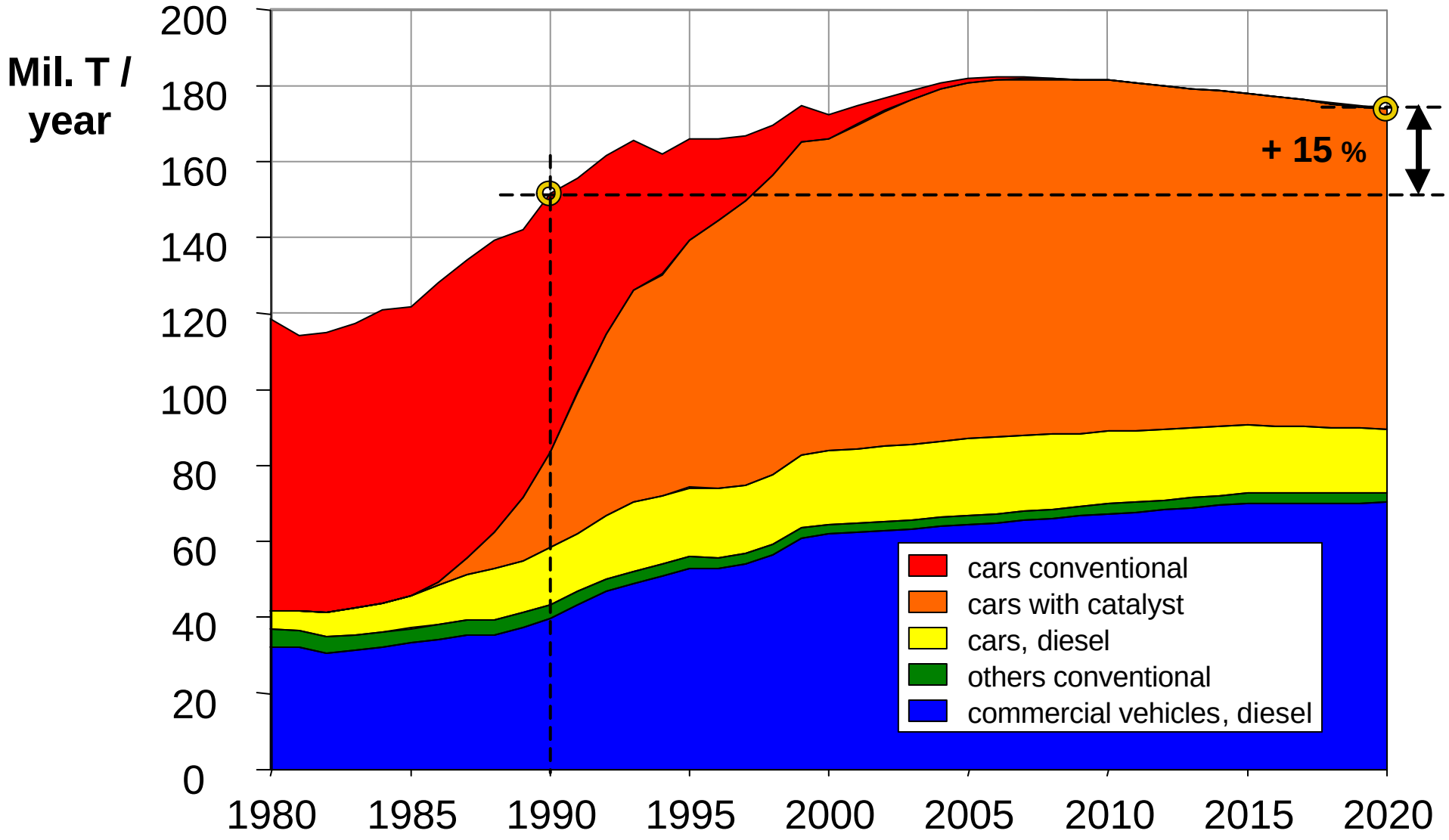
Dipl.-Ing. Christian Gruber

Advanced Engineering, MAN Nutzfahrzeuge AG / Munich

- Driving factors for alternative fuels/drivetrains
- Hydrogen powered ICE - buses
- Fuel cell drive systems for city buses

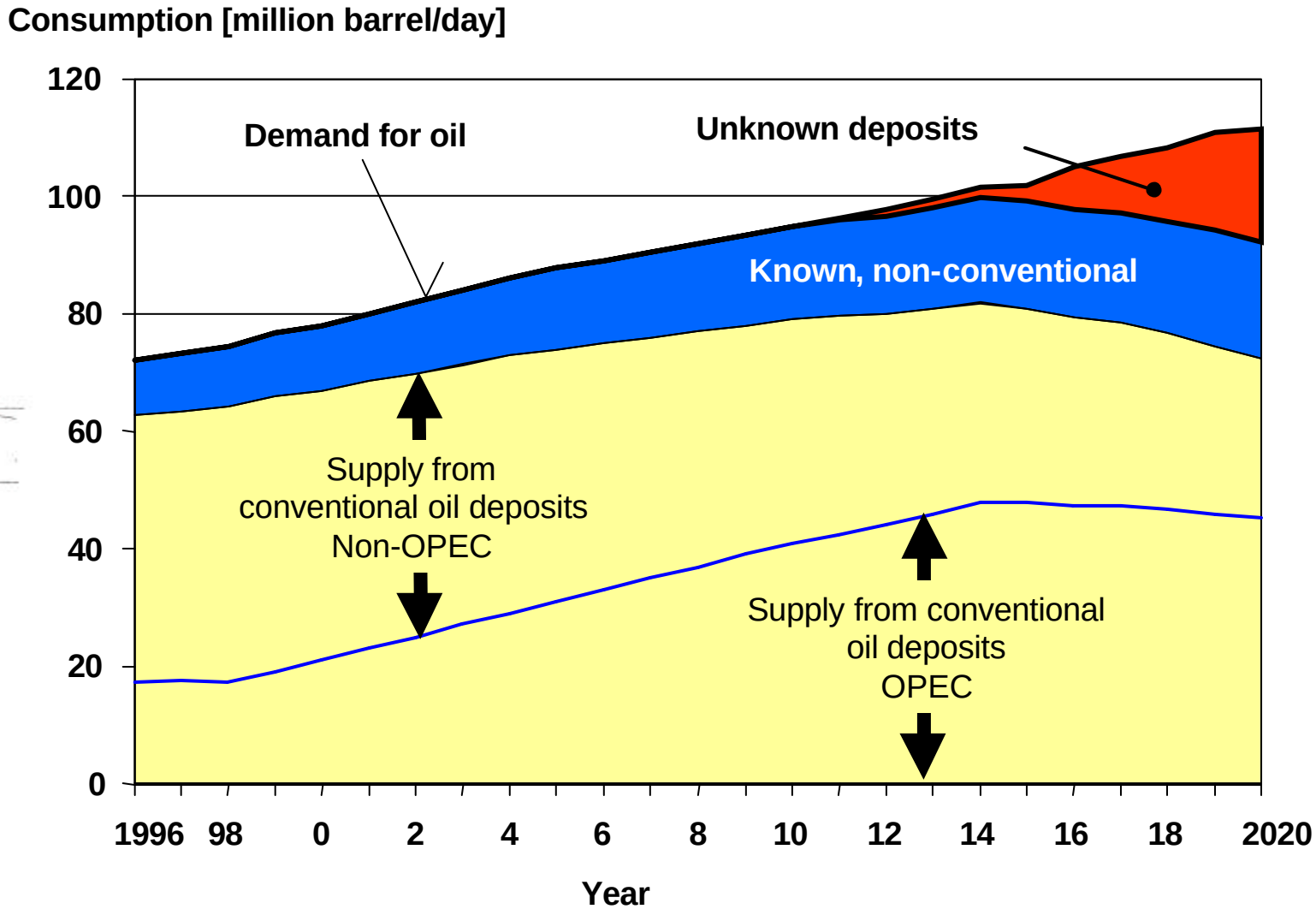
CO_2- emissions, ACEA scenario

Road transport in Germany 1980 - 2020



Source: IFEU Heidelberg, status 9/2000, using TREMOD

IEA prospects of the world crude oil supply



Source: International Energy Agency (IEA) Paris

Into the future

H_2 with hydrogen

2002-2003

LH_2-bus with hybrid-PEMFC (2002),
2 CGH_2-buses with 150 kW PEMFC (2003)
bus operation at the Airport Munich

5/2000

CGH_2-bus with 120 kW - PEMFC
(Siemens KWU), bus demonstration
in Erlangen/Nuremberg

