Proceedings

of the Mid-Term Assessment Workshop of the

European Integrated Hydrogen Project - Phase II [EIHP2]

Proceedings Volume 3

Breakout Session Refuelling Interfaces

held at the European Commission's

CCAB - Centre Albert Borchette

Brussels, 02 October 2002

Moderators: Fernando Isorna, Friedel Michel

- **14:10: "Optimum storage pressure for on-board CGH_2 storage issues" (J. Zieger, Daimler Chrysler).**
- **14:35: "High pressure tank refuelling tests" (Serge Chaudourne, CEA).**
- **15:00: "Experiences in > 70 MPa pressure storage" (S. Rau, Dynetek).**
- **15:25: "Nozzles, LH_2 Refuelling connectors devices" (F. Michel, Messer).**
- **15:50: "Elements of Liquid and High Pressure Filling Stations" (J. Wolf, Linde AG)**
- **16:15: General discussion and formulation of conclusions/findings**

Conclusions of the Breakout Session
”WP 3 – Refuelling Interface”.

The main conclusions achieved were the following:

1. Some of the invited persons think that if we (EIHP2) recommend an optimum on-board pressure very high, at the end, it will become an standard and we will have problems with ISO committee. It means that we can expect some reactions from ”conservative” delegates and gas companies.

WP3 Refuelling Interfaces - Breakout Group - Summary 2

2. Regarding fast or slow filling, at the end of the discussion, it has been recommended not to focus our work in fast or slow filling processes. Just, do not pass the limit of 85ºC gas temperature. We have to reflect this maximum temperature in the Regulation.

3. For normal filling procedures 10% of the liquid hydrogen or even more evaporates and cannot be filled into the LH2 vehicle storage tanks. This means that at least 10% of the H2 liquifaction energy gets lost. Additional energy has to be spent for the compression of evaporated hydrogen in order not to loose the gas completely.

It was recommended therefore to study possibilities for an optimization of the filling procedure.

Mid-Term Assessment Workshop

Brussels
02 October 2002

Presentation by
Dr. Josef Zieger

High Pressure Storage of Hydrogen

December 2000

L-B-Systemtechnik GmbH
D-85521 Ottobrunn

Study for DaimlerChrysler AG

Shortened Version for EIHP II

Hydrogen Powered Fuel Cell Car

Vehicle Range Requirements:

driving cycle	NEDC
range	400 – 500 km
fuel economy (average compact car)	3.6 $l_{gasoline\ equivalent}$/100km
required net hydrogen mass	3.9 - 4.8 kg

Goal for a Hydrogen Storage System:

system weight	< 100 kg
system volume	< 150 liter

Goal of the Study

The goal of this study was a statement to the feasibility of a high pressure on-board storage system (> 350 bar) to get higher ranges.

In an international context pressures as high as 70 MPa are discussed (probably because this is equivalent to 10,000 psig).

The task of this study was structured in 2 topics:

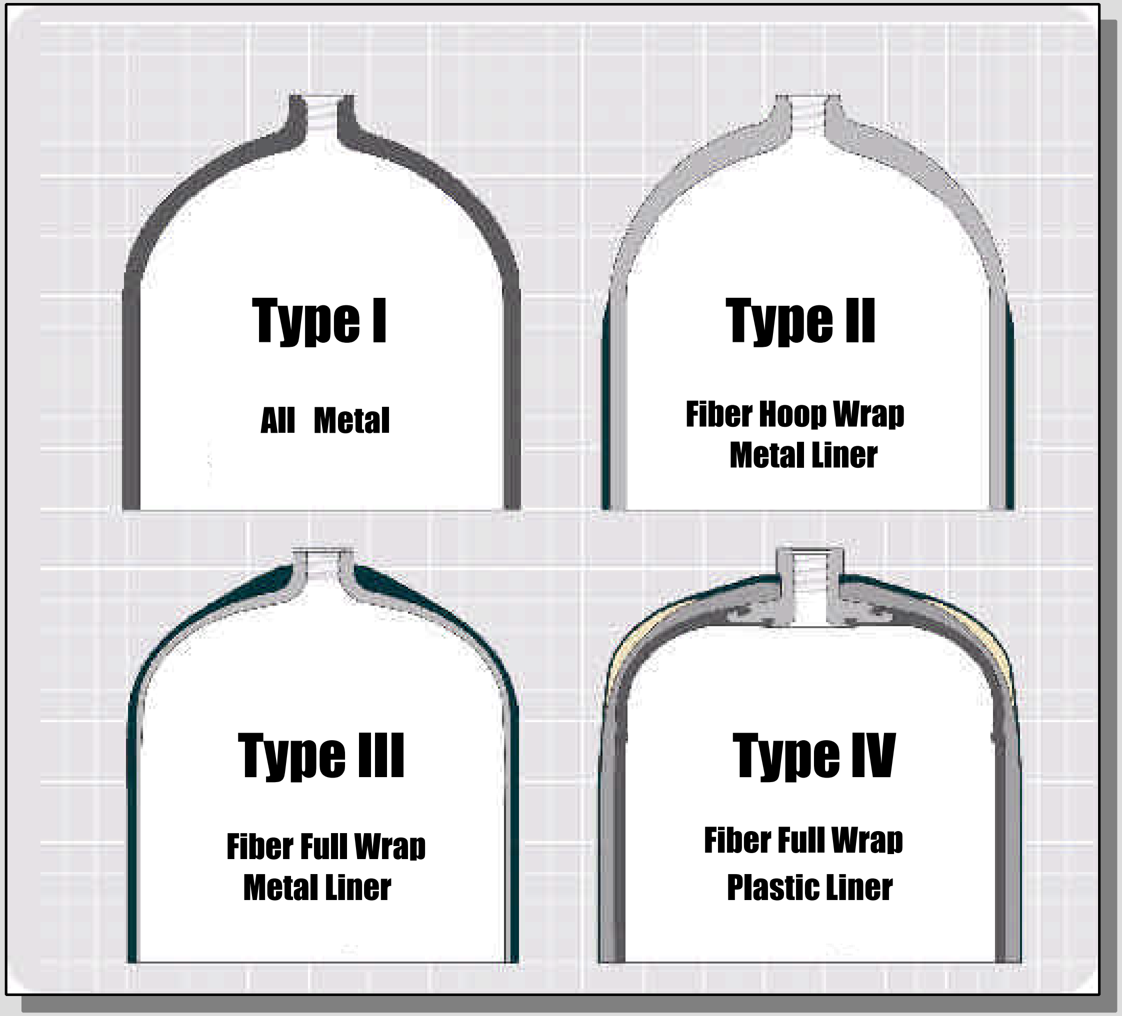
- to uncover potential technological hurdles in the storage system or infrastructure technology in comparison with the existing 35 MPa technology
- to informally discuss 70 MPa safety and regulatory consequences with relevant authorities and experts.

Pressure Vessel Design

According to EIHP pressure vessels are divided into five groups depending on the cylinder wall design.

- Type I (Metal): all metal cylinder
- Type II (Hoop wrapped): load-bearing metal liner hoop wrapped with continuous filament
- Type III (Fully wrapped): non load-bearing metal liner axial and hoop wrapped with continuous filament
- Type IV (Non-metallic): non load-bearing non-metal liner axial and hoop wrapped with continuous filament
- Type V (Other): type of construction not covered by types I to IV above.

Cylinder Nomenclature



Result I - Hydrogen Storage Tanks for High Pressure Storage

- for hydrogen storage for automotive applications only type III and type IV tanks are of interest especially at elevated pressures because of the relatively high specific weight of type I and II tanks
- the choice of tank type for pressurised hydrogen, i.e. the liner material, is almost a philosophic one and the positions of tank producers differ widely.

The further study only refers to type III and IV tanks.

Type III Tank - Major Components:

- Overwrap

  The overwrap has to be seen as a structural unit together with the liner.

  The stiffness of the overwrap is mainly influenced by the fibre choice and/or the overwrap wall thickness.

- Metallic Liner

  The flange is an integral part of the metallic liner.

  The metallic liner prevents the hydrogen permeation.

  The metallic liner serves as mandrel for the overwrap.

Result II - Type III Tank

Potential Problems Concerning Higher Pressures

- Liner Material:

  Today mainly aluminium is used as liner material. Changing to higher pressures may lead to problems. Therefore other materials have to be taken into consideration.

- Liner Permeation:

  At current pressures permeation was never a problem with metal liners. This may change at higher pressures inside an aluminium-lined tank.

  (No data are known to us for these conditions.)

- Fatigue Life:

  Fatigue life problems have to be considered for type III tanks. They have to be solved by well adapting liner and overwrap structural properties.

Type IV Tank - Major Components:

- Overwrap

  The overwrap characteristic is not influenced by the plastic liner. The overwrap can be designed without any retroactive effects of the liner.

- Plastic Liner

  The plastic liner can not prevent the hydrogen permeation totally.

  The filament winding process requires a mandrel to withstand the forces occurring.

- Boss

  It is necessary to integrate a so called polar boss carrying the thread, because the plastic liner is not strong enough to hold a screwed-in valve at elevated pressure.

Result III - Type IV Tank

Potential Problems Concerning Higher Pressures

- Liner Material and Liner Permeation:

  Today hydrogen permeation through the liner is a problem for type IV tanks. For higher pressures the material choice will mainly be driven by permeation rates or other measures have to be taken to solve this problem (gas tight housing).

- Boss:

  The boss-liner-interface is a very critical location, especially for higher pressures.

- End-caps:

  Similar to type III tanks the end-caps contribute over-proportionally to total cylinder weight. According to each individual company's boss design this effect can be relatively large and can offset other measures for weight reduction.

Result IV - Conclusions for 70 MPa Tank Technology

For short term applications (< 2007):

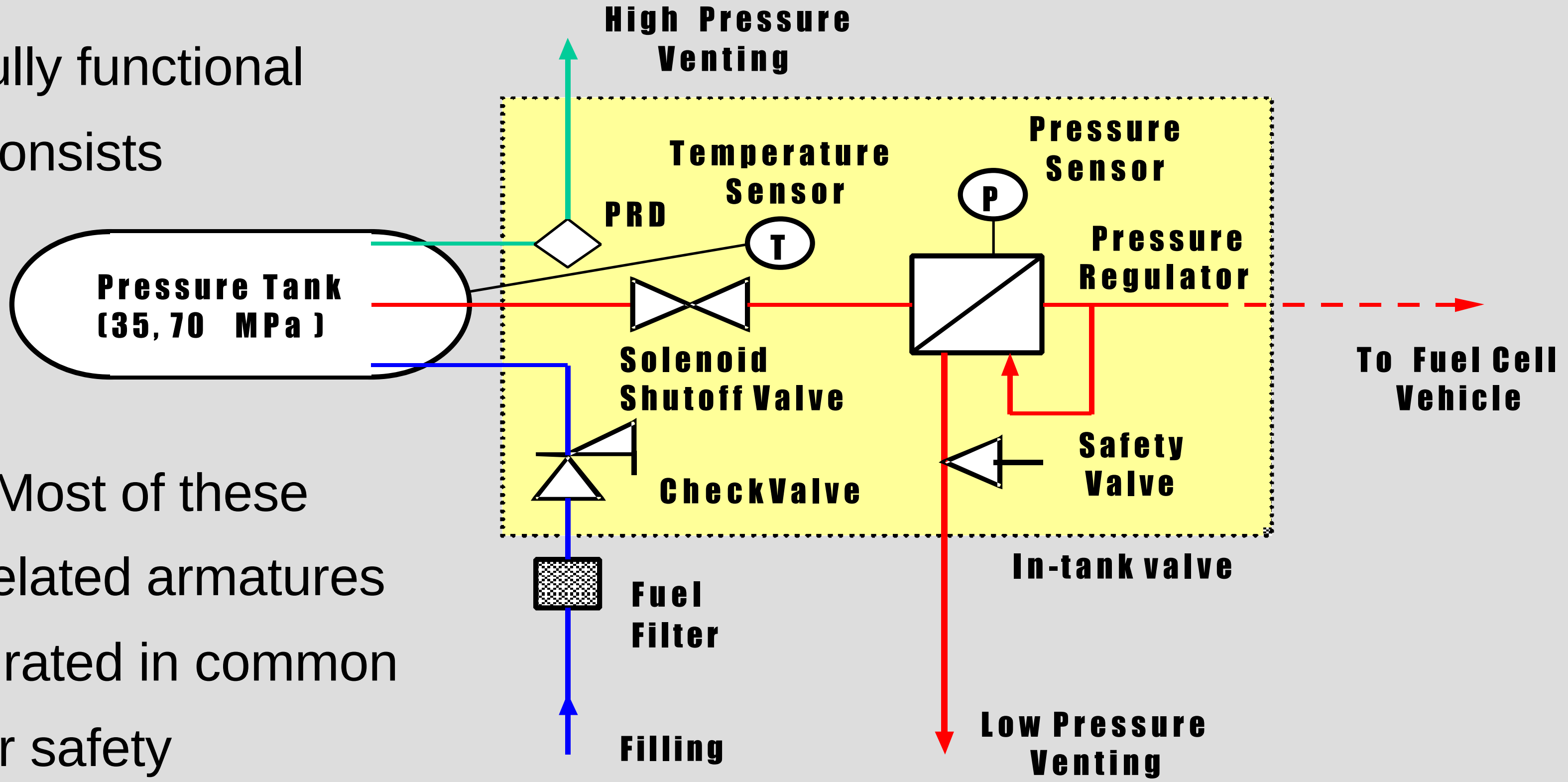
- thin plastic liners are not sufficient for highest pressures due to unduly high permeation rates
- Al-lined tanks have to be carefully designed for long fatigue life by choosing specific high E-modulus fibres
- for other liner materials further investigations are required

For long term tank systems (> 2007):

- thin plastic liners provide the highest potential for volumetric and gravimetric storage density at unlimited fatigue life and at low cost
- even if permeation rates through the liner material can not be guaranteed other measures are possible (forced ventilation).

Major Components of a CGH_2 Tank System

A complete, fully functional tank system consists of the tank itself and additional components. Most of these tank system related armatures could be integrated in common valve units for safety reasons or cost reduction.



Temperature Rise during Fast Fill / Rapid Discharge

Following the theory of adiabatically filling of an ideal gas without heat exchange with the tank wall the theoretical temperature rise being maximum 115 K for hydrogen starting at T_1 = 288 K.

The main temperature effect takes place at relative low pressures of below 10 MPa.

Result V - Temperature Rise during Fast Fill / Rapid Discharge

The high temperature peaks during or after fastfilling at 70 MPa probably would be not more critical than at 35 MPa.

- Concerning temperature rise type III tanks are thought to be less problematic due to their higher m x c_p which helps to transfer the heat from the gas to the wall instantly.
- The temperature rise causes lower gas densities. To compensate the missing hydrogen mass during fast fill over-pressurisation is used to achieve a full tank at design temperature (15 °C). The consequence is higher stationary storage pressures.

System Simulation for the Calculation of the Storage Densities

- A tank layout model was created which represents the current technology (35 MPa) using an iterative adjusting method and the manufacturer specified data.

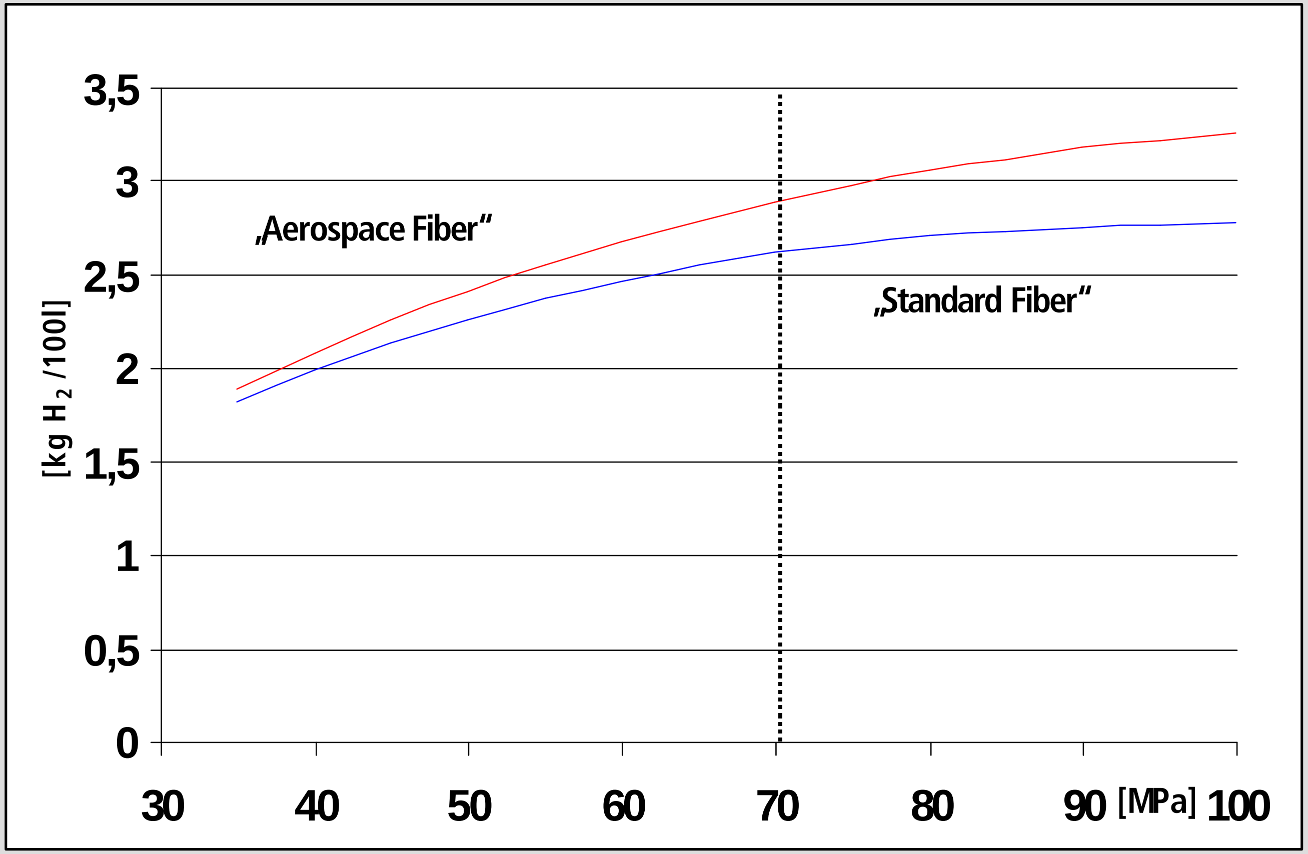
- Extrapolation of the tank layout towards a 70 MPa design.