5/1999

3 CGH_2- articulated buses with
140 kW-ICE, bus operation
at the Airport Munich

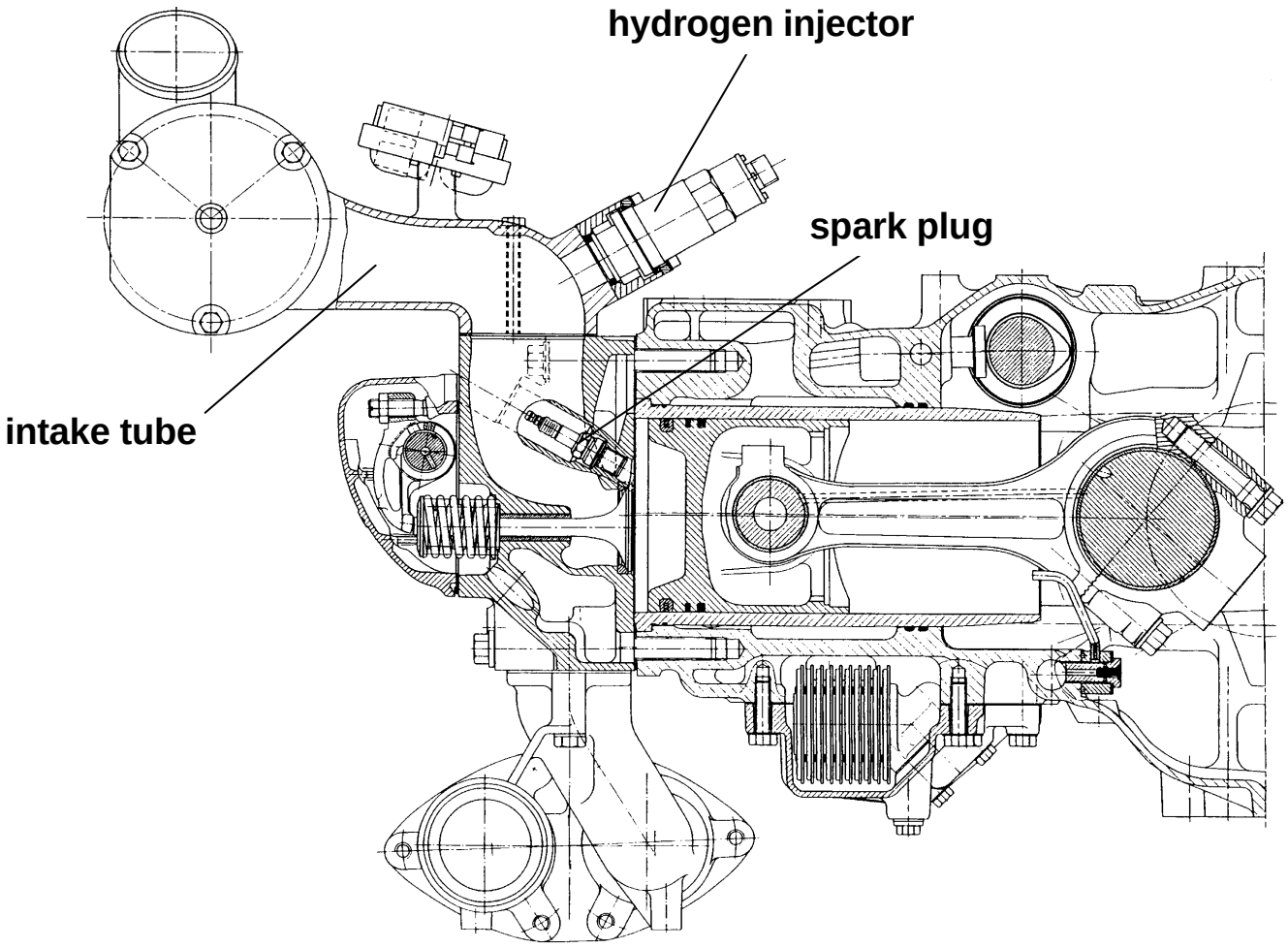
5/1996

LH_2-bus with 140 kW-ICE
bus operation in
Erlangen/Munich

City bus with hydrogen ICE and LH_2-storage

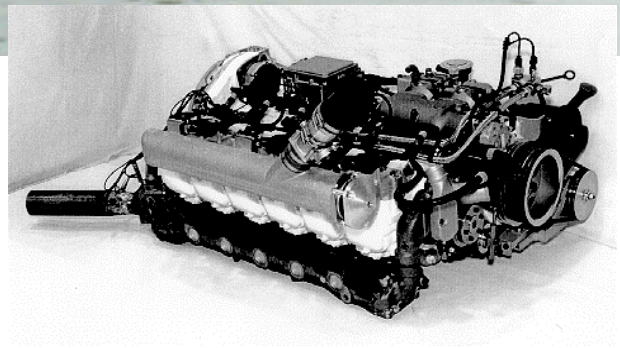
operation in Erlangen/Munich 1996-1998

Cross section hydrogen ICE MAN H2866UH01
rated output 140kW



Hydrogen buses Airport Munich

operation of 3 articulated buses since 5/1999



H2866DUH hydrogen ICE / 140 kW

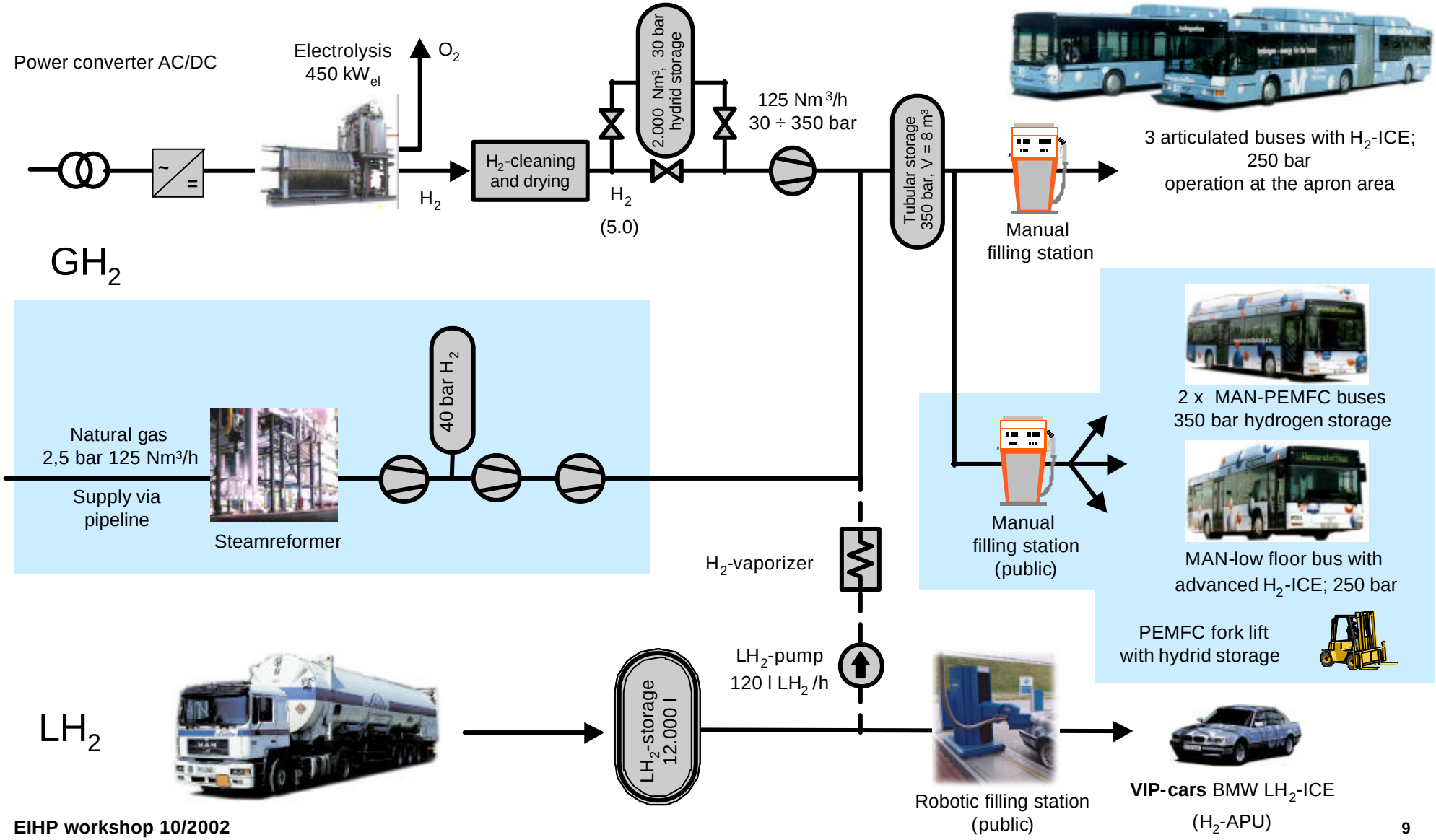
- external hydrogen mixture, injection by valves
- ?=1 control
- reduction catalyst (NO_X)

Hydrogen refueling stations at the Airport Munich

Bus refueling with 250 bar, car refueling with liquid hydrogen

Hydrogen Project Airport Munich

Phase II

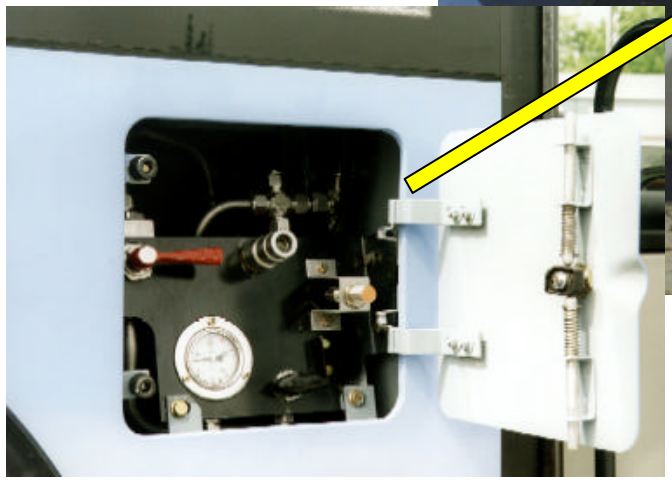


MAN‘s 1st low floor bus with PEMFC propulsion

Projectpartners

Bavarian Ministry for Economic Affairs, Transport and Technology

Compressed hydrogen refueling station for MAN's 1st fuel cell bus during operation in Nuremberg



bus coupling system for 250 bar refueling

source: Linde

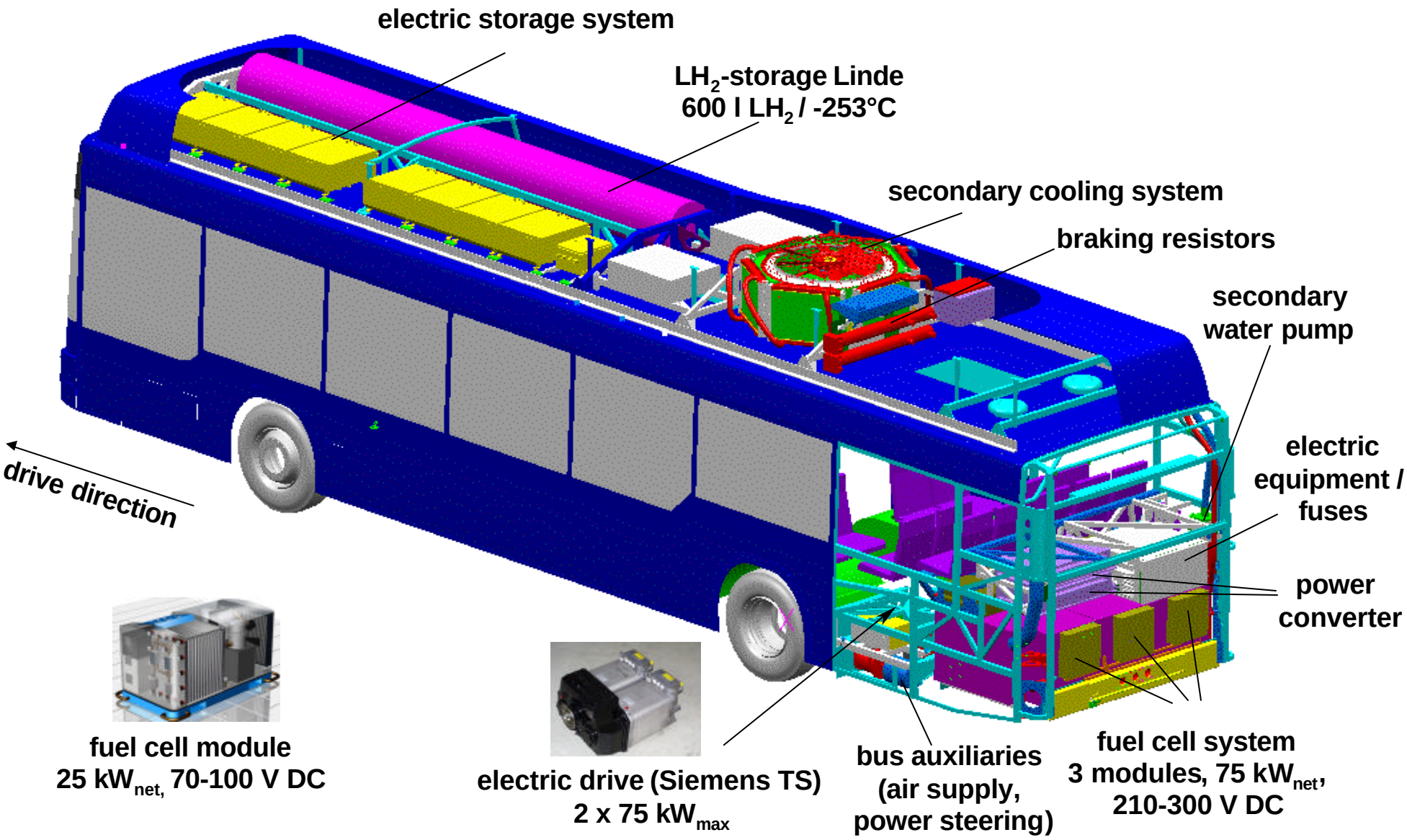
FC bus operation phases in bavarian cities

Bus operation in Nuremberg
(10/2000 - 01/2001)

8.000km in public bus operation

Bus operation in Erlangen/Fürth
(01/2001 - 04/2001)

MAN‘s second generation hybrid fuel cell bus



Linde‘s mobile liquid hydrogen refueling station for MAN‘s second FC bus

Linde‘s coupling system for LH_2-refueling

Engineering Assets for FC vehicles - useful supports of bus development & licence

Fuel storage

CNG vehicles

LNG trucks

LH_2 buses

CGH_2 buses

compressed + cryogenic storage

Electric drive

battery

diesel-electric

diesel-electric hybrid

trolley

wheel hub + central drive units

Hydrogen buses licenced for passenger transport

Buses	propulsion	H_2-storage	public operation total range	MOT approval
1 x 12m city bus	140 kW ICE	600l LH_2 (- 253°C)	Erlangen/Munich 42.000km [1)]	TÜV Bayern [4)]
3 x 18m articulated low floor buses	140 kW ICE	2580l CGH_2 (250bar)	Airport Munich 200.000 km [2)]	TÜV Bayern [4) 5)]
1 x 12m low floor bus	120 kW PEMFC	1548l CGH_2 (250bar)	Nuremberg/ Erlangen/Fürth 8.000 km [3)]	TÜV Bayern [4)]
1 x 12m low floor bus	75 kW hybrid PEMFC	600l LH_2 (- 253°C)	planned in three cities	TÜV Saarland [6)]

total: 250.000 km

1) 5/1996 - 10/1998
2) operation since 5/1999, ongoing until 12/2004
3) 10/2000 – 4/2001
4) no restrictions for bus operation
5) operation at the apron area Airport Munich
6) in preparation

DWV
DEUTSCHER • WASSERSTOFF • VERBAND

German Hydrogen Association

Hydrogen Safety

Ulrich Schmidtchen
Federal Institute for Materials Research and Testing (BAM)
Berlin

Facts and fiction

„Experts see problems concerning transport and storage of the **highly elusive** and **explosive** hydrogen which after a while disappears even from steel vessels.“
(*Kölnische Rundschau*, 11 January 2001)

„Every time I think about hydrogen I remember the **Zeppelin**.“
(Former VW chairman Ferdinand Piëch on 20 February 2001)

Parts of the public consider hydrogen as highly dangerous.

What are the facts?