Definition:

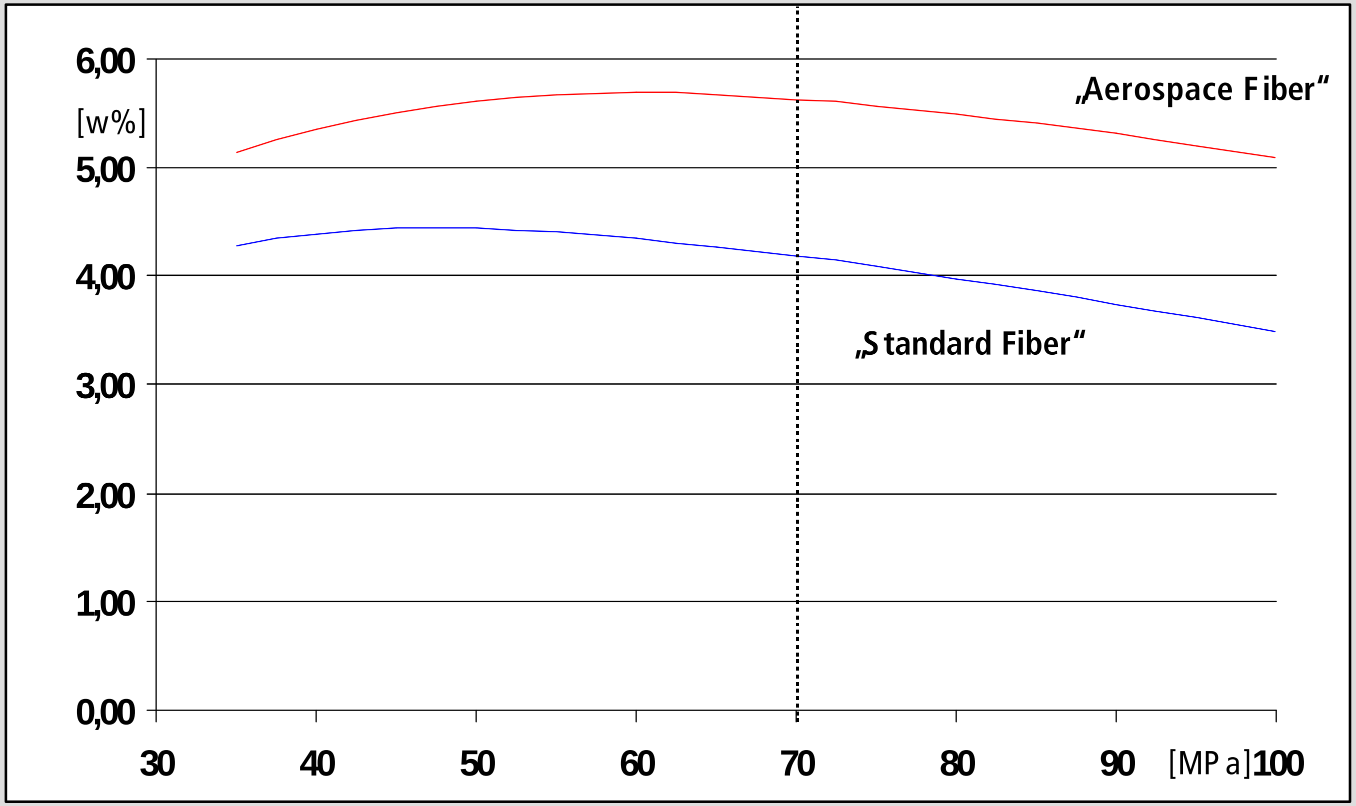
$$\text{gravimetric storage density [\%]} = \frac{\text{weight of stored hydrogen [kg] x 100 [\%]}}{\text{weigth of tank system} + \text{weight of stored hydrogen [kg]}}$$

$$\text{volumetric storage density [kg/100 l]} = \frac{\text{weight of stored hydrogen [kg]}}{\text{required envelope [100 l]}}$$

Volumetric Storage Density vs. Service Pressure (qualitative result)



Gravimetric Storage Density vs. Service Pressure (qualitative result)



Result VI - System Simulation for the calculation of the Storage Densities

Simulation results for the transition of a 350 bar tank system to 700 bar tank system:

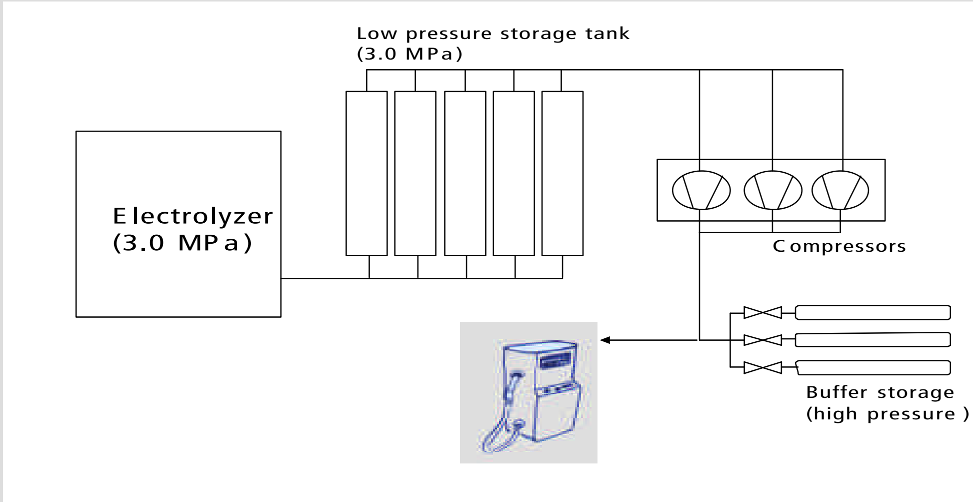
- gain of volumetric storage density of 50 to 70 %
- no gain in gravimetric storage density with the same materials
- gain in gravimetric storage density with other materials

Infrastructure Comparison and Selection of the Compressor Technologies

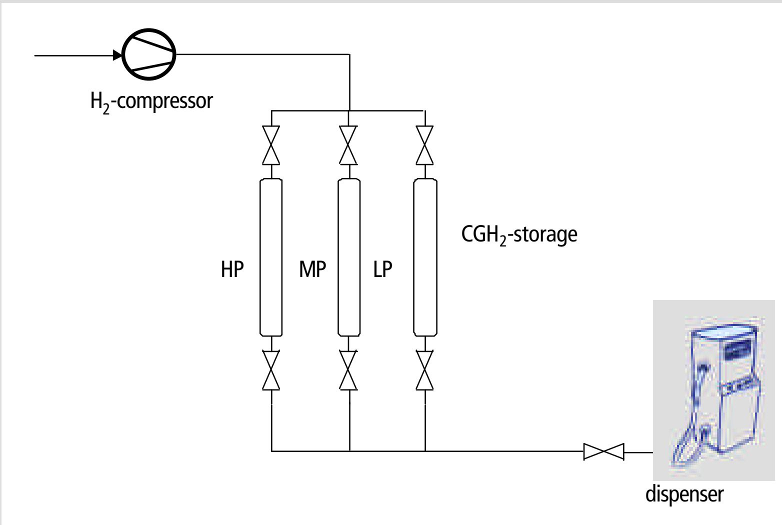
	Trunk piston compressor	Cross head piston compressor	Cross loop piston compressor	Diaphragm compressor	Hydraulic compressor
Hydrogen purity	oil-free design possible for small machines	oil-free design possible	oil-free design possible	oil-free	“oil carry over”
Reasonable suction pressure	> 0.1 MPa	> 0.1 MPa	> 0.1 MPa	> 3.0 MPa	> 1.5 MPa
Max. discharge pressures	35 MPa	85 MPa (oil-free) > 100 MPa (lubricated)	31 MPa (oil-free)	448 MPa	40 MPa > 85 MPa possible

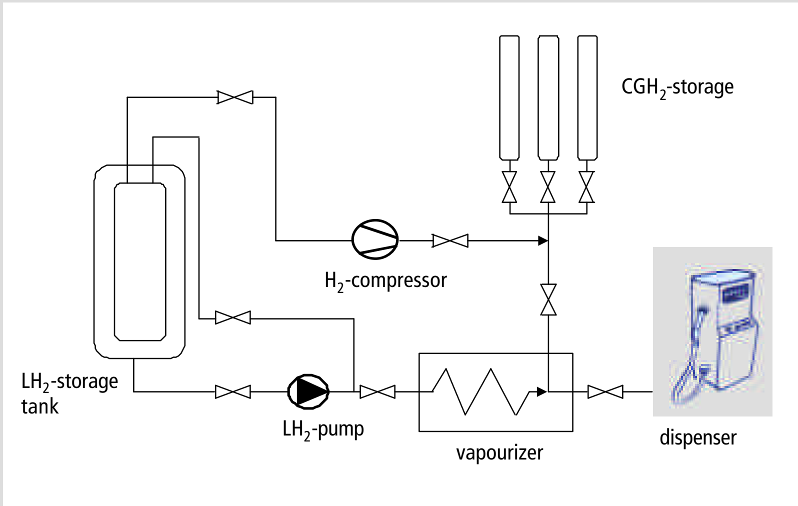
Infrastructure
Filling Station Concept

Booster Concept



Multi-Bank Concept





LCGH2 Filling Concept

Result VII - Infrastructure for High Pressure Storage 70 MPa

- no majors hurdles are expected for a 700 bar infrastructure
- research and development is needed, concerning the design of couplings and hoses for high pressures for handling by private customers.
- because of the temperature increase up to 85°C filling stations must provide a pressure of about 43.8 MPa for 35 MPa and about 87.5 MPa for 70 MPa onboard storage
- if multi-bank systems are used the stationary storage tanks must be about 55 MPa for 35 MPa or 109 MPa for 70 MPa onboard storage
- the advantage of booster concepts is that no pressure difference between the full vehicle tank and the outlet of the hydrogen compressor is needed

Result VIII - "Operational Safety"

- None of the discussion partners from manufacturing companies or regulatory bodies saw any safety related hurdles for the introduction of a 70 MPa vehicle storage technology.
- Both existing as well as proposed regulations or directives do not pose any limitations to pressure levels.

Result Summary - Feasibility of Vehicle Technologies for 70 MPa

- Neither pressure vessel and component industry nor safety authorities and experts saw any major hurdle for the introduction of 70 MPa vehicle hydrogen storage technology .

- Standard pressure levels both for vehicle onboard as well as stationary storage should be agreed upon with as many partners as possible.

Mid-Term Assessment Workshop

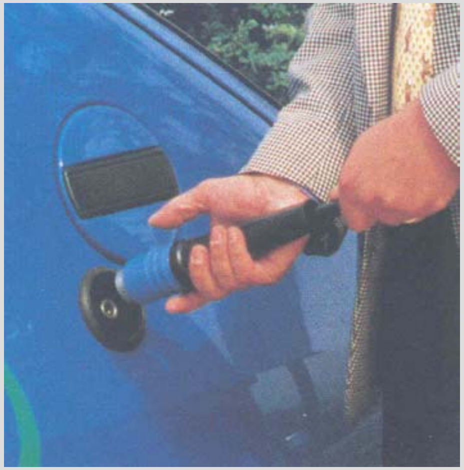
Brussels
02 October 2002

Presentation by Serge CHAUDOURNE
(CEA-Grenoble, France)

Development of a High Pressure Gaseous Hydrogen Refuelling Procedure

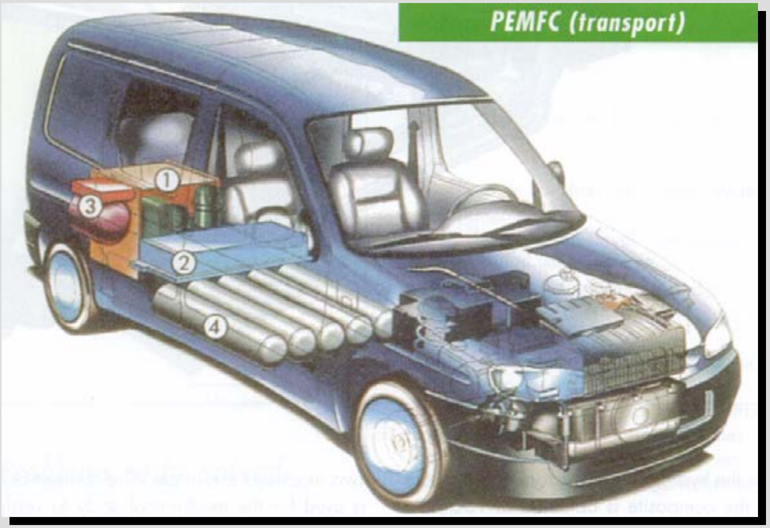
Objectives of the Work Package 3.2

- **Development of a refuelling procedure for vehicles with high pressure hydrogen tanks (35 to 70 MPa)**
- **Experimental study of the high pressure Hydrogen transfer**
  - ✓ Development of a test facility
  - ✓ Measurement of various parameters in real conditions (refuelling time, temperature rise, mass flow rate, leakage detection on the connector)
  - ✓ Reproducibility
- **Thermodynamic modelling**
  - ✓ Calculation of pressure variation in the tank
  - ✓ Calculation of instant flowrate and refuelling time
  - ✓ Calculation of temperature rise



CEA expertise on high pressure Hydrogen storage

- **Participation to the HYDRO-GEN European project with PSA**



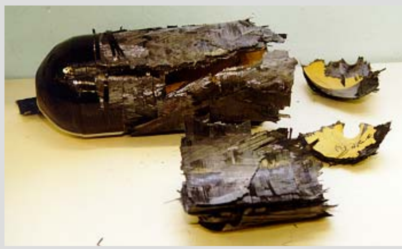
- **Conception and tests of high pressure hydrogen storage tanks**
  - ✓ Aluminium liner with overwrap in carbon fiber (type III)
  - ✓ Design pressure and test : 70 MPa
  - ✓ Volume : 28 liters

Security test performed by CEA – Cesta (Bordeaux)

- **Fall (14 m)**

- **Car crash (65 km/h)**

- **Hydrocarbon Fire**
- **Gun firing**



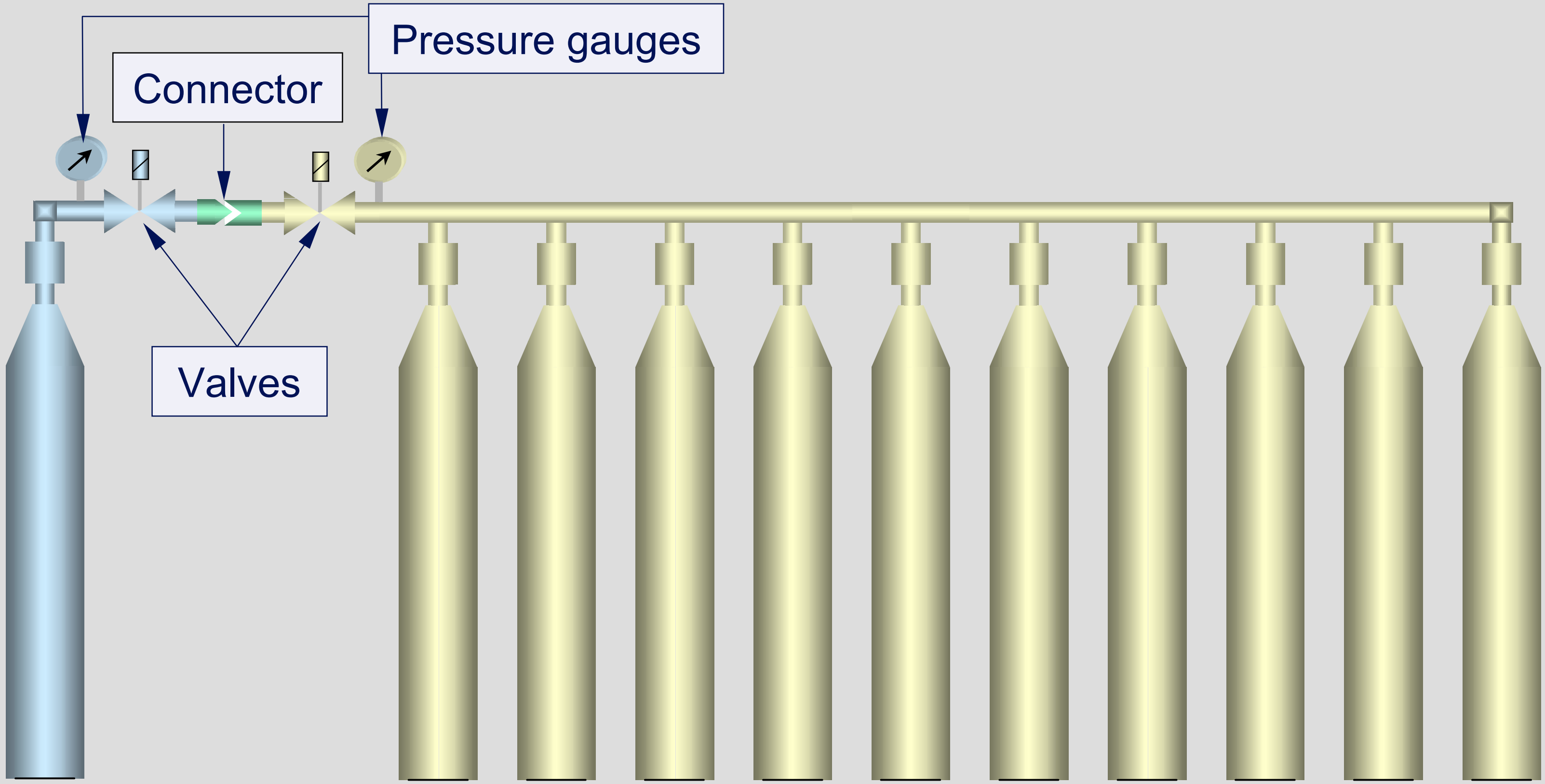
▪ Standards

- ✓ **ISO DTR 15916 :** Basic considerations for the safety of hydrogen systems
- ✓ **ISO WD 17268 :** Fuelling connectors (in progress, will be probably equivalent to SAE standard)
- ✓ **SAE J 2600 :** Compressed hydrogen surface vehicle refuelling connection devices
- ✓ **SAE J 2601 :** Compressed hydrogen surface vehicle refuelling procedure

▪ Regulations

- ✓ Compressed gaseous hydrogen regulation : **EIHP2 Draft Rev. 9**

Test of the refuelling procedure - Experimental device

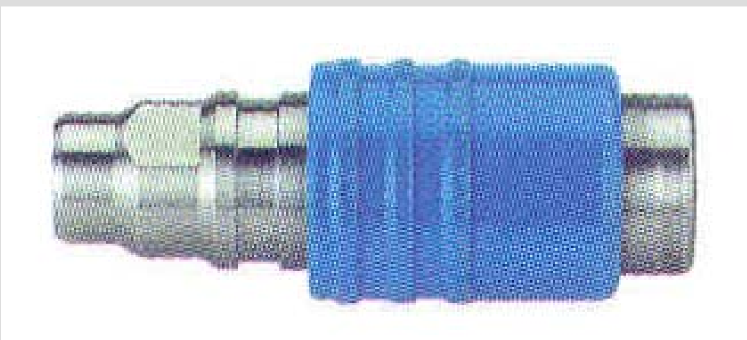


Initial P = 0 MPa
Final P = 35 MPa
Volume V = 9 l

Initial P = 40 MPa
Final P = 35 MPa
Volume V = 90 l

Connectors specifications for the test

- **Manufacturer : STAUBLI**
- **Initially designed for GNV**
- **Service pressure 35 Mpa**
- **All parts in stainless steel ANSI 316L (no hydrogen embrittlement)**