Potential dangers

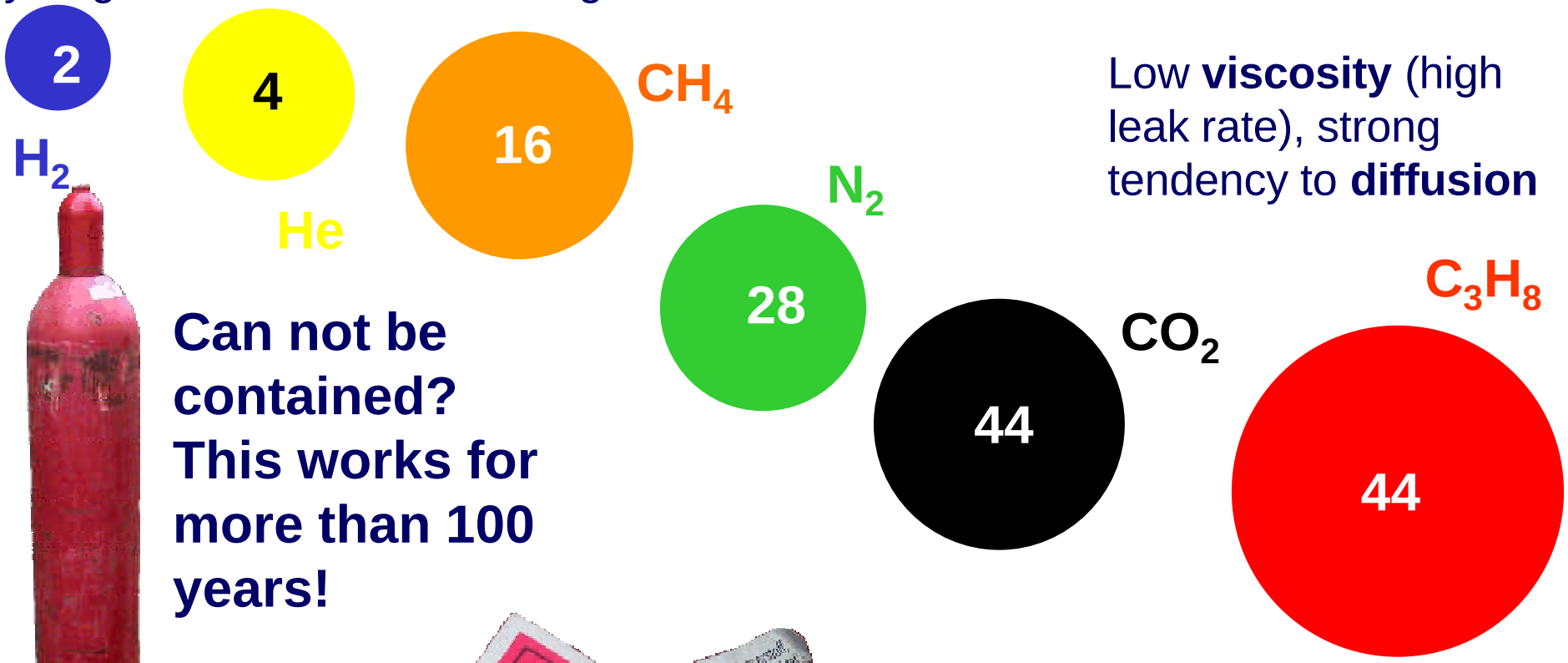
- Hydrogen is **flammable**
  - Mixtures with oxygen (air) can be **explosive**
  - low **ignition energy**

- **Small molecule**
  - low viscosity, high **leak rate**
  - **diffuses** rapidly (also downwards!)
    - **embrittles** certain materials

- **Storage**
  - **compressed:** under tension
  - **liquefied:** low temperature

Hydrogen is „highly elusive“...?

Hydrogen is the smallest and lightest molecule



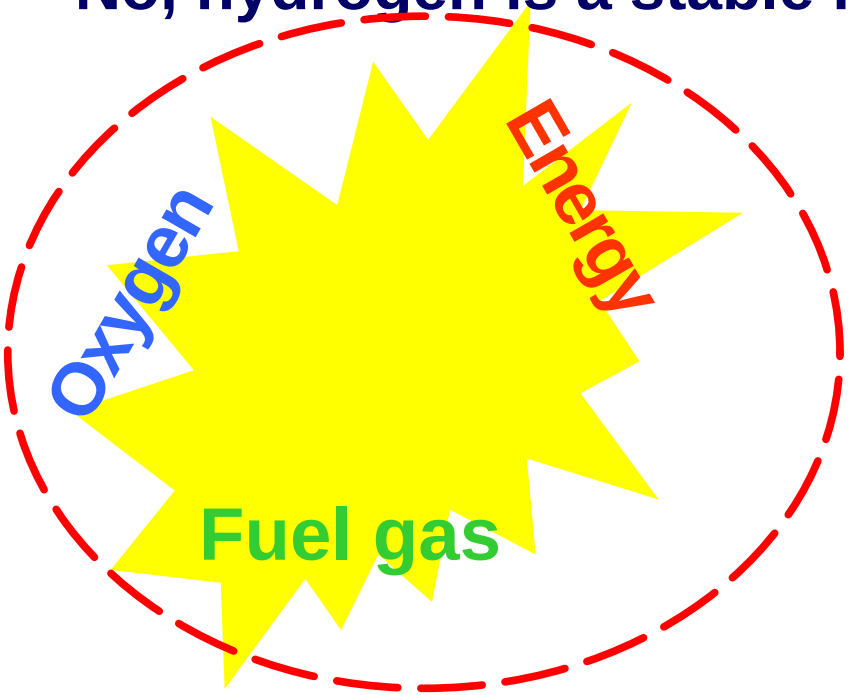
Low **viscosity** (high leak rate), strong tendency to **diffusion**

Can not be contained? This works for more than 100 years!

Diffusion through metallic walls is technically insignificant. When organic material is used gas loss may appear after a while; the formation of explosive mixtures is not to be expected.

Hydrogen is explosive...?

No, hydrogen is a stable molecule



A gas explosion requires:

Fuel gas
oxygen
} Mixed within certain concentration limits

Ignition energy (sufficient amount of it)

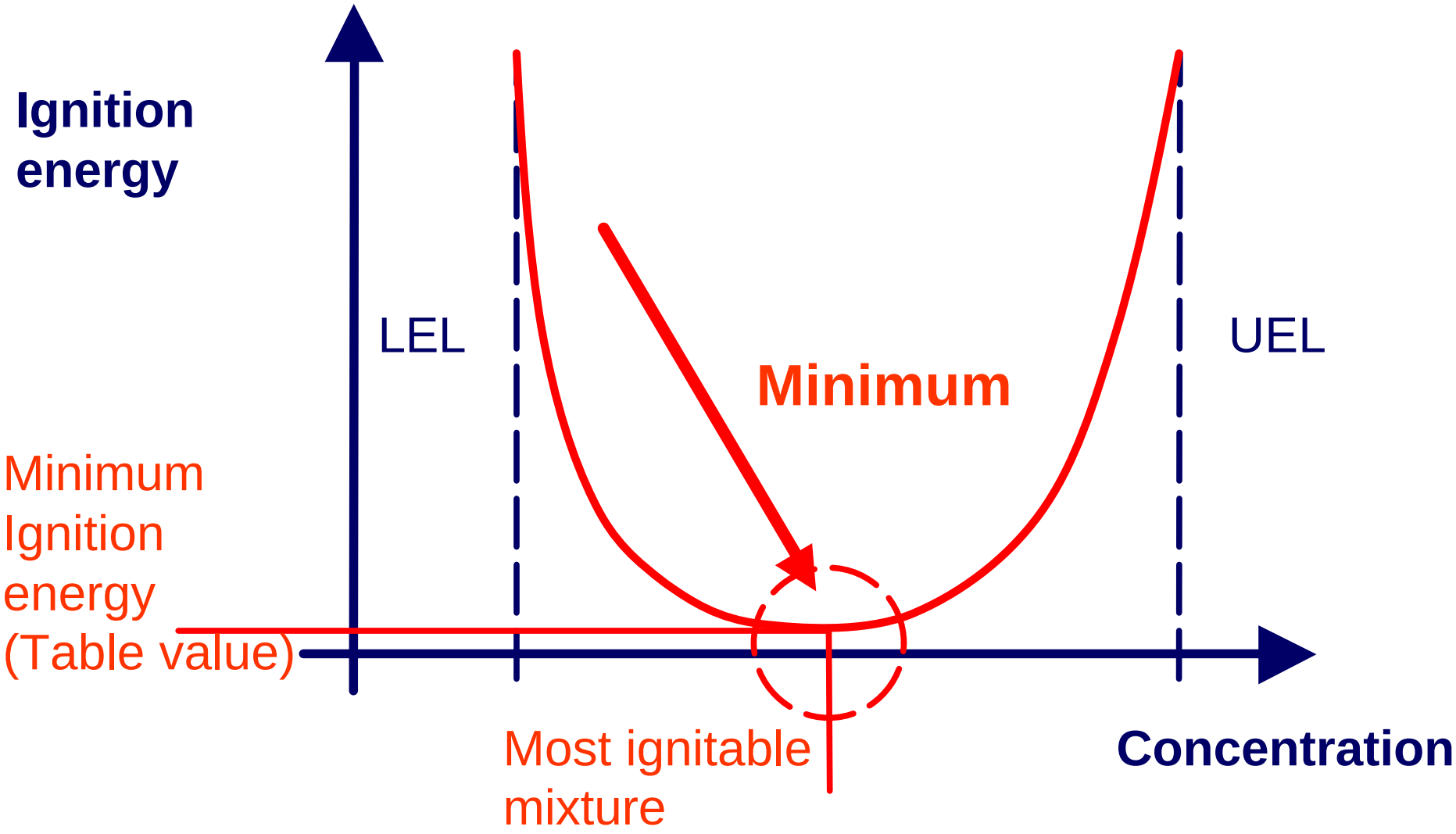
Unlike **explosives** (they need no external hydrogen)

Unlike acetylene (molecule **decays**)

Even in the presence of ignition energy there is no explosion danger in a tank of pure hydrogen, because no oxygen is present (unlike gasoline etc.)

Ignition energy, explosion limits etc.

What are ignition energy and minimum ignition energy?

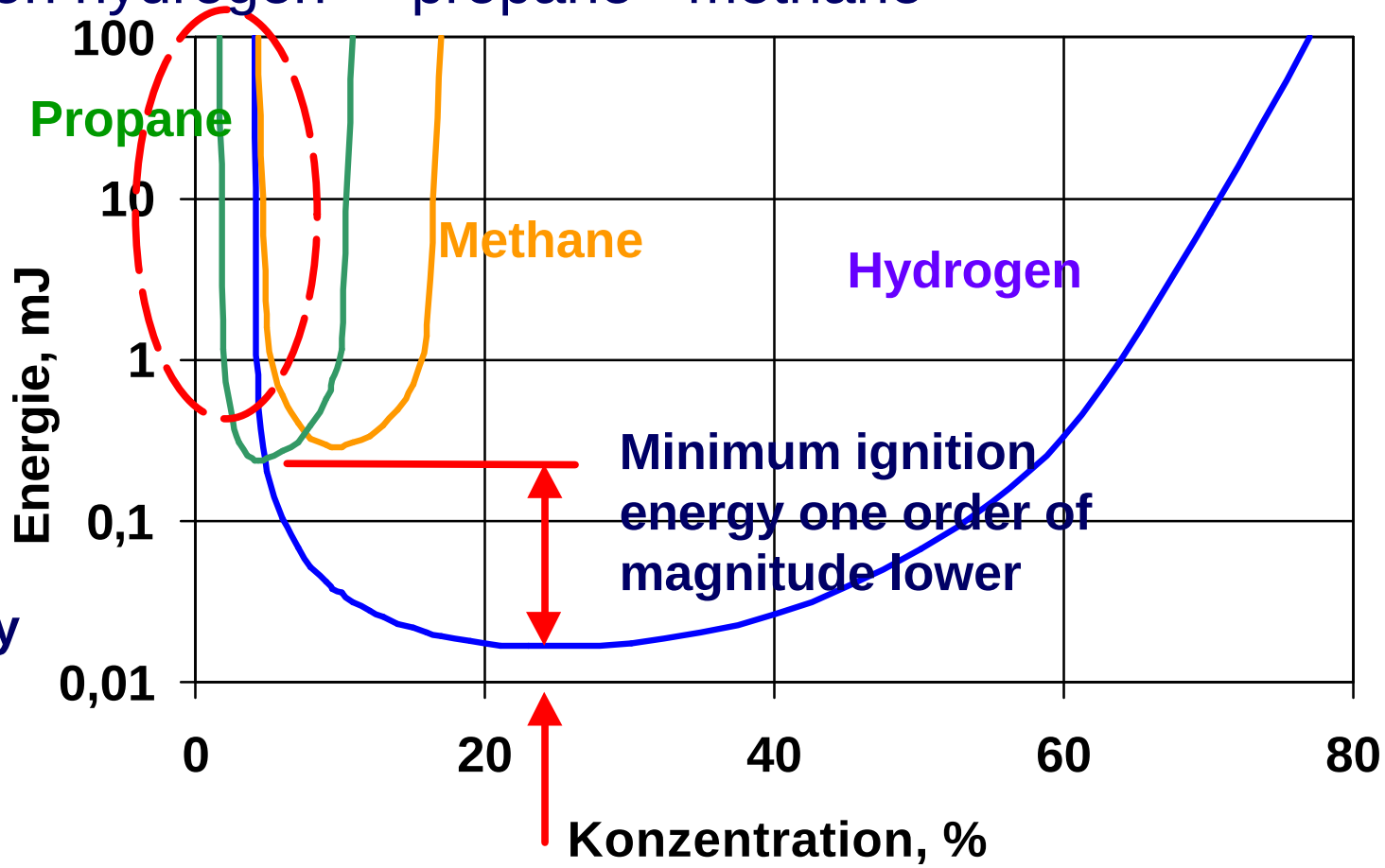


Low ignition energy ...?