Modelling

- Simple model (first step)
  - ✓ 0 – D (nodal)
  - ✓ No external heat exchange

➡

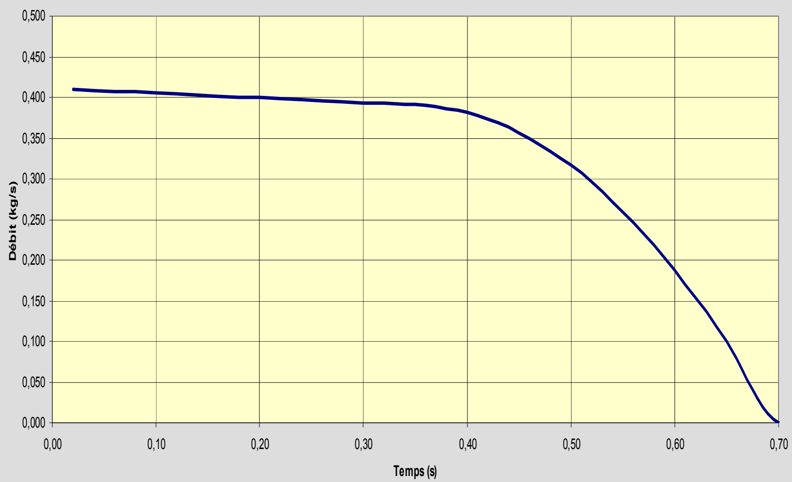
- Sophisticated model (second step)
  - ✓ 1 – D to 3 – D
  - ✓ Heat exchange through the wall

- **Preliminary results**
  - ✓ Sonic velocity is reached by the gas flow in the connector
  - ✓ Temperature rise of the tank can reach ten to hundred degree C

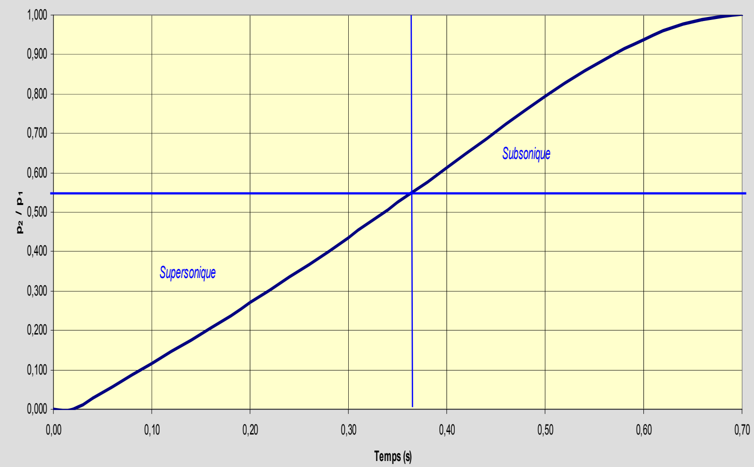
0 – D Model

- Preliminary validation of the model has been done by comparison with an experiment using air (pressure release in the atmosphere of a 30 liters tank pressurized at 33 Mpa)

- Example of simulation of Hydrogen transfer



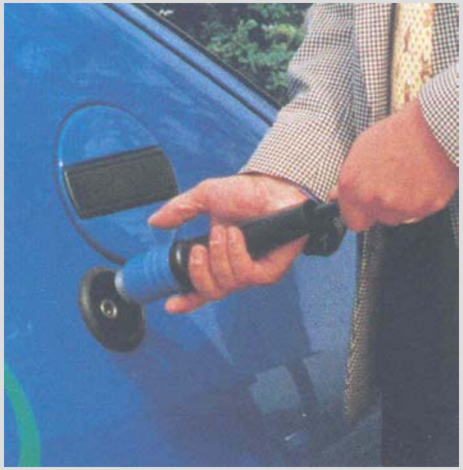
Mass flow rate evolution



Pressure evolution

Conclusion

Modelling and tests in real conditions are yet necessary before finalizing a good refuelling procedure for gaseous hydrogen



Dynetek Europe GmbH

Advanced Lightweight Fuel Storage Systems ™

Development of a 700 Bar Fuel Tank System for Hydrogen

- **Project Goals**
- **Liner Concept**
- **Cryoforming Process**
- **Project Partners**
- **Project Schedule**

Martin Kesten
Dynetek Europe GmbH, Ratingen, Germany

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

H2 700 (NRW)

Task: **Development, Testing and Approval of a 700 Bar Tank System**

Sub-Task 1: UHP Storage Tank
Sub-Task 2: Peripheral Equipment incl. all Control and Safety Devices

Solution Approach

- **UHP Storage Tank Design based on a fully wrapped Stainless Steel Liner**
- **Improved Mechanical Properties of the Liner through Cryoforming**

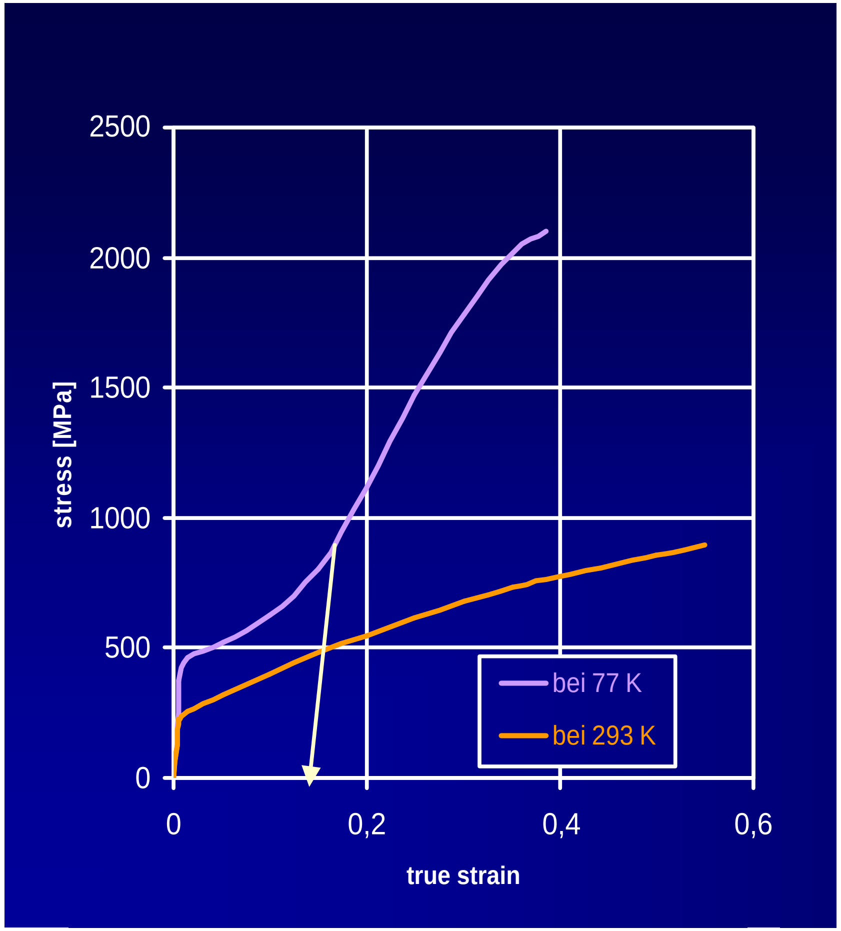
Cryoformed Stainless Steel Liner

- **Basic Advantages**
  - Very comon and frequently used alloy (AISI Type 304)
  - Minimum design strength increased by a factor of four (Rp>800 MPa)
  - Improved fatigue resistance

- **Project Activities**
  - Defining the optimal liner pre-form
  - Deciding about the most suitable liner manufacturing technique
  - Realising a series of prototype vessels
  - Conducting performance tests paying particular attention to a possible influence of hydrogen and its controlling parameters
  - Design and installation of a production line for liners and stainless steel cylinders

The Concept of Cryoforming Metastable Stainless Steels

Stress-Strain curve of AISI 304 at RT and 77 K

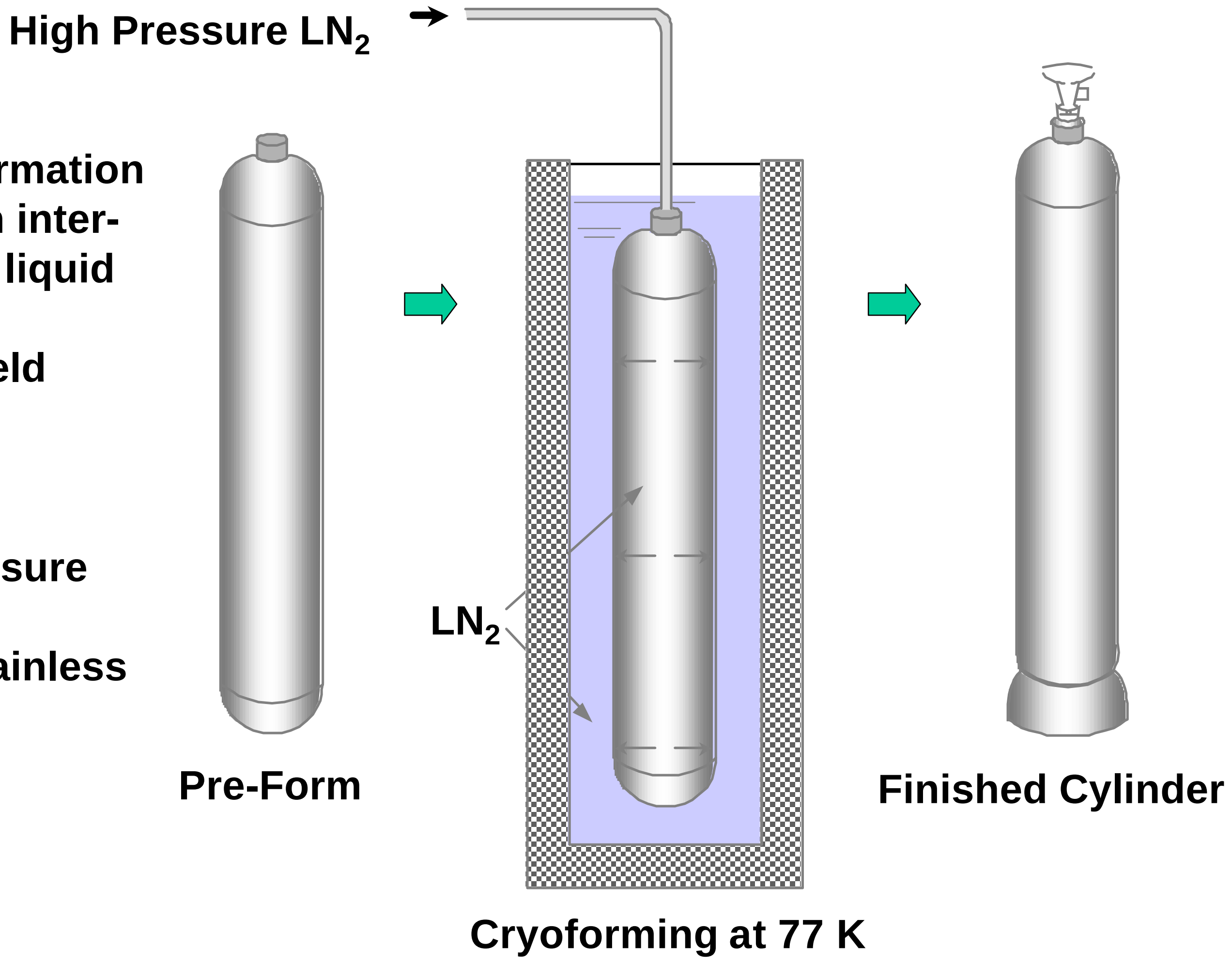


- significant strength hardening at cryogenic temperatures due to martensitic transformation
- remaining high level of ductility
- degree of strength hardening is controlled by alloy composition

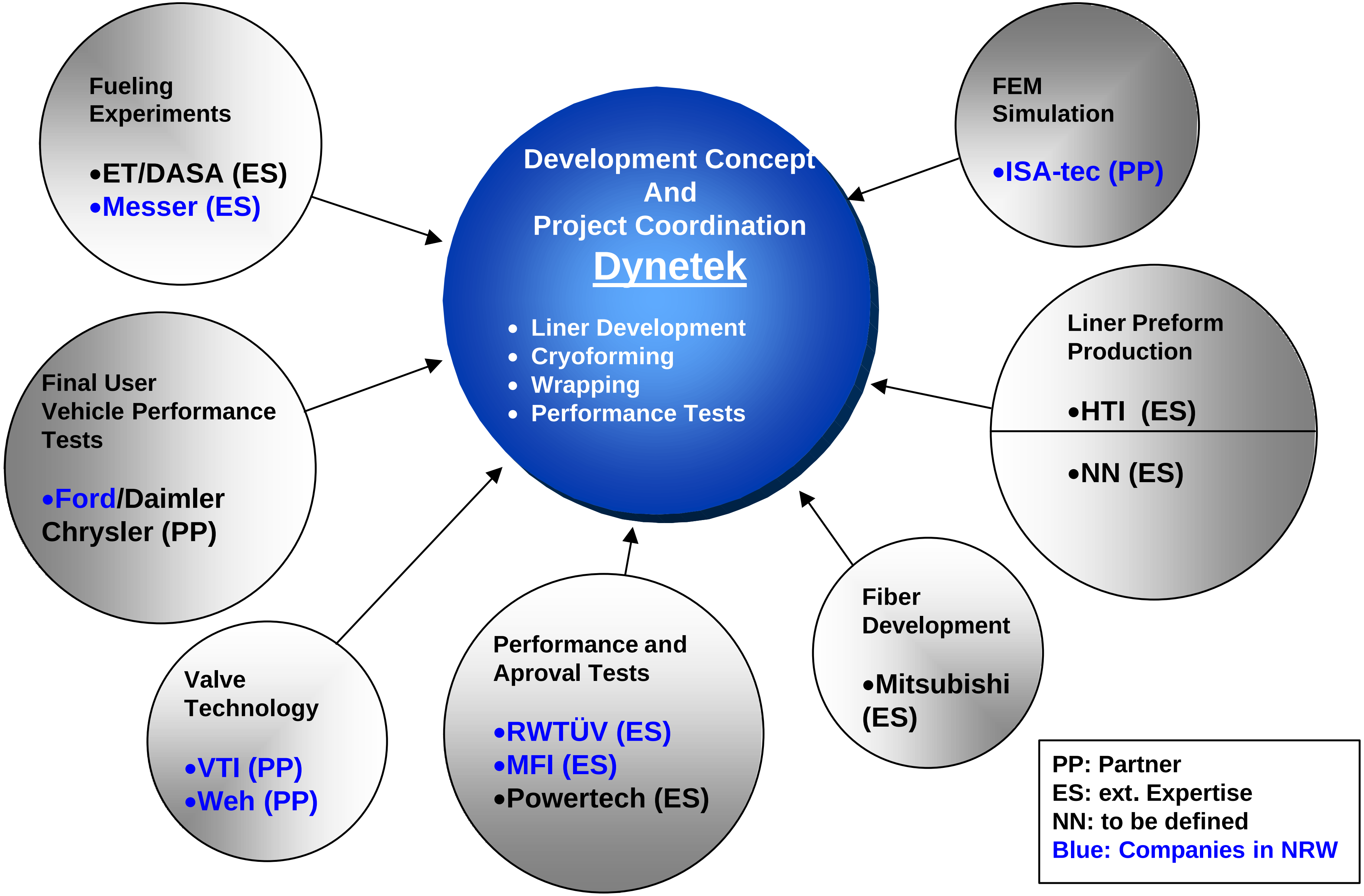
The Cryoforming Process

Controlled plastic deformation of the pre-form through inter-nal pressurization with liquid nitrogen.
Increase of the local yield strength to > 800 MPa

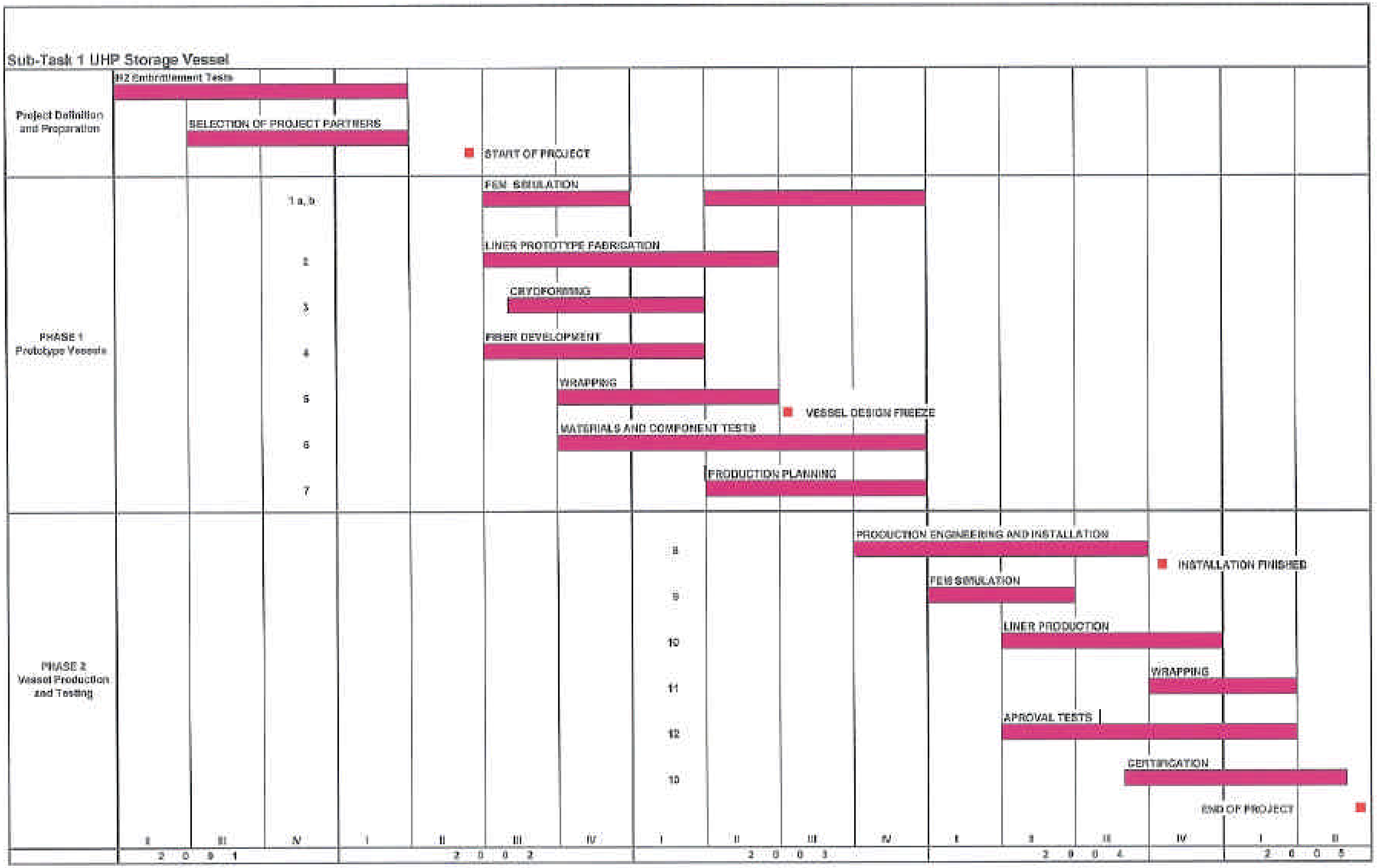
Result:
- **Light weight high pressure vessel**
- **Corrosion resistant stainless steel**