Comparison hydrogen – propane - methane

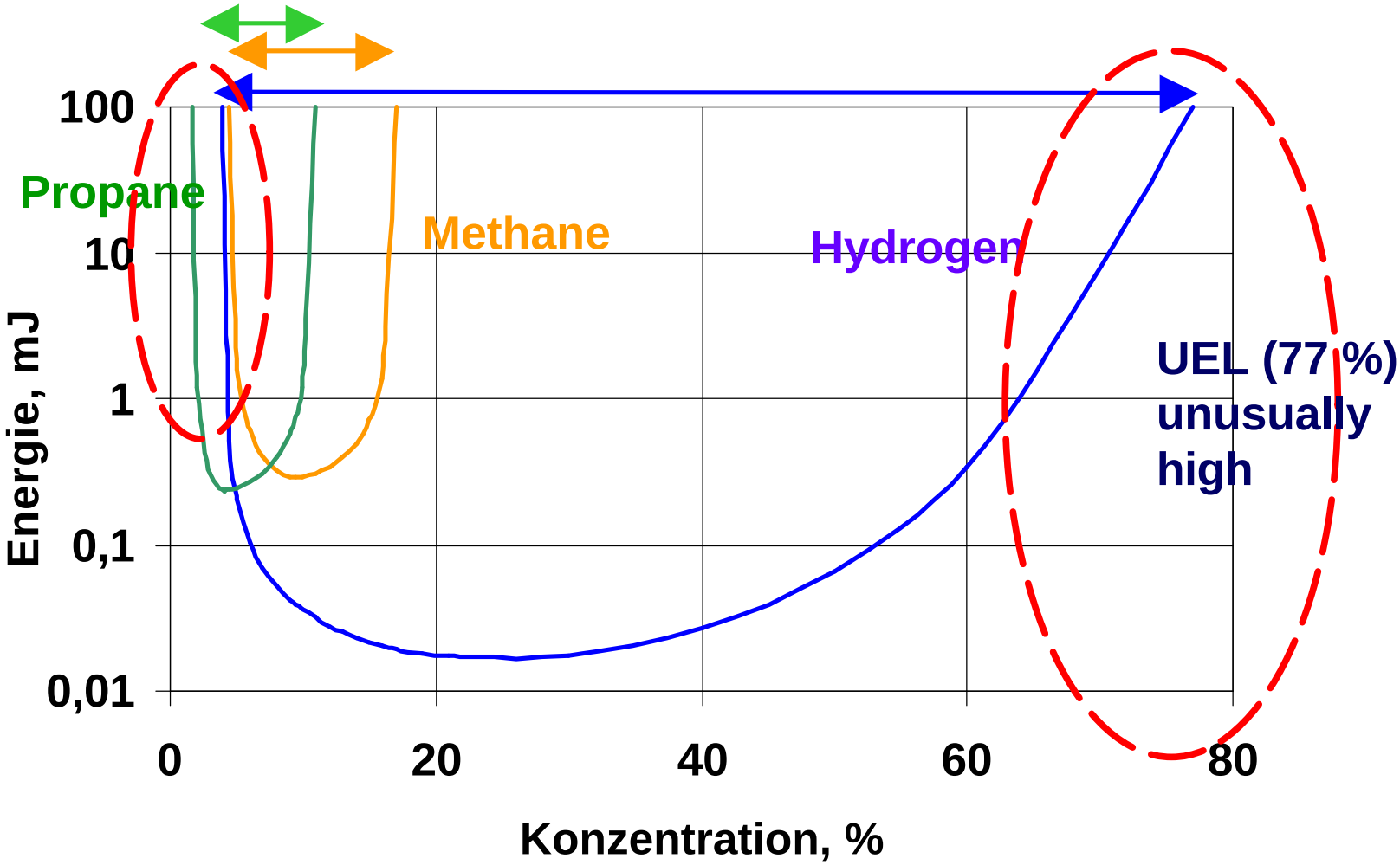
Near LEL differences not significant

The energy of most ignition sources is higher anyway



Associated concentration very high

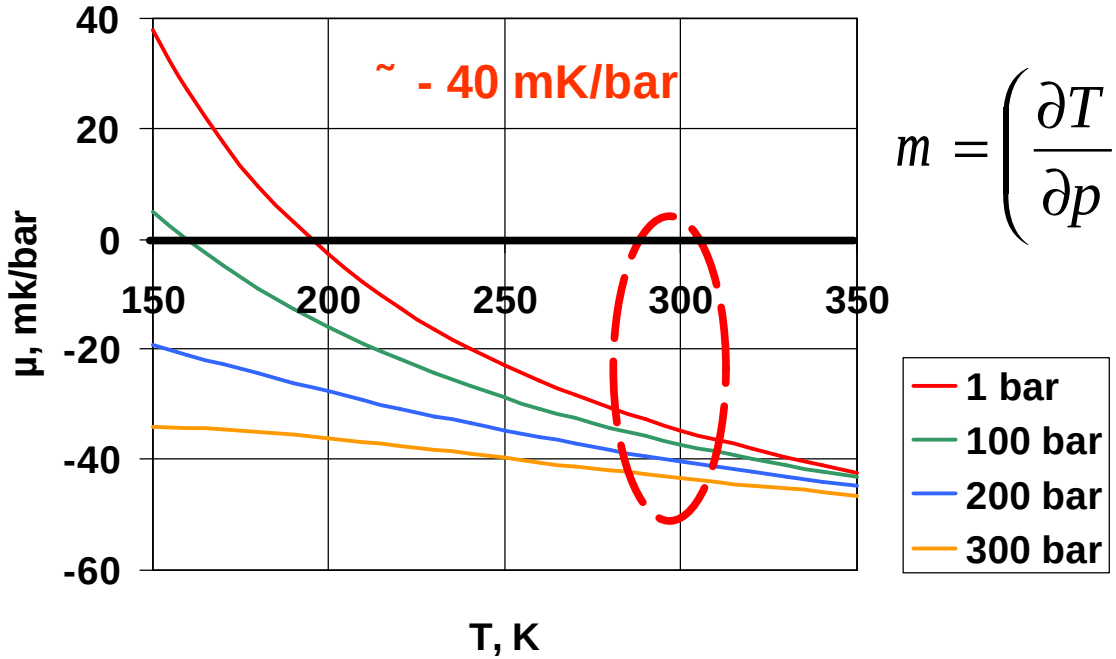
Wide explosive range ...?



But it is usually the lower that matters

Here hydrogen offers no particular features

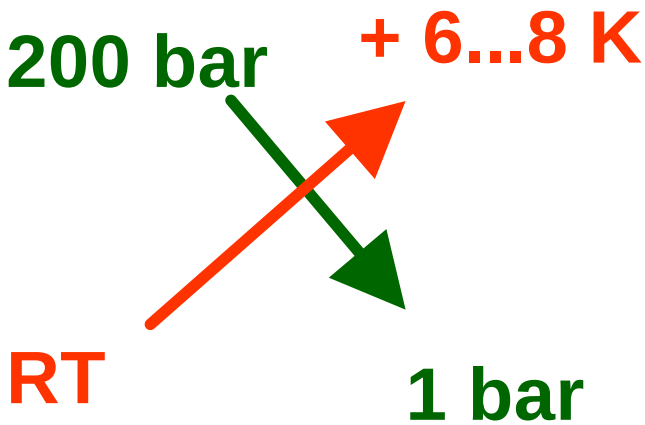
Negative Joule-Thomson coefficient ...?



$$m = \left(\frac{\partial T}{\partial p}\right)_H$$

Under **isenthalpic expansion** (Joule-Thomson process) hydrogen at ambient temperature does not cool down, like many other gases, but **becomes warmer**.

Is this dangerous?



Theoretical warming of 6...8 K

No danger of ignition!

Combustion generates nitrous oxides ...?

Oxygen

Nitrogen

= 2000 °C

Nitrous oxides

During combustion in air the oxygen and the nitrogen from the air react with each other.
Not a hydrogen specific problem

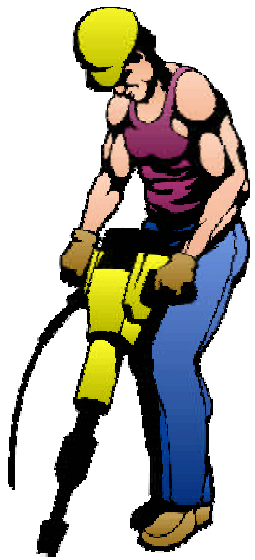
With hydrogen the problem is even smaller:
The wider reactive concentration range of hydrogen/air mixtures permits the choice of operating conditions with emissions which are lower than what could be achieved with hydrocarbons, even theoretically.

„**When the air leaves our motor it is sometimes cleaner than when it came in**.“ (BMW developer)

Hydrogen embrittles materials ...?

Cold embrittlement: by contact with cryogenic liquids or cooling of any kind. Reversible process. Can be controlled by choice of materials.

Hydrogen embrittlement: Interaction of hydrogen atoms (!) with crystal lattices, enhances the generation of stress corrosion cracks. Body-centered cubic lattices (ferrite steel) are susceptible under inappropriate conditions (high tension in the material). Face-centered cubic lattices (austenitic steel, Al, Ni, Ms) are less susceptible.



Case histories

- **There are not many cases of hydrogen accidents.**
- **Some „hydrogen accidents“ were not hydrogen accidents.**
- **Lessons learnt from accidents contributed to a higher level of public safety.**

Tempelhof airport

Berlin central airport since 1923
Present buildings date from 1934-1941

around 1920

Tempelhof Field until 1914

For 200 years training and parade ground of the Prussian army (picture: William I. during a victory parade in 1871)

Recreational area

Flight experiments: first motor flights in Germany (Wright brothers), balloons, air ships, including military ones

Tempelhof Field, 25 May 1884 (1)

- The soldiers of the Royal Prussian Air Ship Division stored large amounts of hydrogen gas. They kept some 1000 cylinders in a shed. On 25 May 1894 about 400 of them burst without apparent reason. Damage was considerable.

- The famous professor **Adolf Martens** was appointed scientific head of the consequent investigation; Martens is seen as the father of materials research and testing in Germany. He founded metal and lattice microscopy and constructed many test machines.

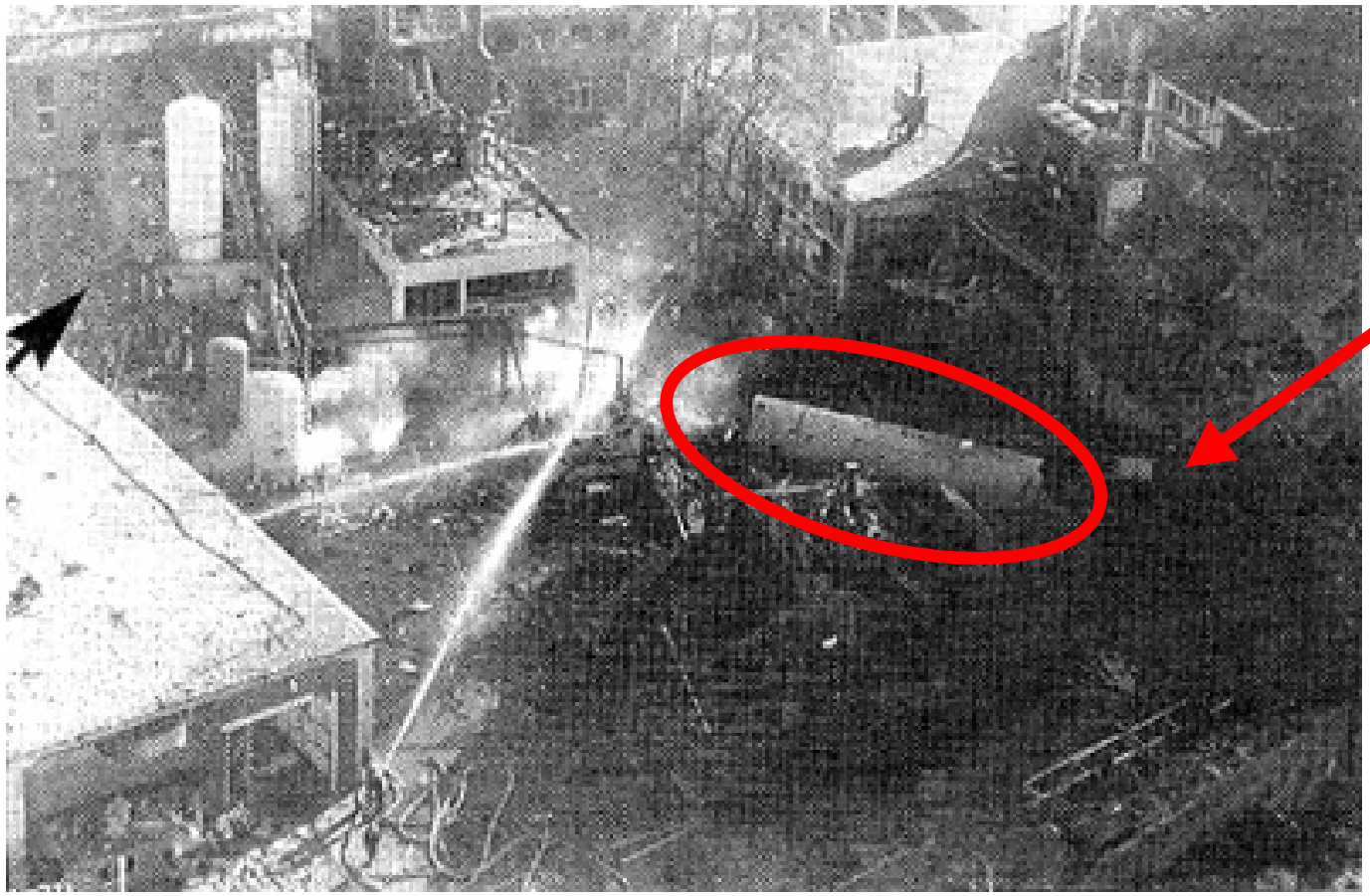
Tempelhof Field, 25. May 1894 (2)

- Result: **The cylinders were made from unsuitable material.**

- Martens made numerous proposals for the prevention of such accidents. The quality assurance program he devised became the **basis of the German pressure vessel code**.