H2 700 (NRW)


Fueling Experiments
•ET/DASA (ES)
•Messer (ES)
Development Concept And Project Coordination
Dynetek
Liner Development
Cryoforming
Wrapping
Performance Tests
FEM Simulation
•ISA-tec (PP)
Final User Vehicle Performance Tests
•Ford/Daimler Chrysler (PP)
Liner Preform Production
•HTI (ES)
•NN (ES)
Valve Technology
•VTI (PP)
•Weh (PP)
Performance and Aproval Tests
•RWTÜV (ES)
•MFI (ES)
•Powertech (ES)
Fiber Development
•Mitsubishi (ES)
PP: Partner
ES: ext. Expertise
NN: to be defined
Blue: Companies in NRW

H2 700 (NRW)



Sub-Task 1 UHP Storage Vessel
H2 Embrittlement Tests
Project Definition and Preparation
SELECTION OF PROJECT PARTNERS
START OF PROJECT
FEM SIMULATION
1 a, b
LINER PROTOTYPE FABRICATION
2
CRYOFORMING
3
PHASE 1 Prototype Vessels
FIBER DEVELOPMENT
4
WRAPPING
5
VESSEL DESIGN FREEZE
MATERIALS AND COMPONENT TESTS
6
PRODUCTION PLANNING
7
PRODUCTION ENGINEERING AND INSTALLATION
8
INSTALLATION FINISHED
FEM SIMULATION
9
LINER PRODUCTION
10
PHASE 2 Vessel Production and Testing
WRAPPING
11
APROVAL TESTS
12
CERTIFICATION
13
END OF PROJECT
I II III IV I II III IV I II III IV I II III IV I II
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2 0 0 4
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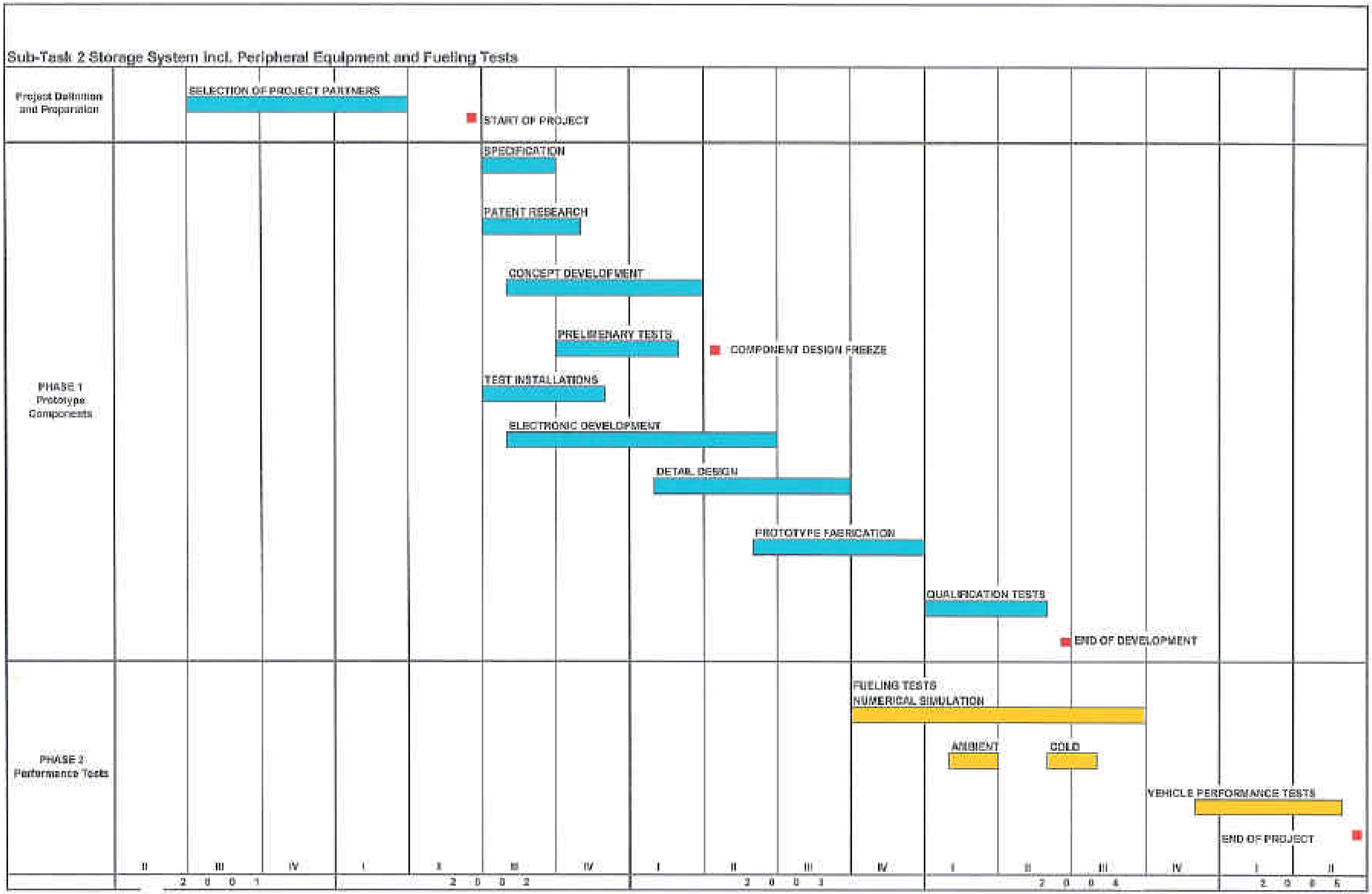
H2 700 (NRW)


Sub-Task 2 Storage System incl. Peripheral Equipment and Fueling Tests
Project Definition and Preparation
SELECTION OF PROJECT PARTNERS
START OF PROJECT
SPECIFICATION
PATENT RESEARCH
CONCEPT DEVELOPMENT
PRELIMINARY TESTS
COMPONENT DESIGN FREEZE
TEST INSTALLATIONS
ELECTRONIC DEVELOPMENT
DETAIL DESIGN
PROTOTYPE FABRICATION
QUALIFICATION TESTS
END OF DEVELOPMENT
PHASE 1 Prototype Components
FUELING TESTS
NUMERICAL SIMULATION
AMBIENT
COLD
VEHICLE PERFORMANCE TESTS
END OF PROJECT
PHASE 2 Performance Tests
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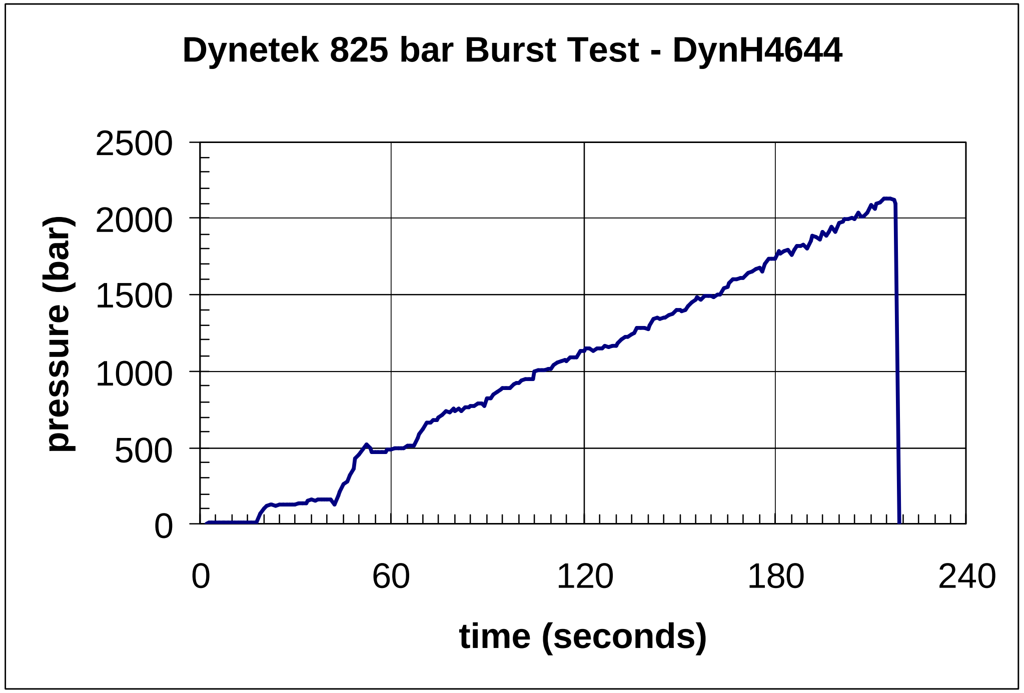
2 0 0 2
2 0 0 3
2 0 0 4
2 0 0 5

Hydraulic Burst Test of a Type III Prototype Vessel

Geometric Volume: 170 Liter | **Hydrogen Capacity: 7.76 kg**

Weight: 135.4 kg | **Storage Efficiency: 5.42 kg/kg Vessel Weight**

Service Pressure: 825 bar | **3.1 kg/100 l Vessel Volume**

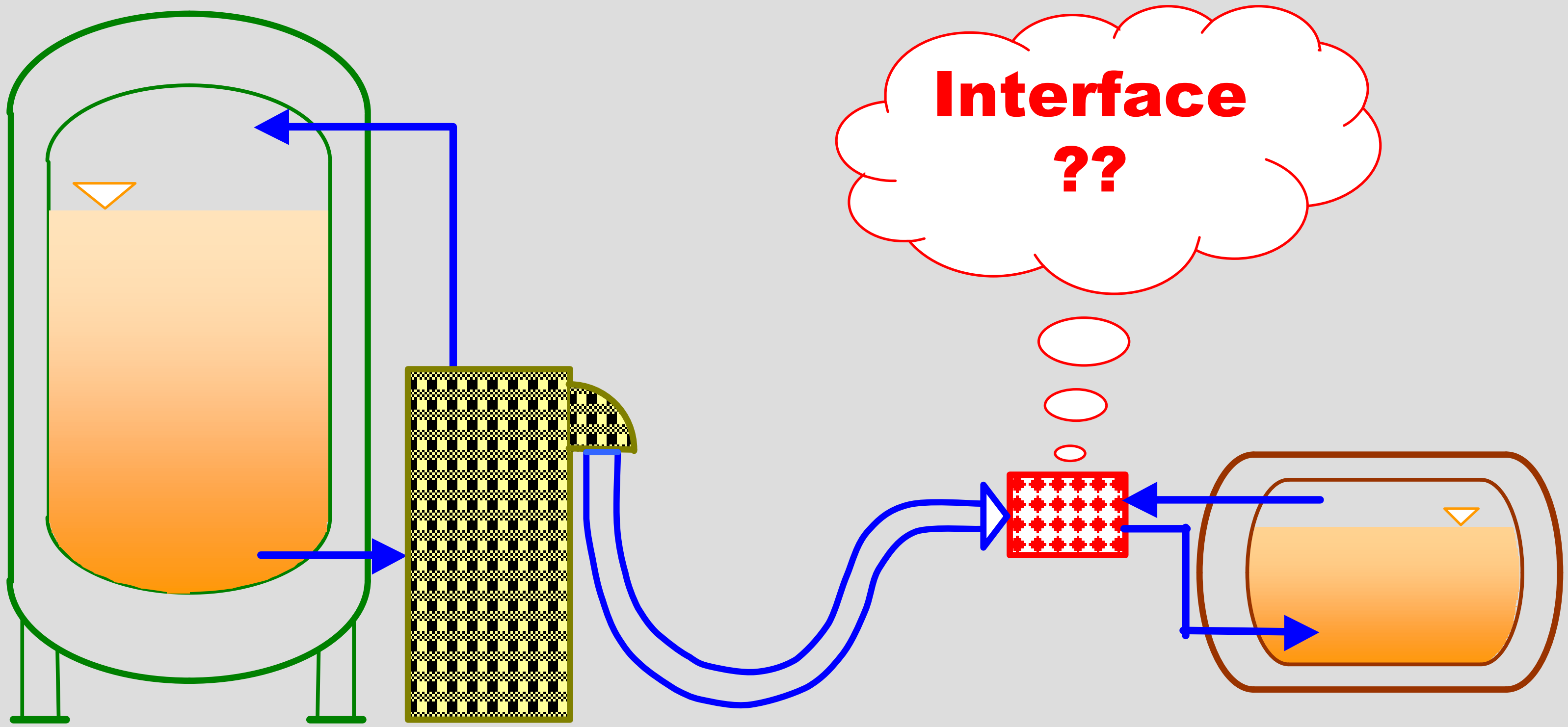


Burst Pressure: 2132 bar

Mid-Term Assessment Workshop

Brussels
02 October 2002

Presentation by
Messer Griesheim GmbH
Friedel Michel



LH2 - Refuelling Station

Vehicle Storage System

General Requirements for the Fuelling System:

1. according to EIHP1 draft (and national?) **regulations**
2. in compliance with ISO 13984 (LH2 - Land vehicle refuelling system interface) ?
3. suitable for public use
- 3.1 operation by laymen (optional: **robot operation**)
  - 3.1.1 no special service personnel required
  - 3.1.2 safe against misoperation (within reasonable limits)
- 3.2 ergonomic manual handling
- 3.3 without need of protection wear e.g. helmets, gloves, goggles, ...
  - 3.3.1 no serious cool-down at surface of coupling

4. operation under common ambient weather conditions
5. one coupling unit for all required connections:
- 5.1 filling connection for liquid hydrogen
- 5.2 gas return / depressurization connection for gaseous hydrogen, if necessary
- 5.3 vehicle grounding
- 5.4 electrical interface ?

6. receptacle suitable for vehicle integration (compact design)

Influence of low temperature (-253°C):

Every kind of non-insulated coupling such as usual ones for high pressure would produce problems, e.g.:

- skin freezing on cold surface
- O_2-liquifaction / increased flammability
- ice production on interface
- leakage / damage
- heat transfer to LH_2 / increased evaporation losses

Only solutions with high-grade insulation are allowed!

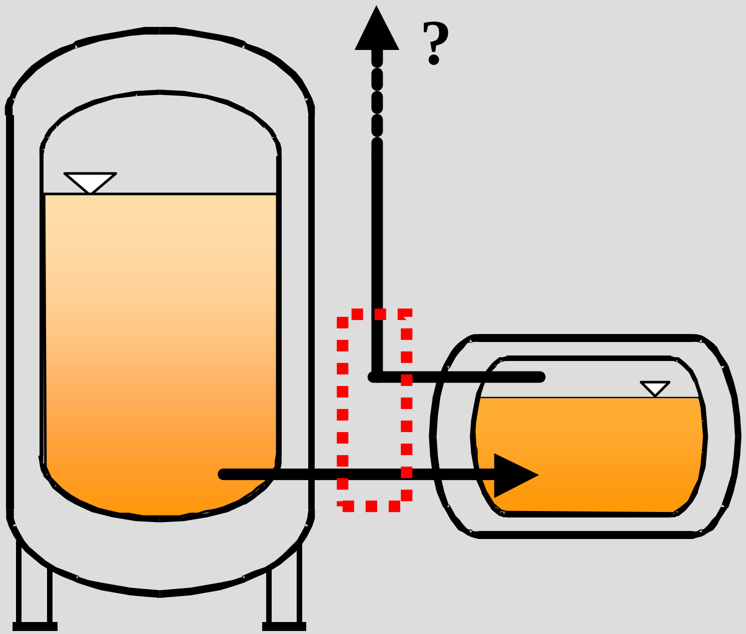
--> More complex design as for warm gas

Influence of fuelling principle:

A Differential pressure system

- flow is produced by lower vehicle system pressure
- gaseous hydrogen develops by evaporation (about 10% lost)
- return of GH2 requires a two-flow system

--> more complex interface
--> more expensive at vehicle side

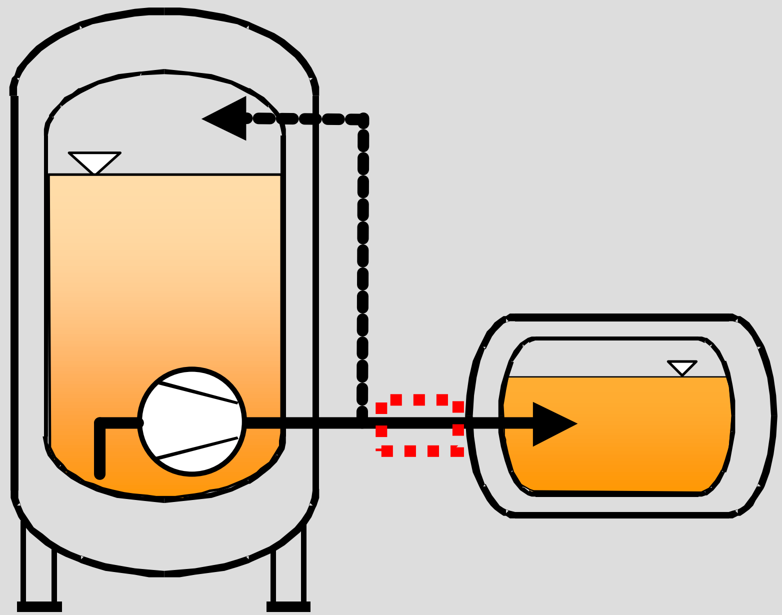


Influence of fuelling principle:

B Pressure raising system

- flow is produced by a pump system
- subcooled liquid causes condensation / pressure decrease
- no gas losses
- one-flow system is sufficient

--> more complex fuelling station
--> less expensive at vehicle side

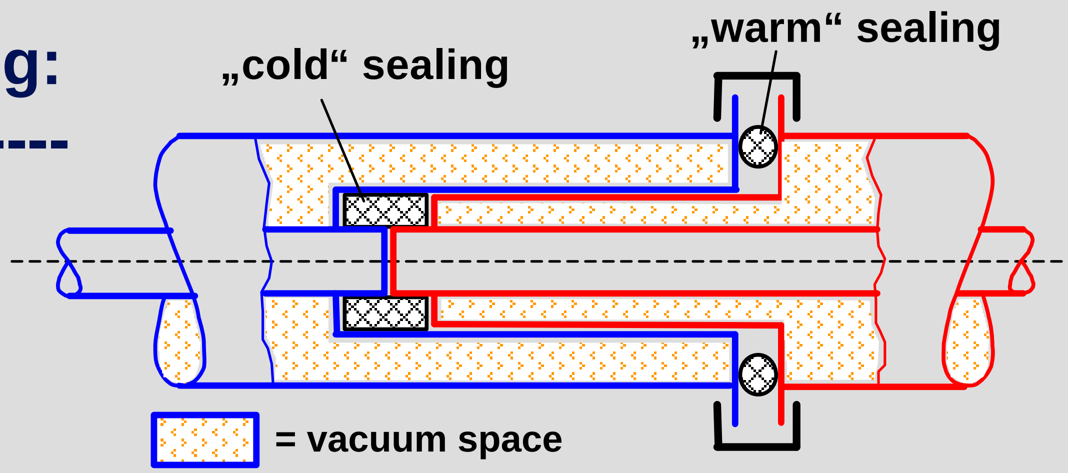


Johnston-Cox Cryo Coupling:

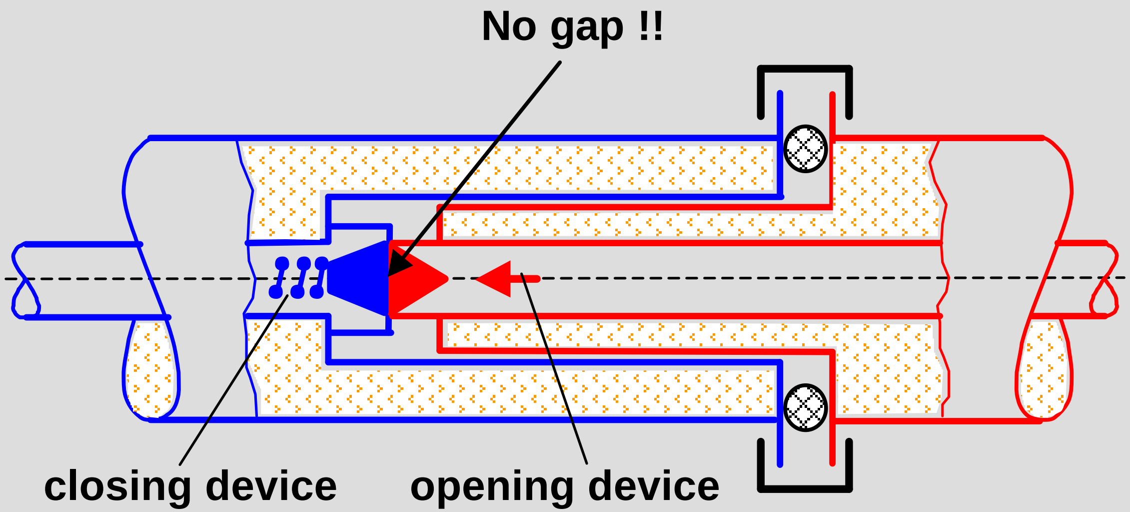
+ simple compact system
+ cheap
+ easy to handle

- purging after connection
- purging / warm-up before disconnection
- danger of contamination
- long duration of fuelling process
- 2 connections if continuous GH2 return is required

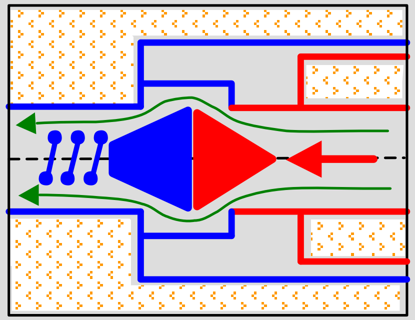
® mainly for long term connections



Principle of Clean Break Coupling



Coupling connected, inner valves of nozzle and receptacle still closed



Inner valves open, fuelling process active

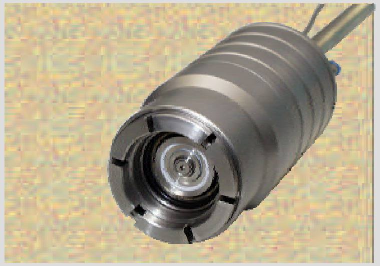
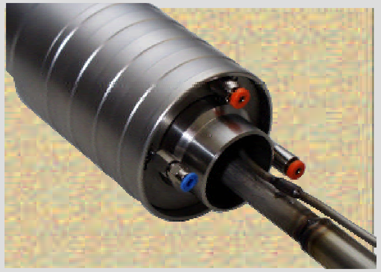
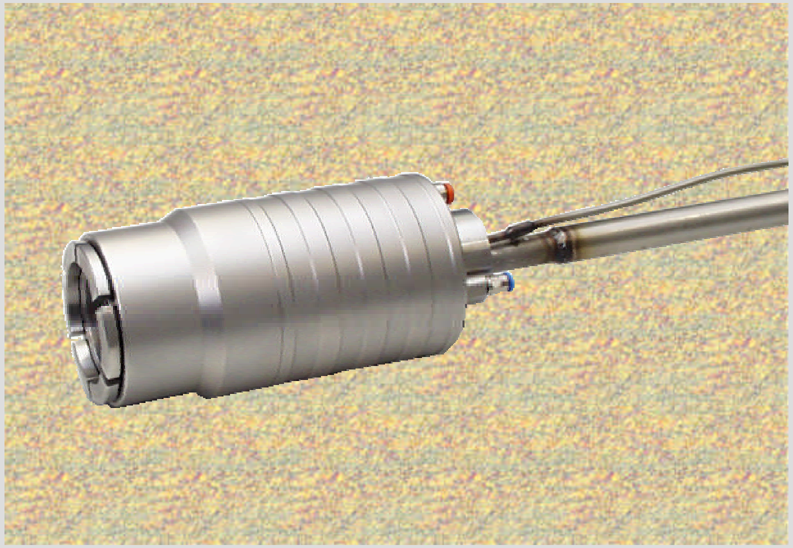
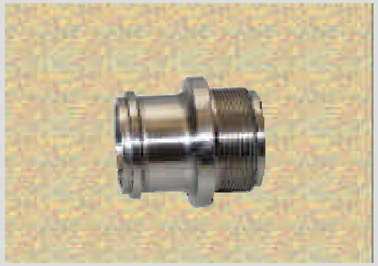
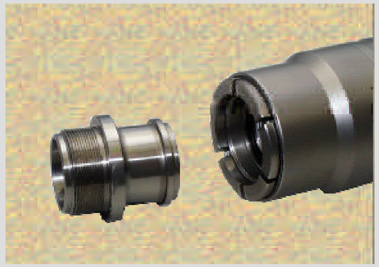
Clean Break Coupling Messer:

+ compact system
+ easy and quick handling
+ safety lock with double sealing system
+ no purging / warm-up (no trapped air)
+ fast fuelling process
+ no danger of contamination
+ fuelling process automat. controlled
+ cheap and small receptacle (vehicle side part)

® suitable one-flow system and manual operation

Messer coupling for manual operation

WEH GmbH
GAS Technology

Automatic connection and operation of inner valves

Fully automated filling process

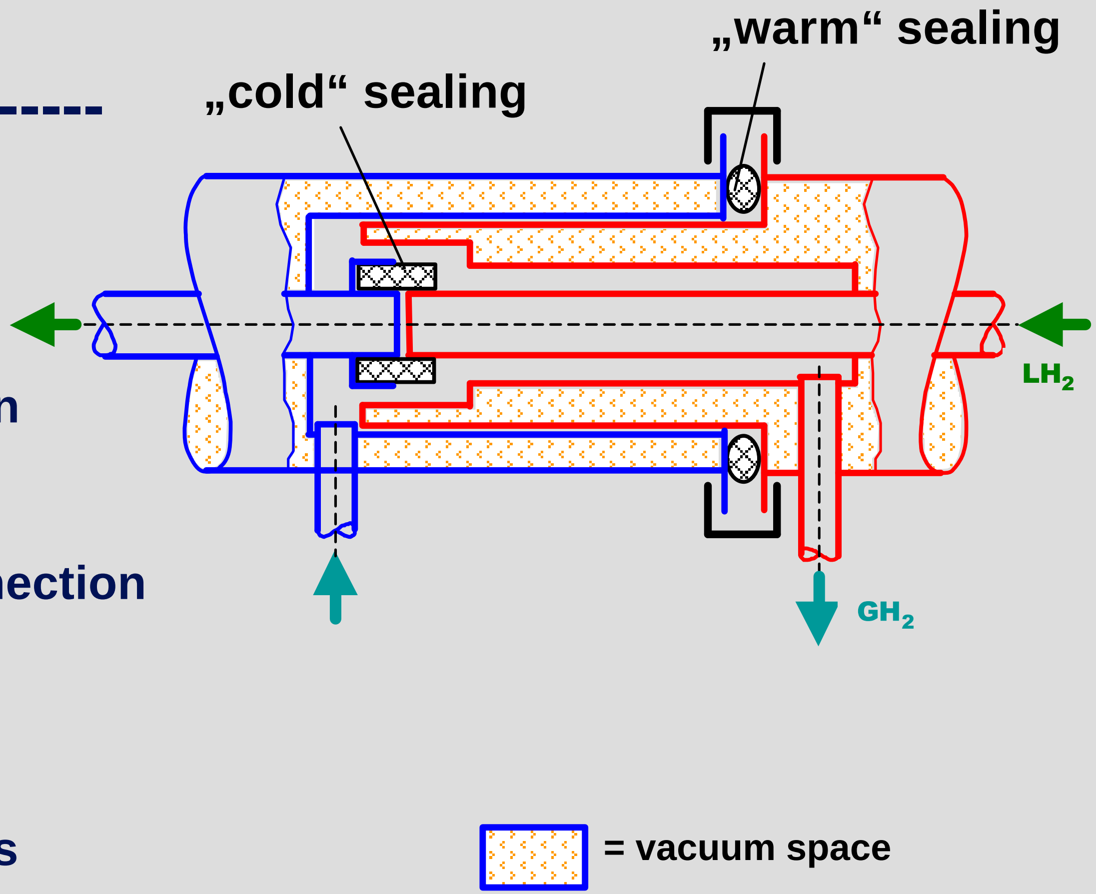
Safe and easy handling

Two-Flow Cryo Coupling:

+ simple system
+ cheap
+ easy to handle
+ second connection for GH2 return

- purging after connection
- purging / warm-up before disconnection
- danger of contamination
- long duration of fuelling process

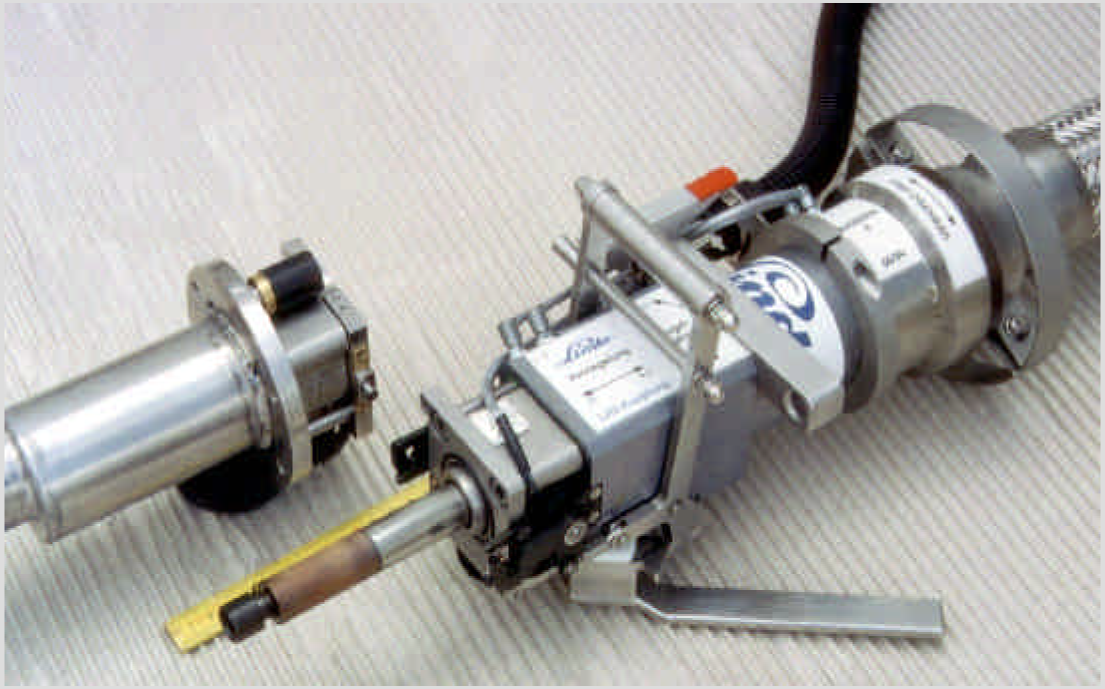
® mainly for long term connections



Two-Flow Cryo Coupling for manual operation - Linde AG -

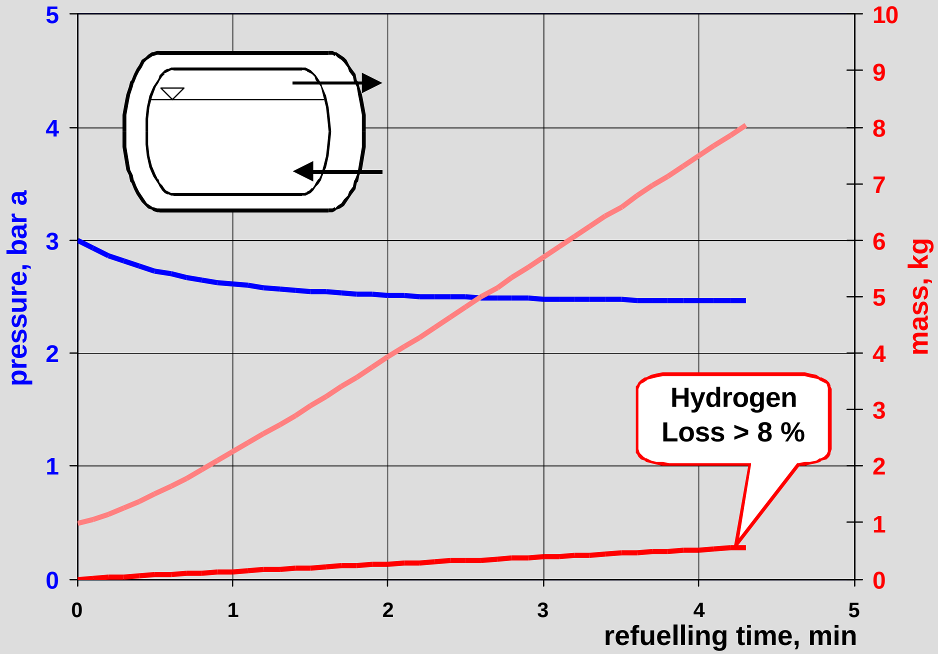
----

* ball-valves at nozzle and receptacle
* no outer cold parts
* gap to be purged after connection with Helium before cold finger is moved into nozzle

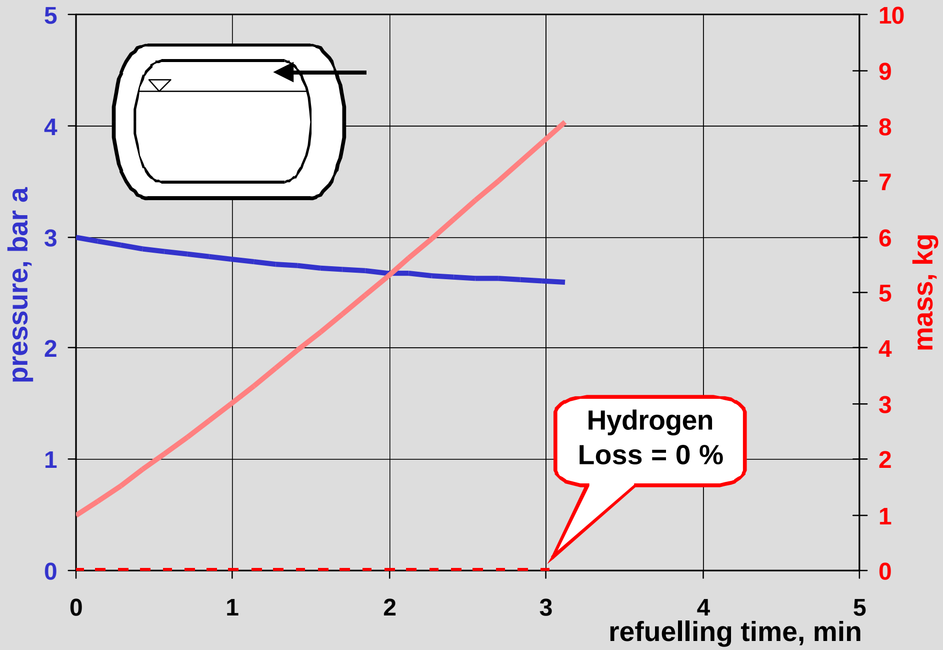


Refuelling of a Liquid Hydrogen Storage Tank (140 l)

Differential Pressure Refuelling (Two Flow)
Storage tank: 3 bara, saturation pressure = 2.8 bara

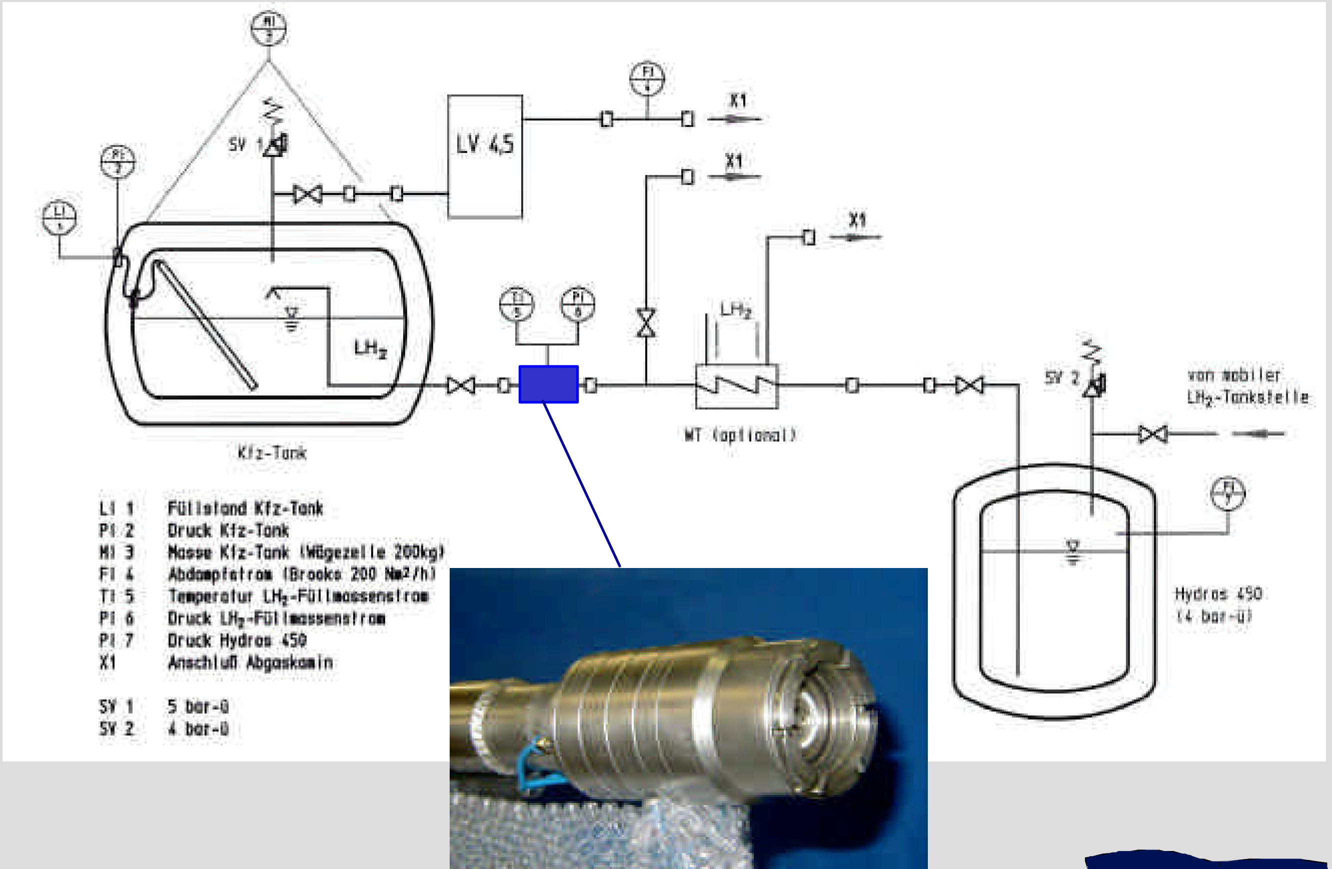


Refuelling with integrated Pump
Storage Tank: 1.5 bara (=Saturation), Pump: 3.5 bara



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



Résumé for WP 3.3:

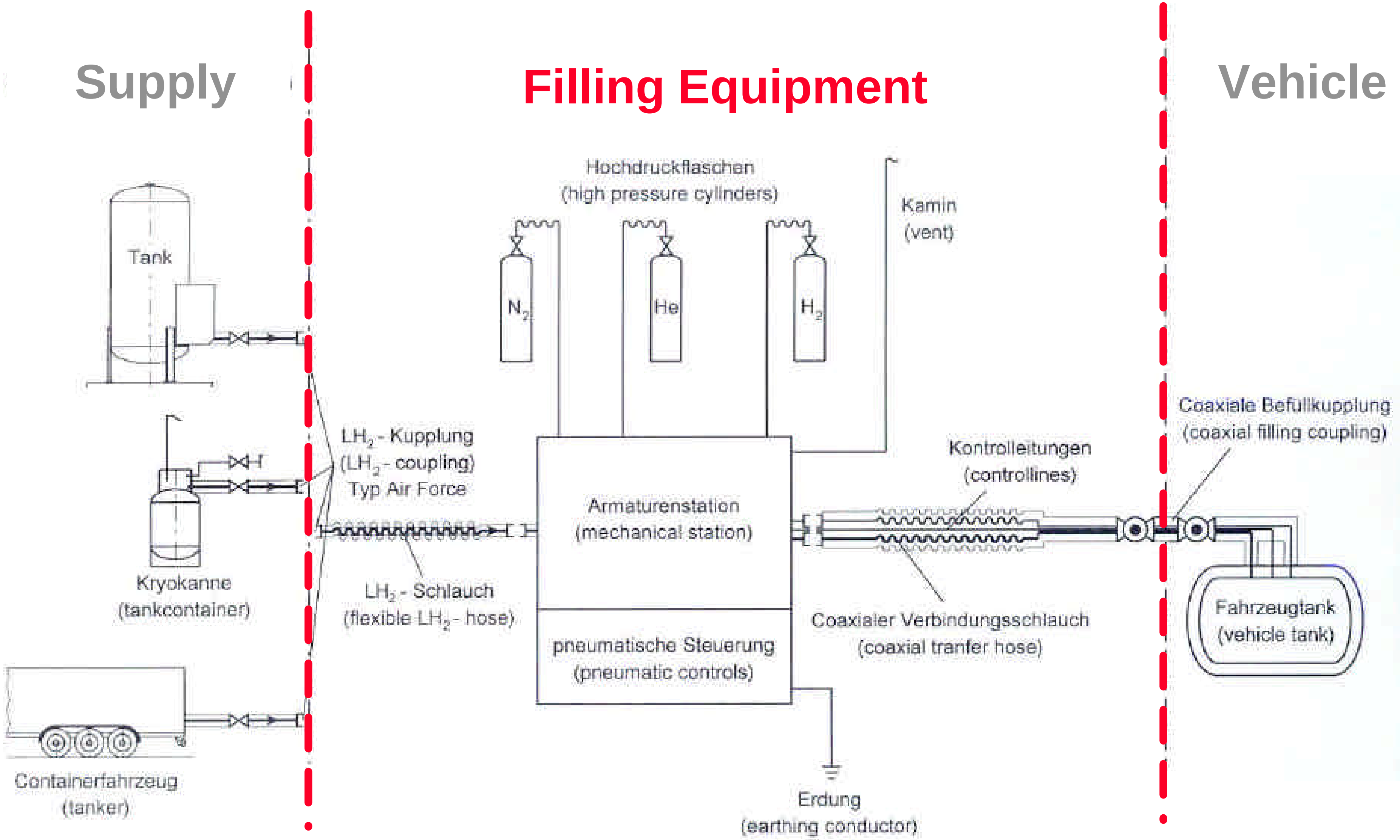
- LH2 interface essentially depends on the fuelling principle
- need of further development for fuelling stations
- to early for final standardisation of hardware / receptacle
- recommendations for standardisation at the present should concentrate on general requirements / fuelling procedures

Elements of Liquid & High Pressure Filling Stations

Mid-Term Assessment Workshop EIHP II, Brussles, 02 October 2002

Hydrogen as Alternative Fuel

general - Supply, Filling, Storage -



Hydrogen as Alternative Fuel

filling stations - NECAR 4, Rally Clermont-Paris, September 2000 -

Hydrogen as Alternative Fuel

filling stations - the ROBOT application -

Hydrogen as Alternative Fuel

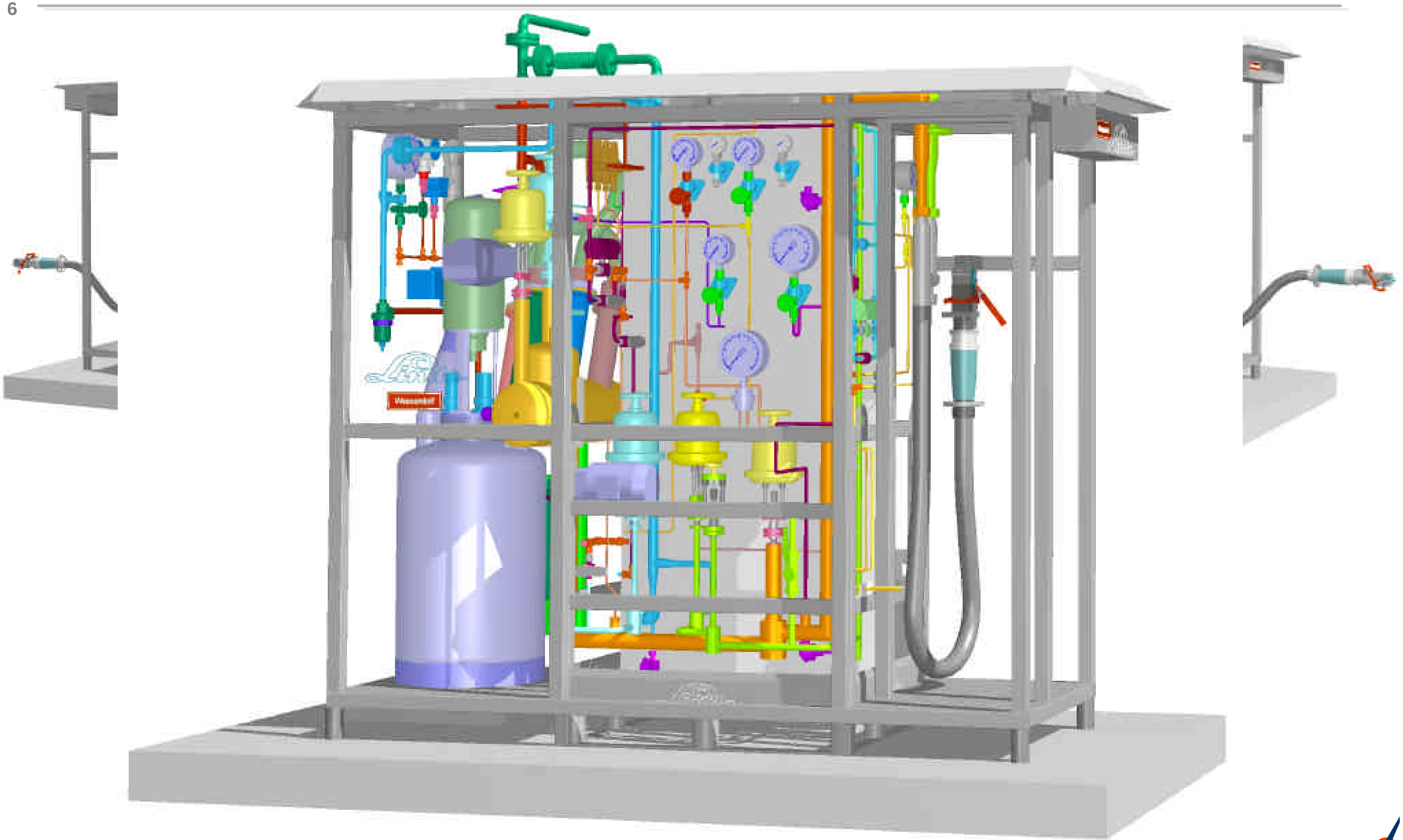
filling stations - manual operated LH_2 fuel station, Hannover 2000 -

The manual fuel station …

… and the filling process.

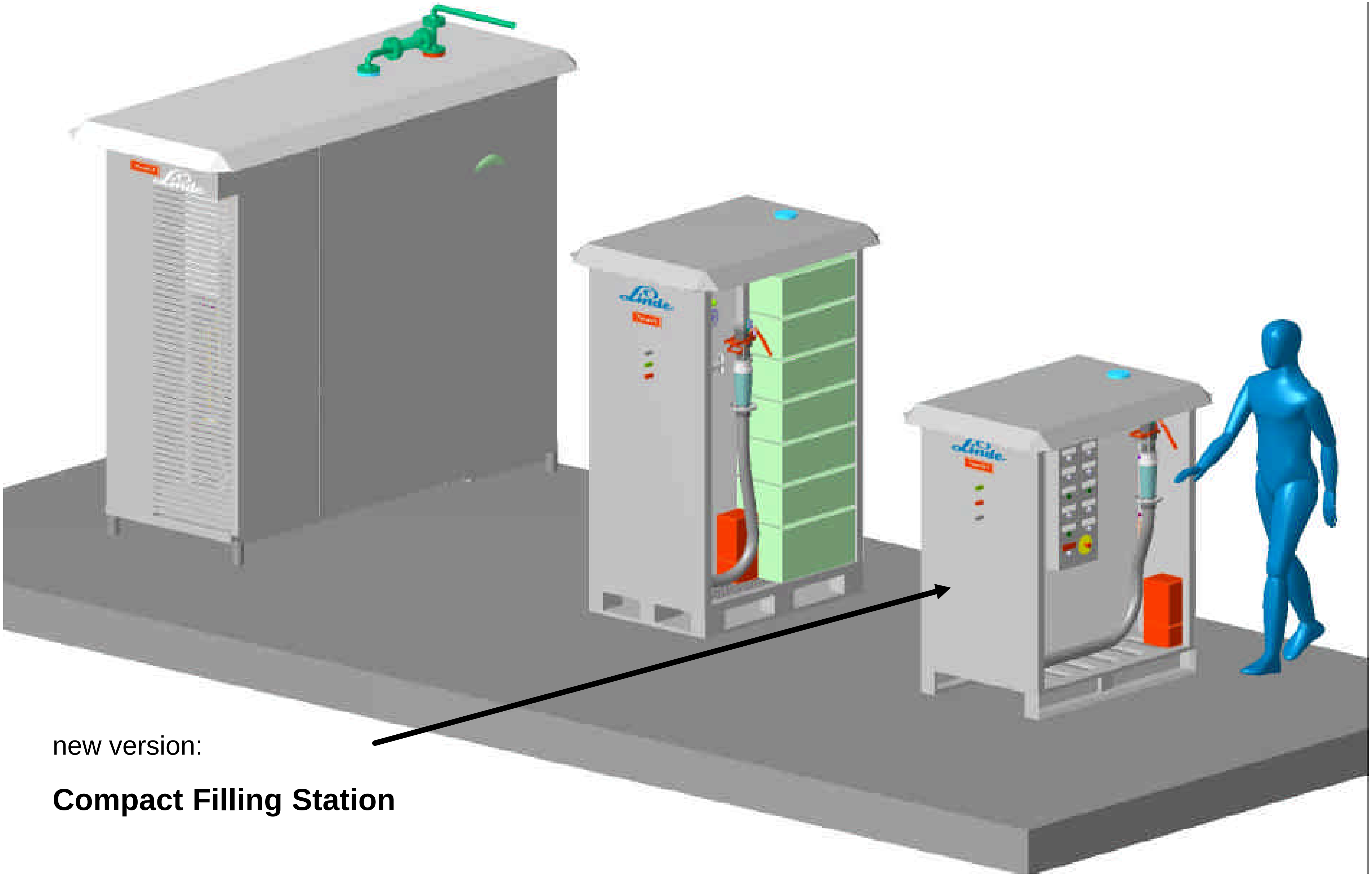
Hydrogen as Alternative Fuel

filling stations - manual operated LH_2 fuel station, Berlin 2001/02 -



Hydrogen as Alternative Fuel

filling stations - manual operated LH_2 ***compact*** fuel station, 2002 -

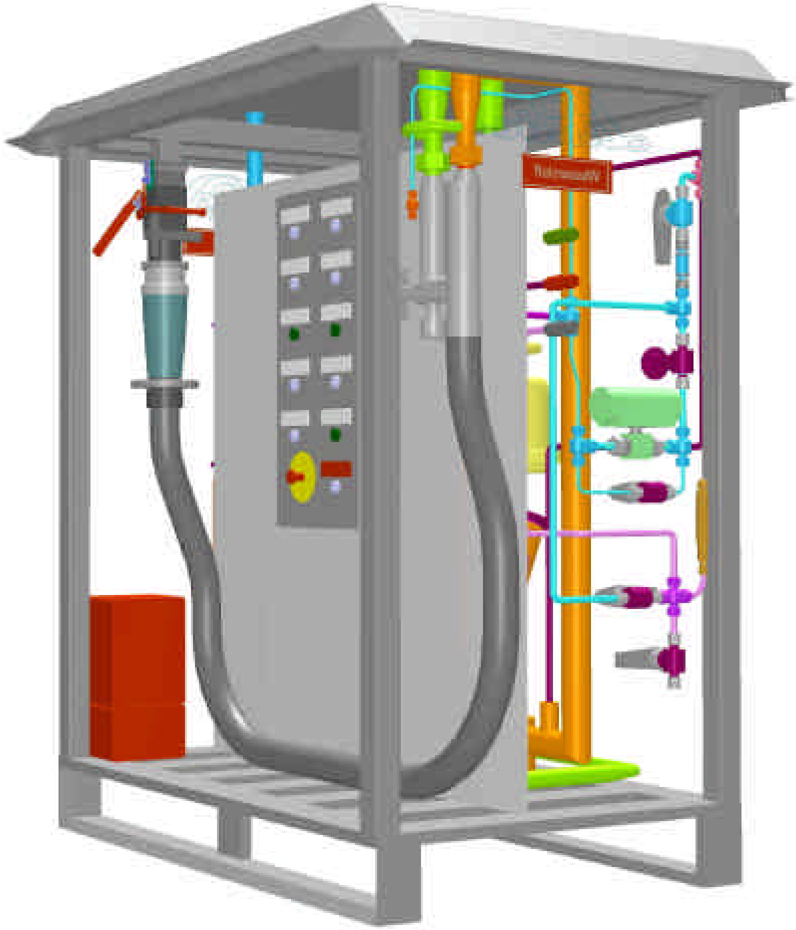


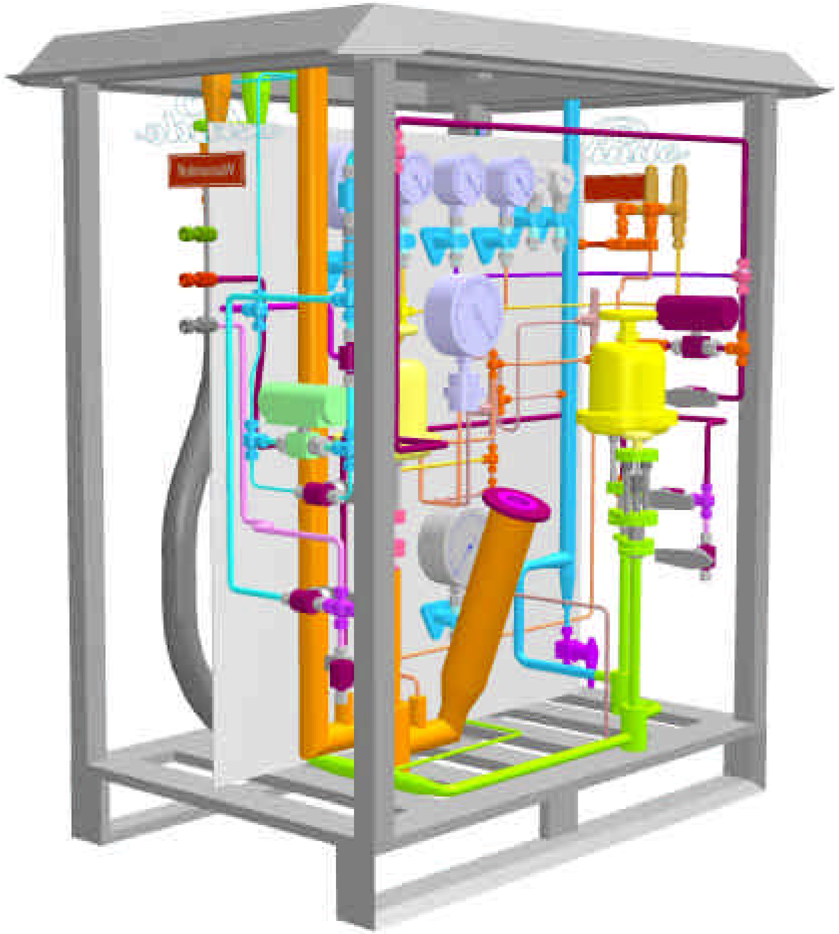
new version:

Compact Filling Station

Hydrogen as Alternative Fuel

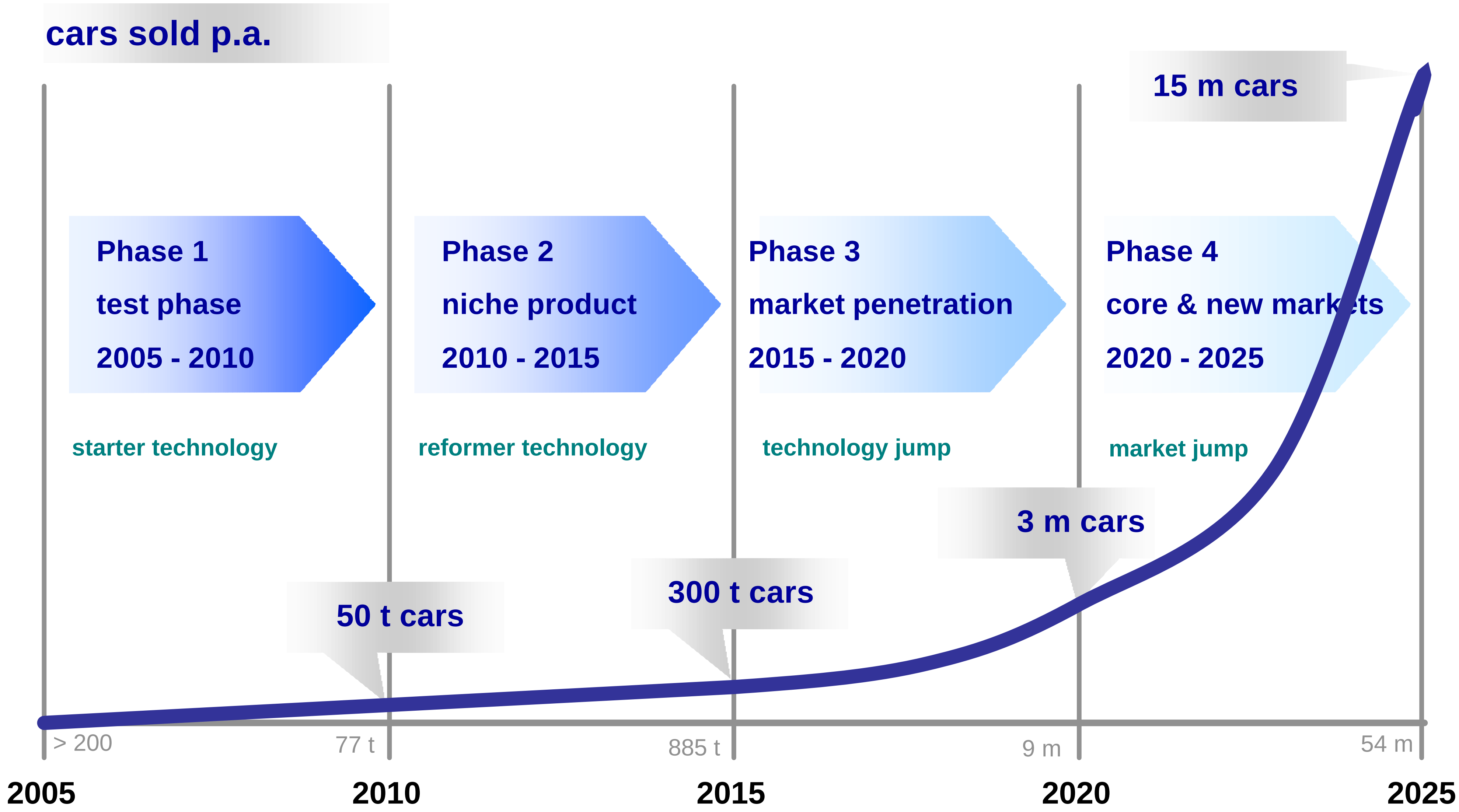
filling stations - manual operated LH_2 ***compact*** fuel station, 2002 -





Hydrogen as Alternative Fuel

outlook - growth scenario for hydrogen fuelled cars -



Source: FH Gelsenkirchen

competitive

The ***costs of the energy carrier hydrogen*** must be comparable to the costs of conventional fuels.

The ***costs of a hydrogen infrastructure*** must be comparable to the invest costs of conventional infrastructure.

compact & capable of being integrated

Hydrogen fillings station must be
capable of being integrated into existing common fuel stations.

That means a hydrogen filling station ***must be compact*** and must be operable ***without additional professional personnel.***

universal

A hydrogen filling station must be universal. That means the hydrogen filling station must be able to deliver ***pressurised hydrogen*** (**CGH_2**) <u>*and*</u> ***liquefied hydrogen*** (**LH_2**).

flexible

A hydrogen filling station must be ***flexibly reactive*** with respect to ***long-term trends*** as well as to ***daily fluctuations*** of the hydrogen consumption.

compatible

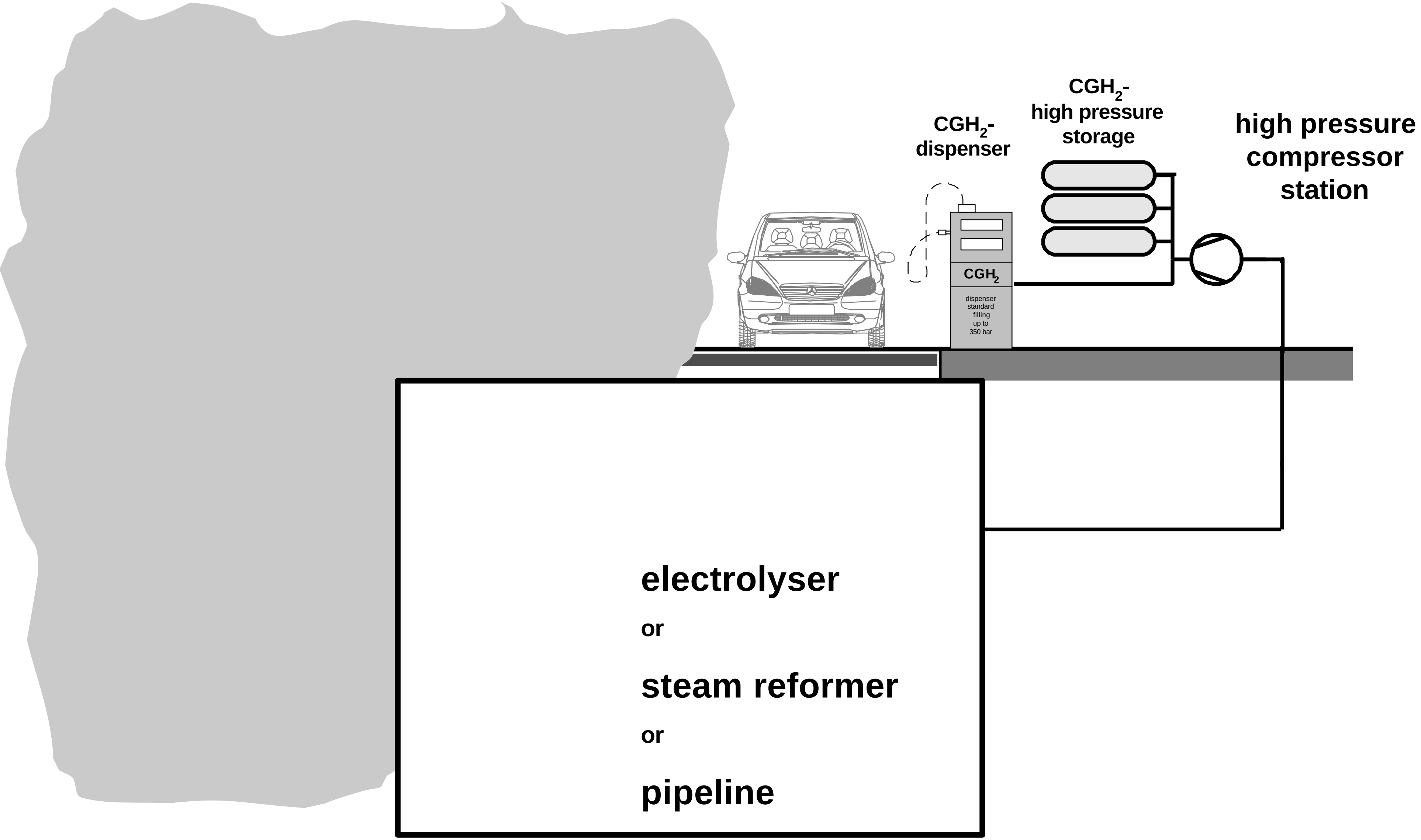
The logistic for hydrogen filling stations
must fit to the concept of the gasoline companies.

forward-looking

The initial overall concept must ensure a direct and cost saving
transfer from fossil to regeneratively generated hydrogen.

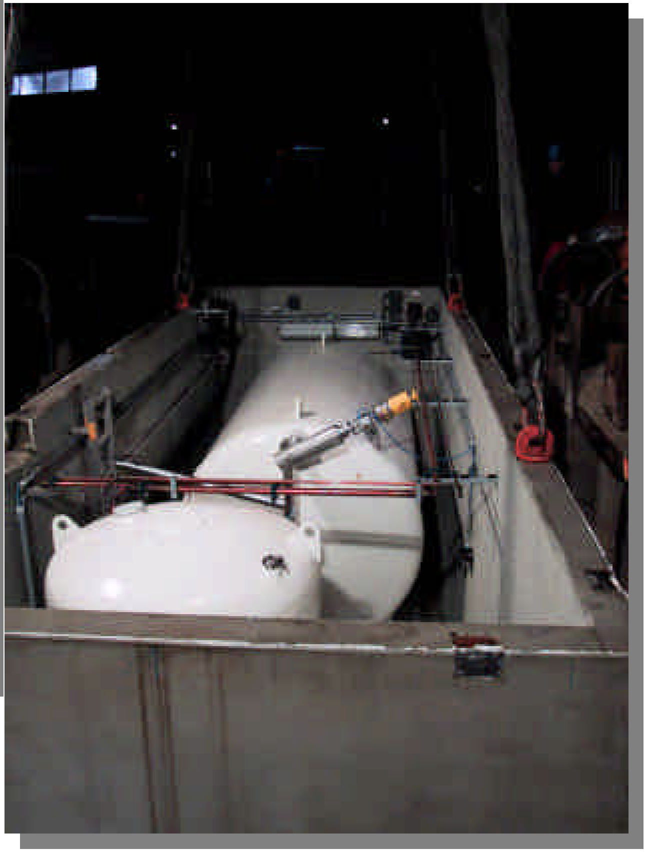
Hydrogen as Alternative Fuel

filling stations - universal cryogenic fuel station, principle scheme -



Hydrogen as Alternative Fuel

filling stations - universal cryogenic fuel station during erection -

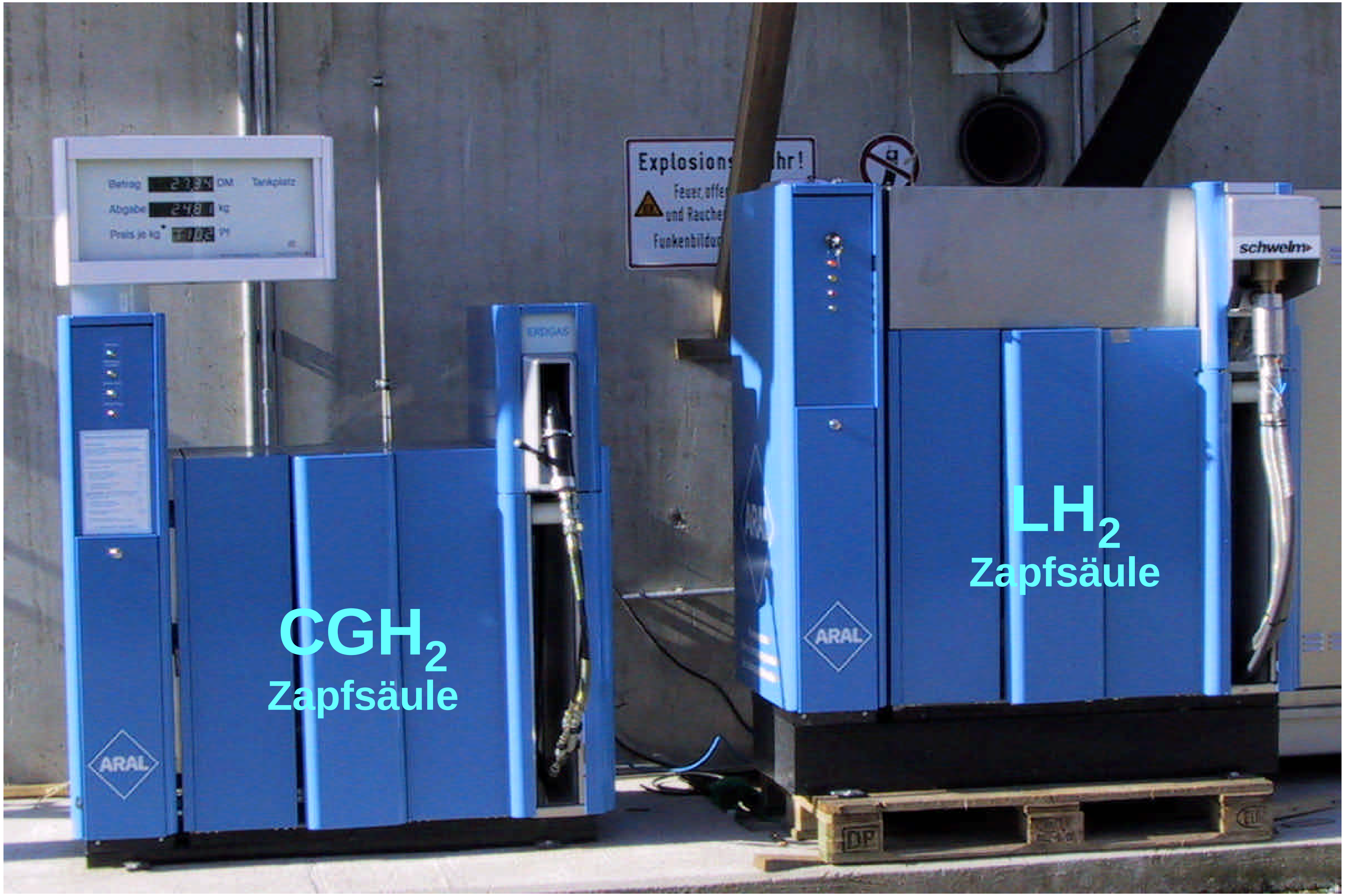


Hydrogen as Alternative Fuel

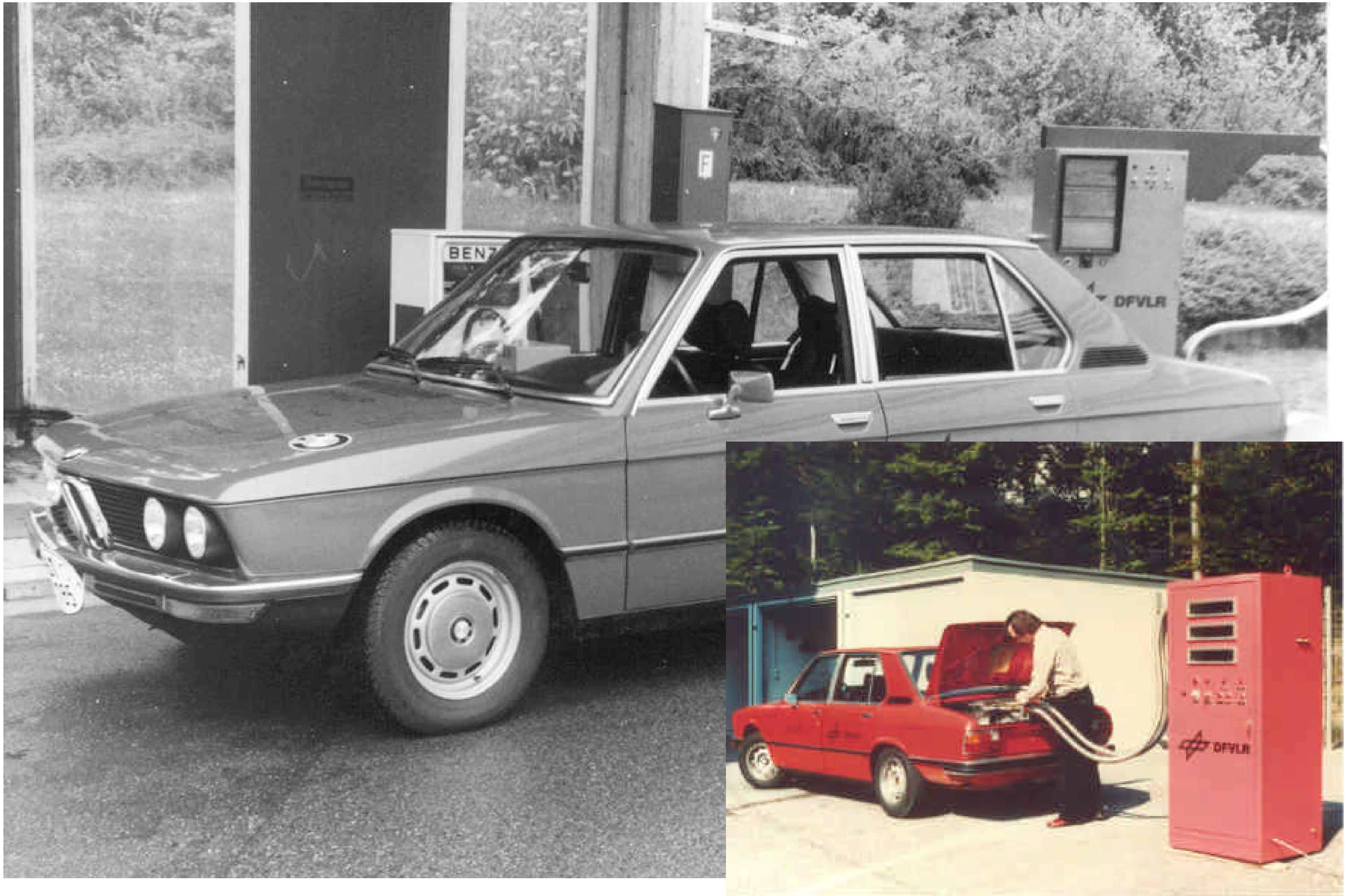
filling stations - universal cryogenic fuel station during erection -

Hydrogen as Alternative Fuel

filling stations - comparison of dispensers -



Hydrogen as Alternative Fuel
coupling - history -

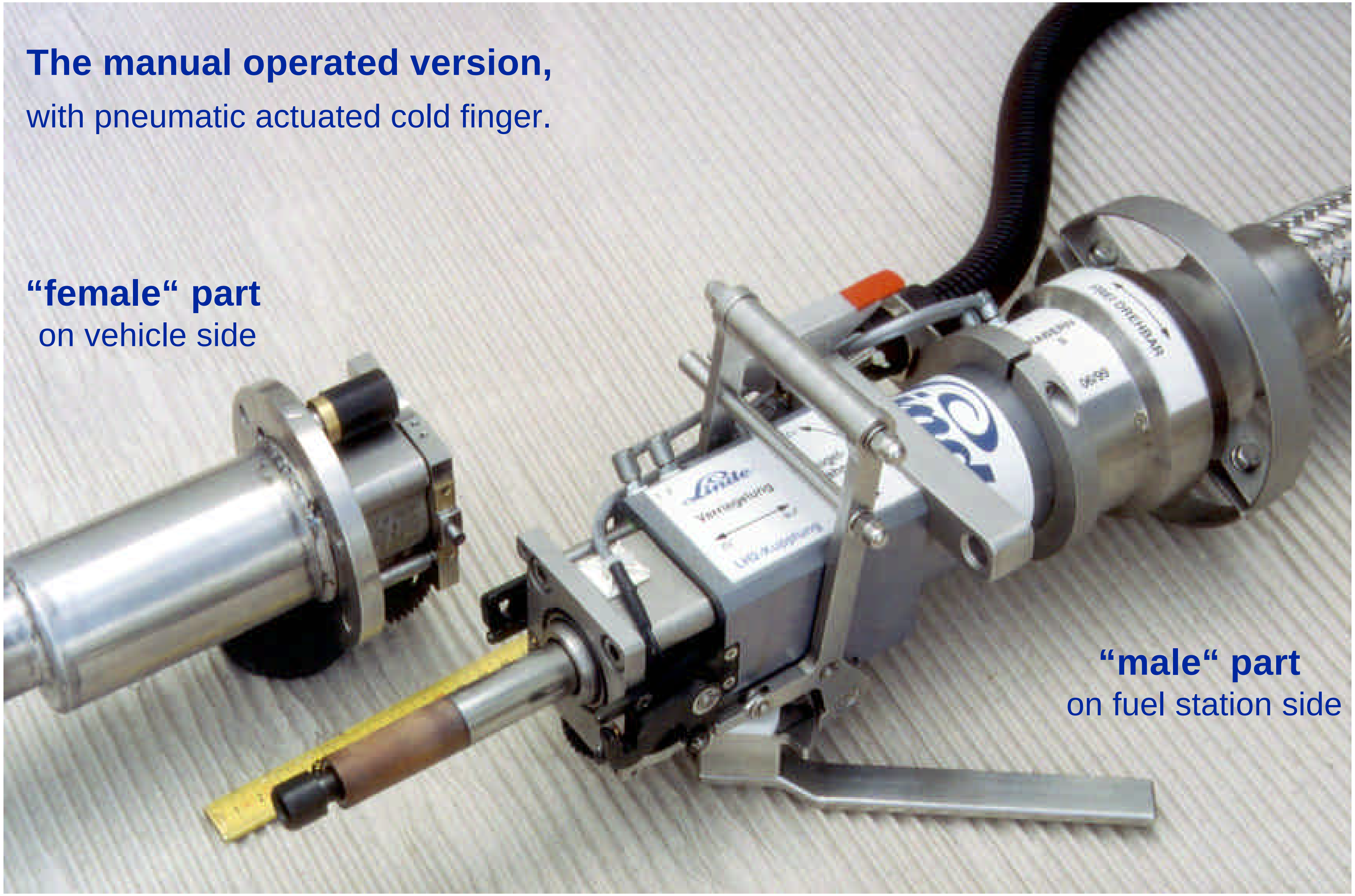


Hydrogen as Alternative Fuel

LINDE coupling - the existing generation -

The manual operated version,

with pneumatic actuated cold finger.