Tank accident at Hanau 1991 (1)

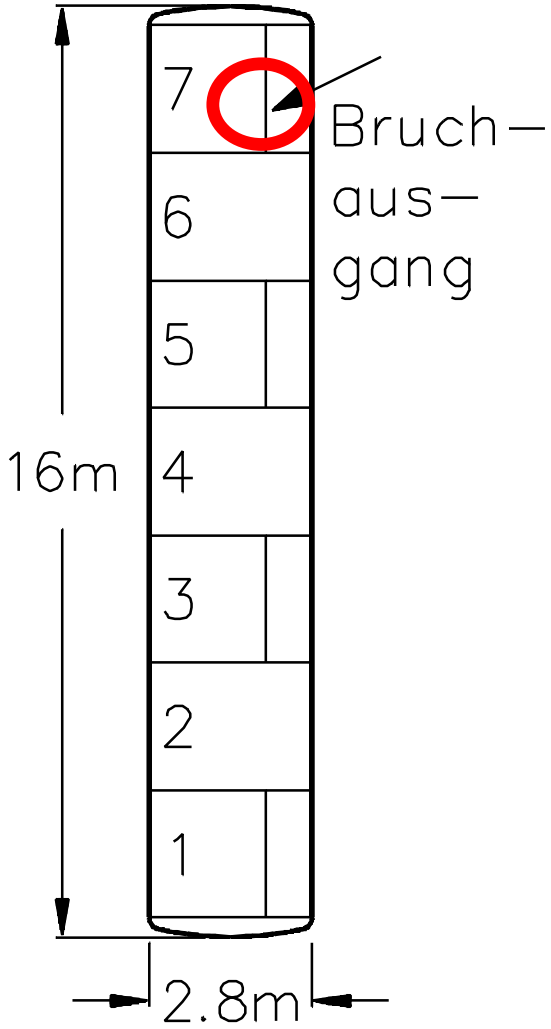
A tank for 100 m^3 hydrogen gas under a pressure of up to 45 bar was situated on an industrial ground at Hanau (Frankfurt area). One morning it burst without apparent reason. There was great damage.



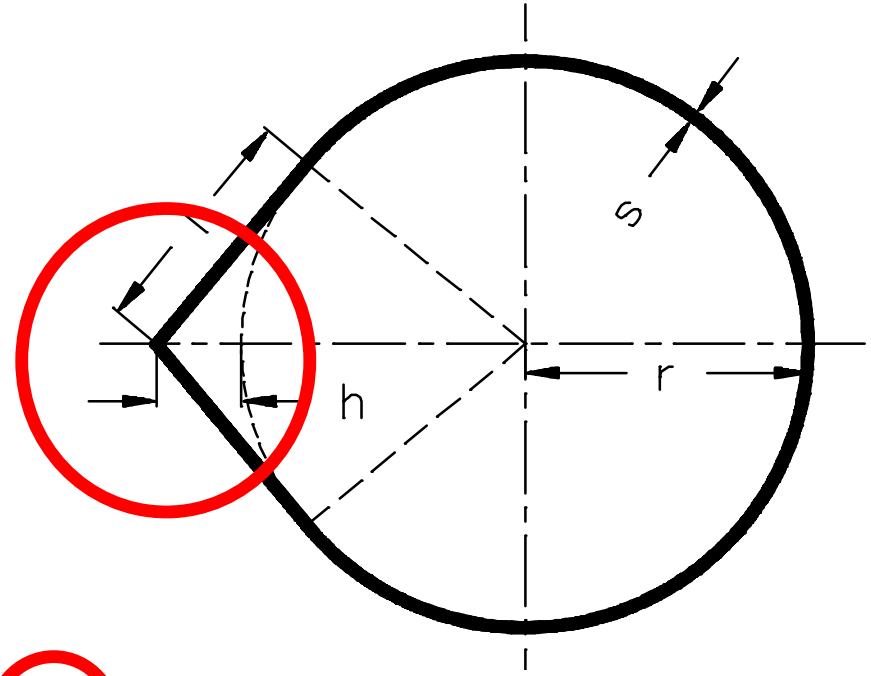
Tank

Factory ground after explosion

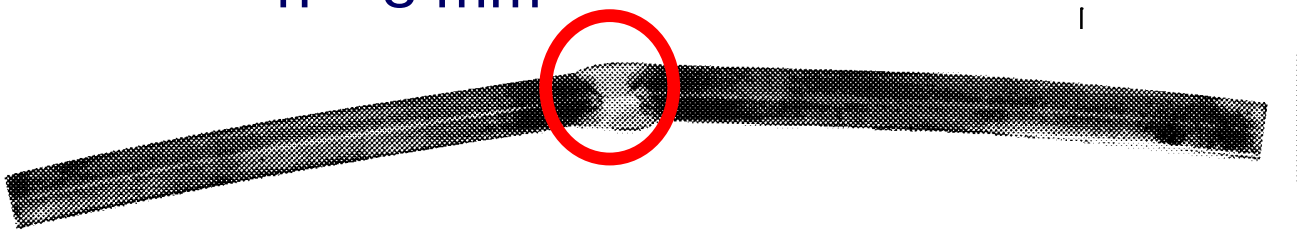
Tank accident at Hanau 1991 (2)



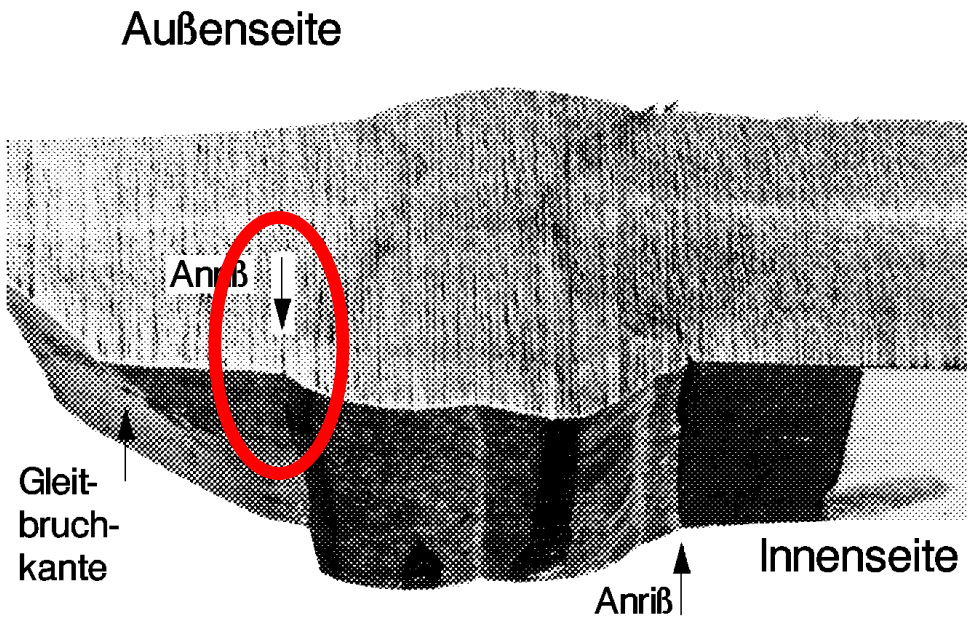
Reason: **corners along the welding seams** had caused enhanced tensions



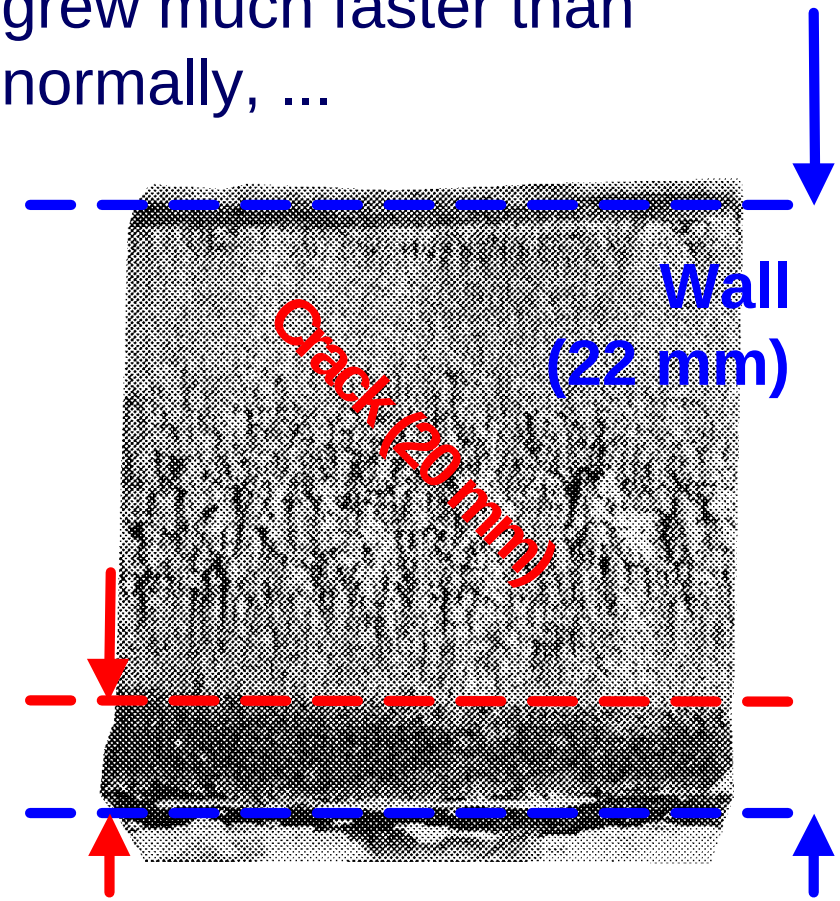
h ~ 8 mm



Tank accident at Hanau 1991 (3)



Soon the first cracks appeared. Under the influence of hydrogen they grew much faster than normally, ...



... until the tank could no longer resist even its normal operating pressure.

Tank accident at Hanau 1991 (4)

Consequences:

- All comparable tanks in Germany were checked.
- Manufacturing rules have been revised (upper limits for corners).
- The calculation method for the residual life time under cyclic stress was modernized.
- New test methods are able to detect cracks in earlier stages

The Hanau accident caused a **progress in safety engineering**.

„Hindenburg“, Lakehurst, 6 May 1937 (1)

Accident reason:
Paint of outer shell

- **low conductivity**
  (potential differences remained)
- **extremely flammable**
  (and not extinguishable)

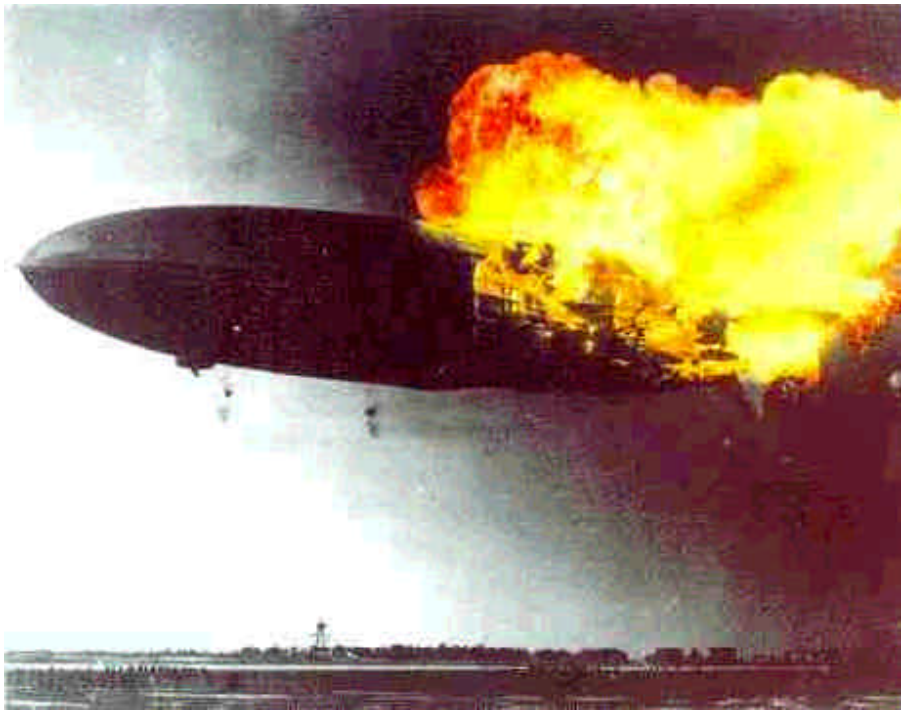
Lakehurst:
- Thunderstorm situation
- Potential difference ship-ground
- Potential difference ship-ship
- discharge (spark)

No explosion!

Comparatively few victims

„Hindenburg“, Lakehurst, 6 May 1937 (2)

What burns here?



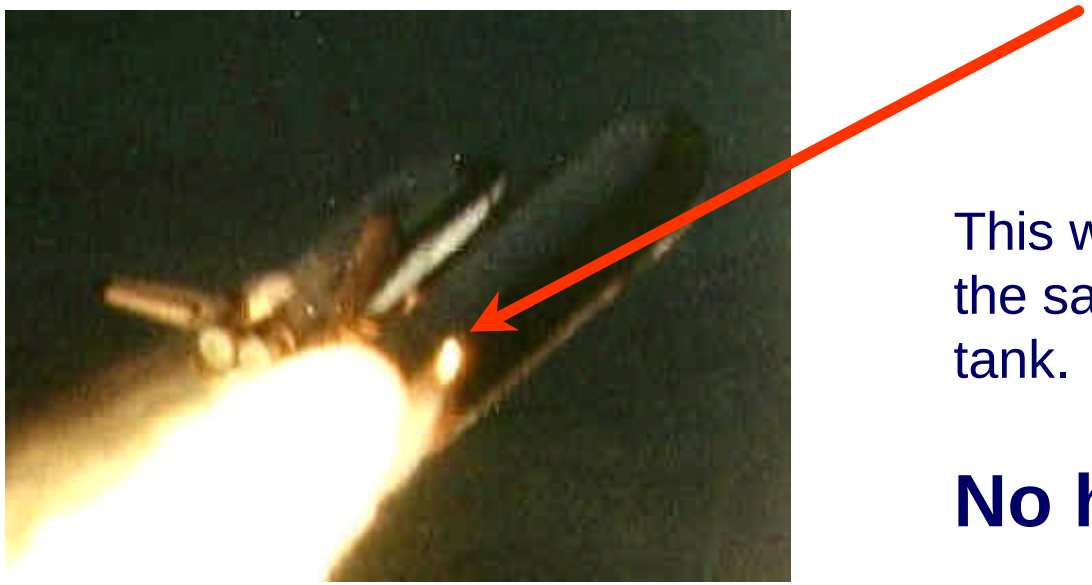
„Hindenburg“: burnt with a very intensive flame (b/w photo, colored on the basis of witness reports) Picture: Bain

Hydrogen (right): almost invisible flame. The big flame tail on the left comes from the auxiliary boosters (solid fuel) Picture: NASA

„Challenger“, 28 January 1986

This explosion, which caused the death of seven astronauts, was caused by a **defective seal** in of of the auxiliary boosters (solid fuel).

A flame (arrow) escaped from the booster flank and damaged some main tank supply lines (liquid hydrogen, liquid oxygen). This caused a leak and ignition.



This would have happened in exactly the same way with any other fuel in the tank.

No hydrogen accident!

Large scale accident simulation

What happens if cryogenic hydrogen escaped into the open air?

What is the influence of buildings?

Experiments were made in summer 1994 in an abandoned barrack ground in Brandenburg (Germany).

About 1 m^3 cryogenic hydrogen each was released, and the dispersion observed; analogous amounts of liquid propane were also released.

There was no ignition.

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.

Hydrogen is not a toy!

- **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!**

Hydrogen safety advantages

- Storage in pressure vessels
- Does not pollute ground or water
- Disappears rapidly if released
- Unconfined gas clouds unlikely to detonate
- Burns rapidly if ignited
- Does not leave harmful reaction products behind

Hydrogen is not ...

- **explosive**
- **unstable** (acetylene!)
- **autoignitive**
- **oxidizing**
- **poisonous**
- **corrosive**
- **radioactive**
- **ugly smelling**
- **contagious**
- **water polluting**
- **embryopathic**
- **cancerogenous**
- **expensive**
- **etc. etc. etc.**

Popular nonsense ...

„The wind power plants operating in Brandenburg reduce the emission of **poisonous carbon dioxide gas** by 677.000 tons per year, according to Wolfgang Fuerniss (CDU), state minister for economy.“

Der Tagesspiegel, 17 December 2000

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Thank you very much for your attention!

And see us occasionally under
www.dwv-info.de!