Hydrogen as Alternative Fuel

LINDE coupling - the manual operated version -

The coupling in operation ...

... after docking ...

... and during filling/refilling of a car.

main features of the proposed concept:

- **based on experienced hardware**
  (more than 4.000 filling sequences)
- **self locking**
- **fully automated filling process**
- **no visible moving parts**
- **lightweight & automotive dimensions**
- **reliable connecting and locking mechanism**
- **safe and easy handling**
- **first functional tests successfully performed**

Hydrogen as Alternative Fuel

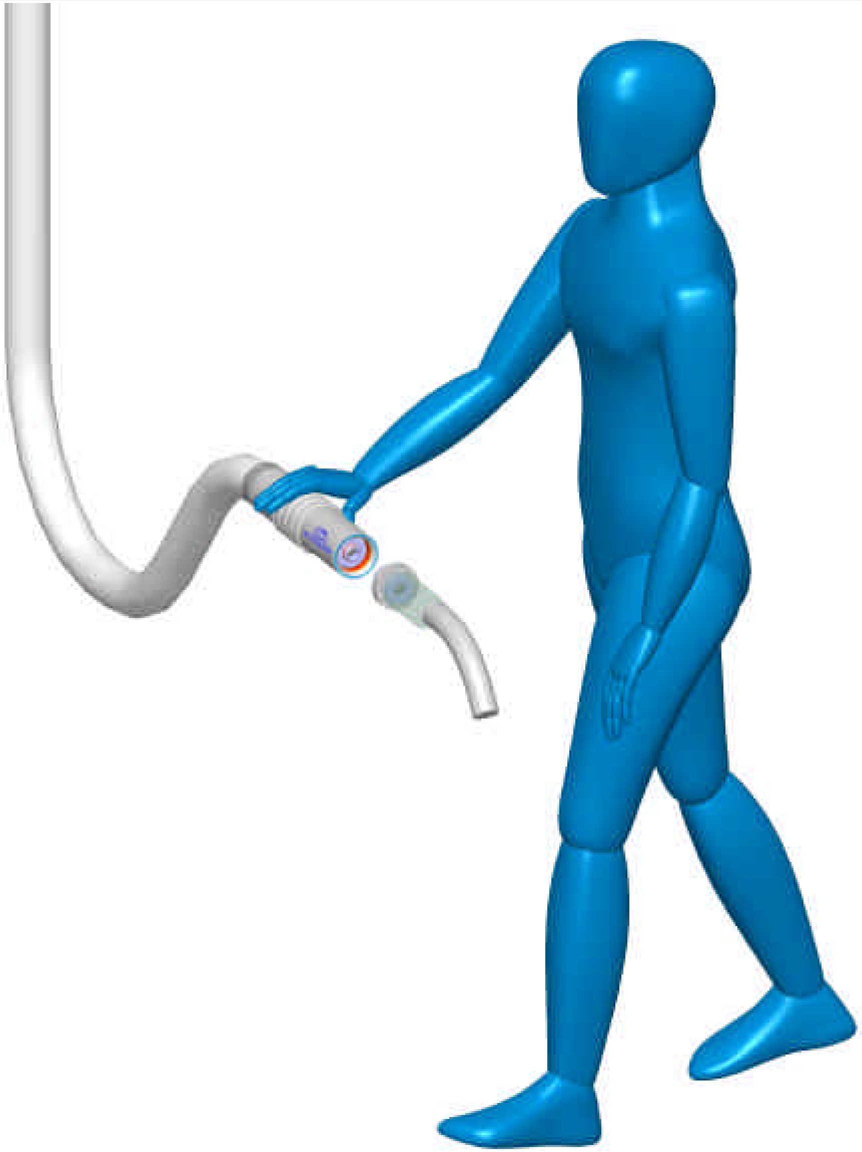
LH_2 coupling - new development of an automotive LH_2 coupling -

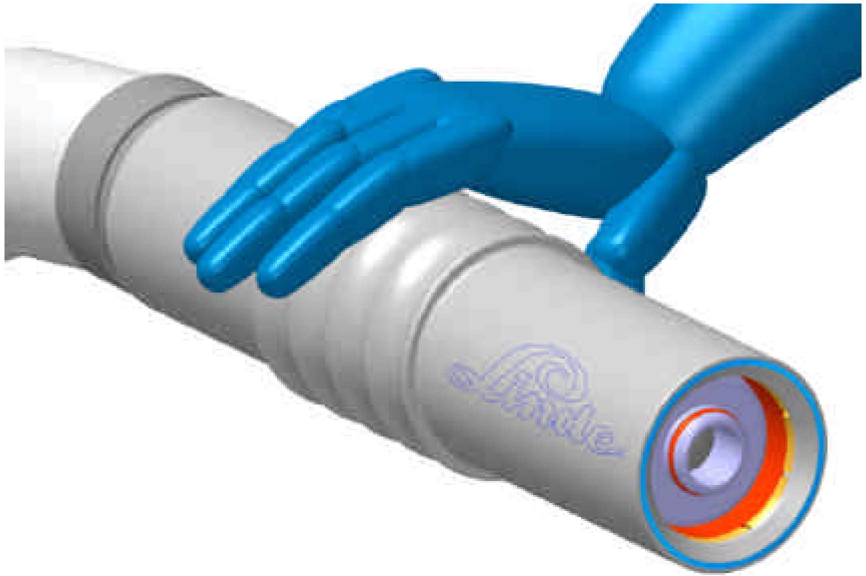
The existing manual version ...

... the future automotive version.

Hydrogen as Alternative Fuel

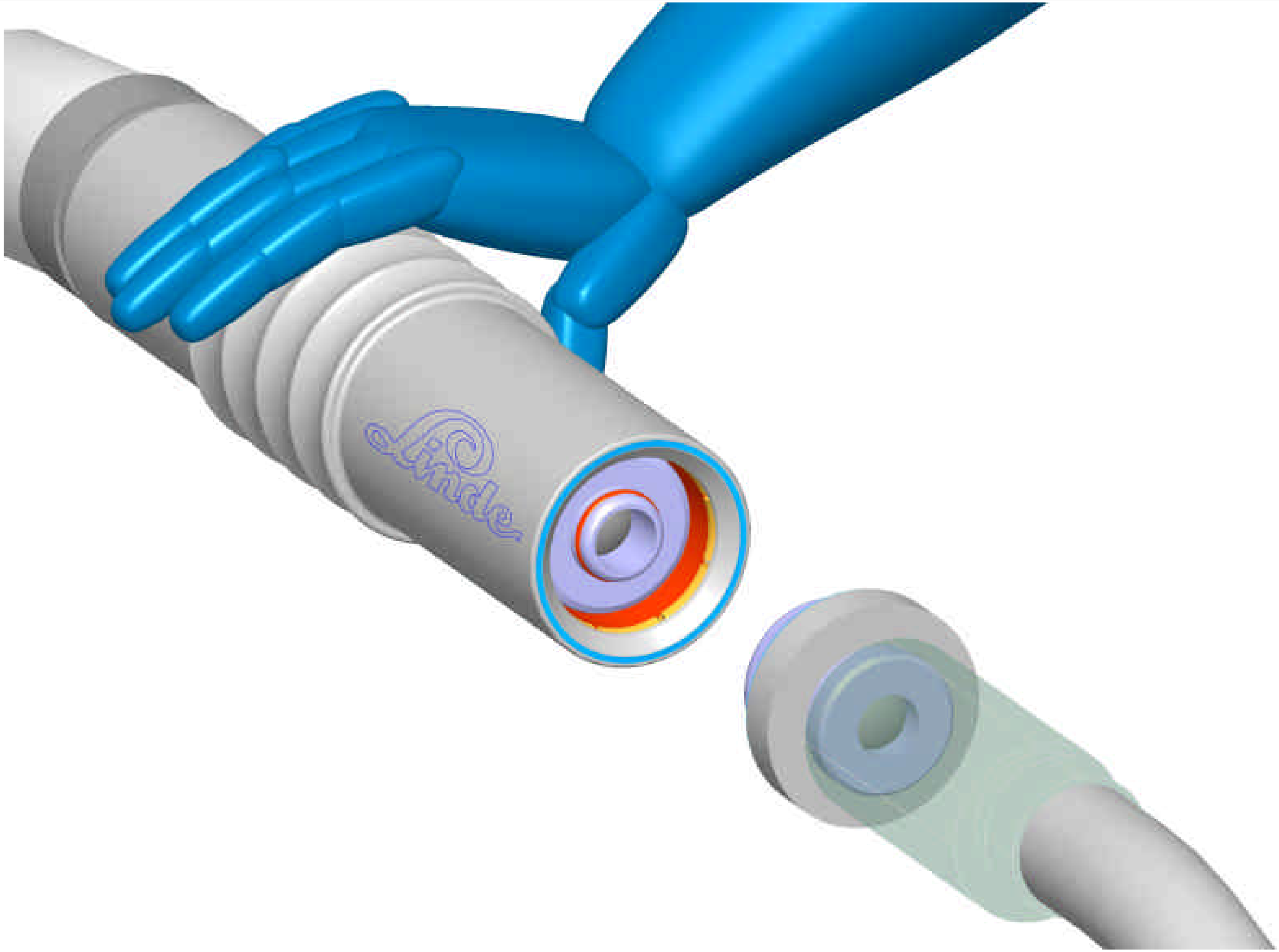
LH_2 coupling - new development of an automotive LH_2 coupling -





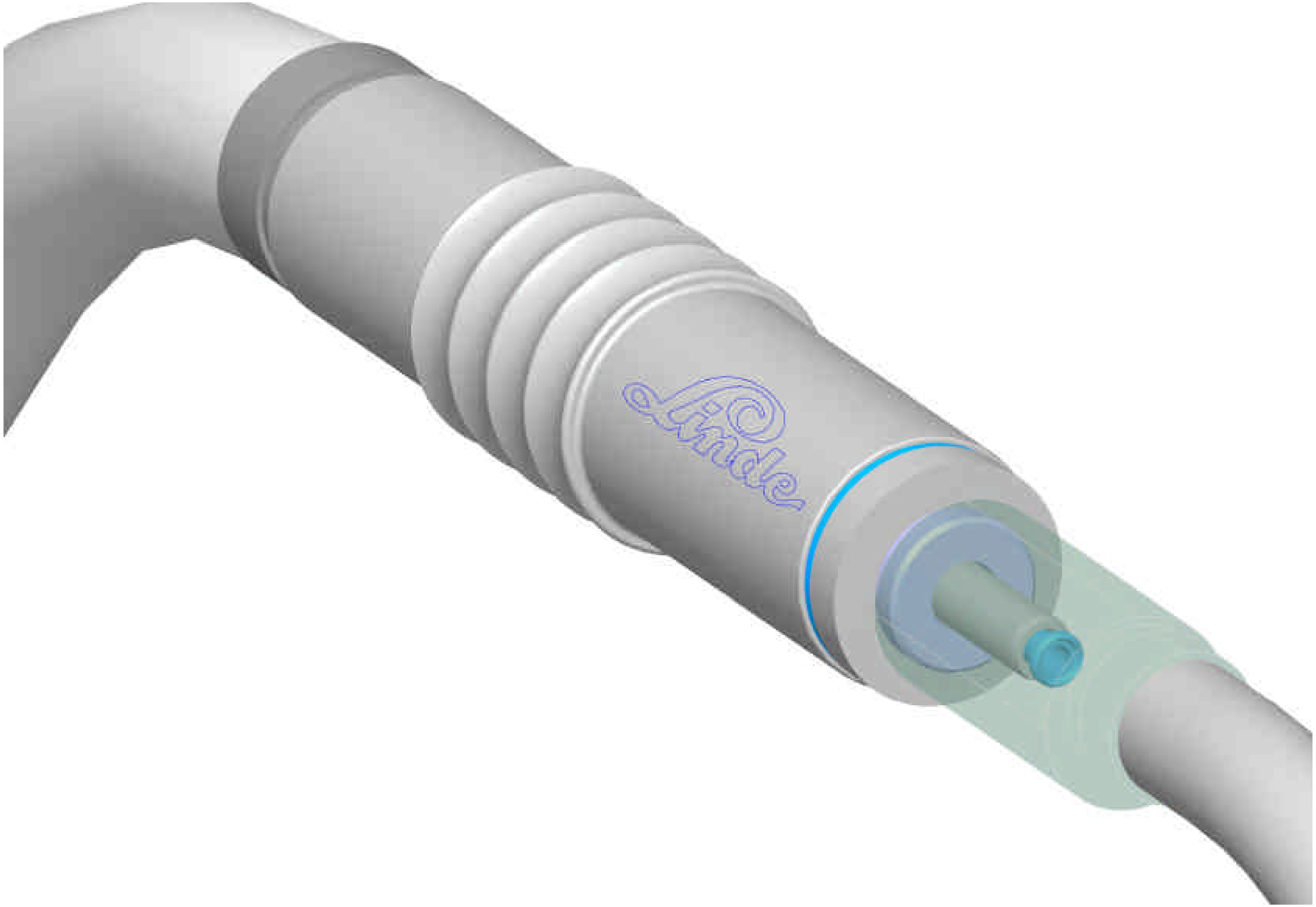
Hydrogen as Alternative Fuel

LINDE coupling - the manual operated version -



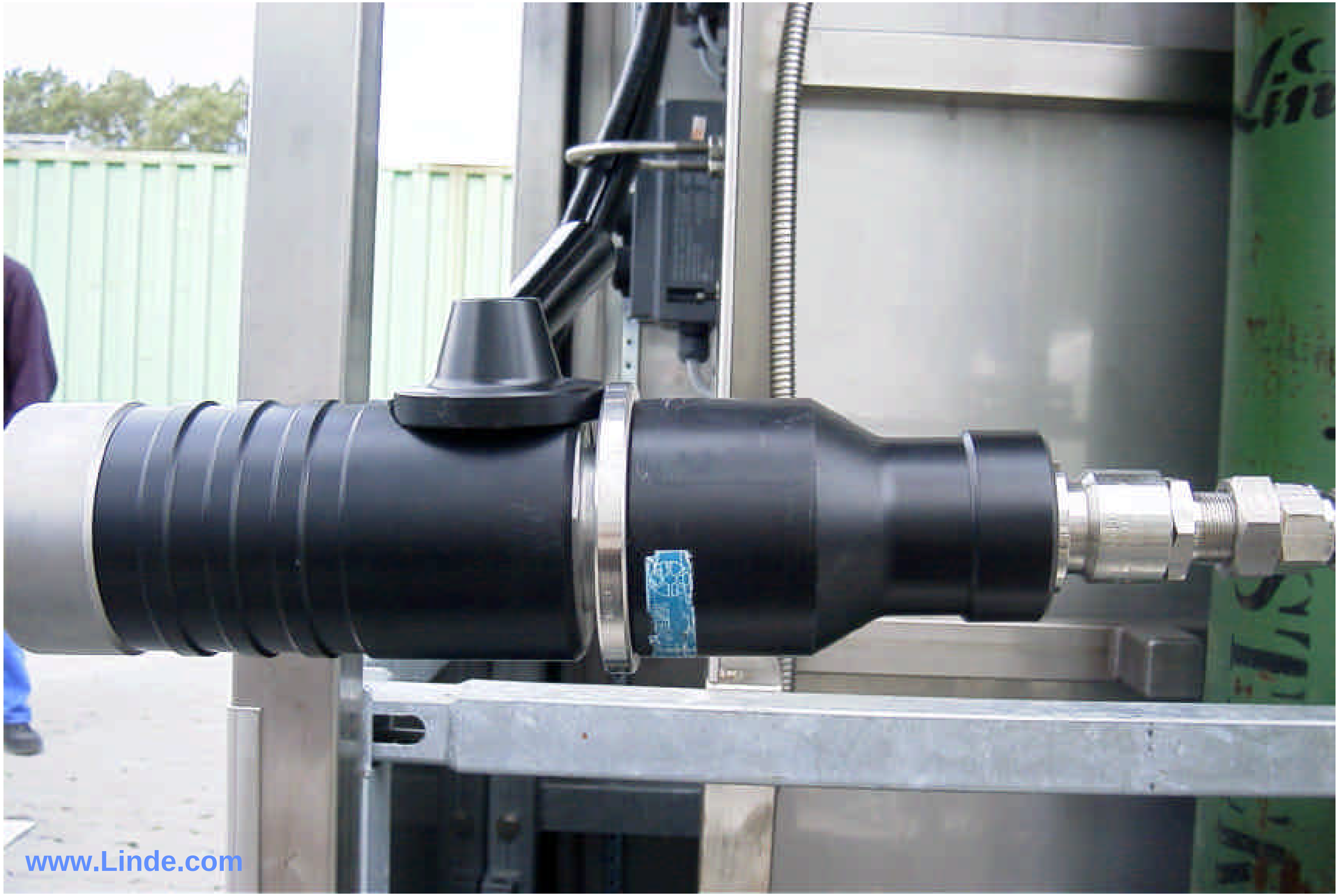
Hydrogen as Alternative Fuel

LINDE coupling - the manual operated version -



Hydrogen as Alternative Fuel

CGH_2 coupling - a typical coupling in WEH design -



Hydrogen as Alternative Fuel

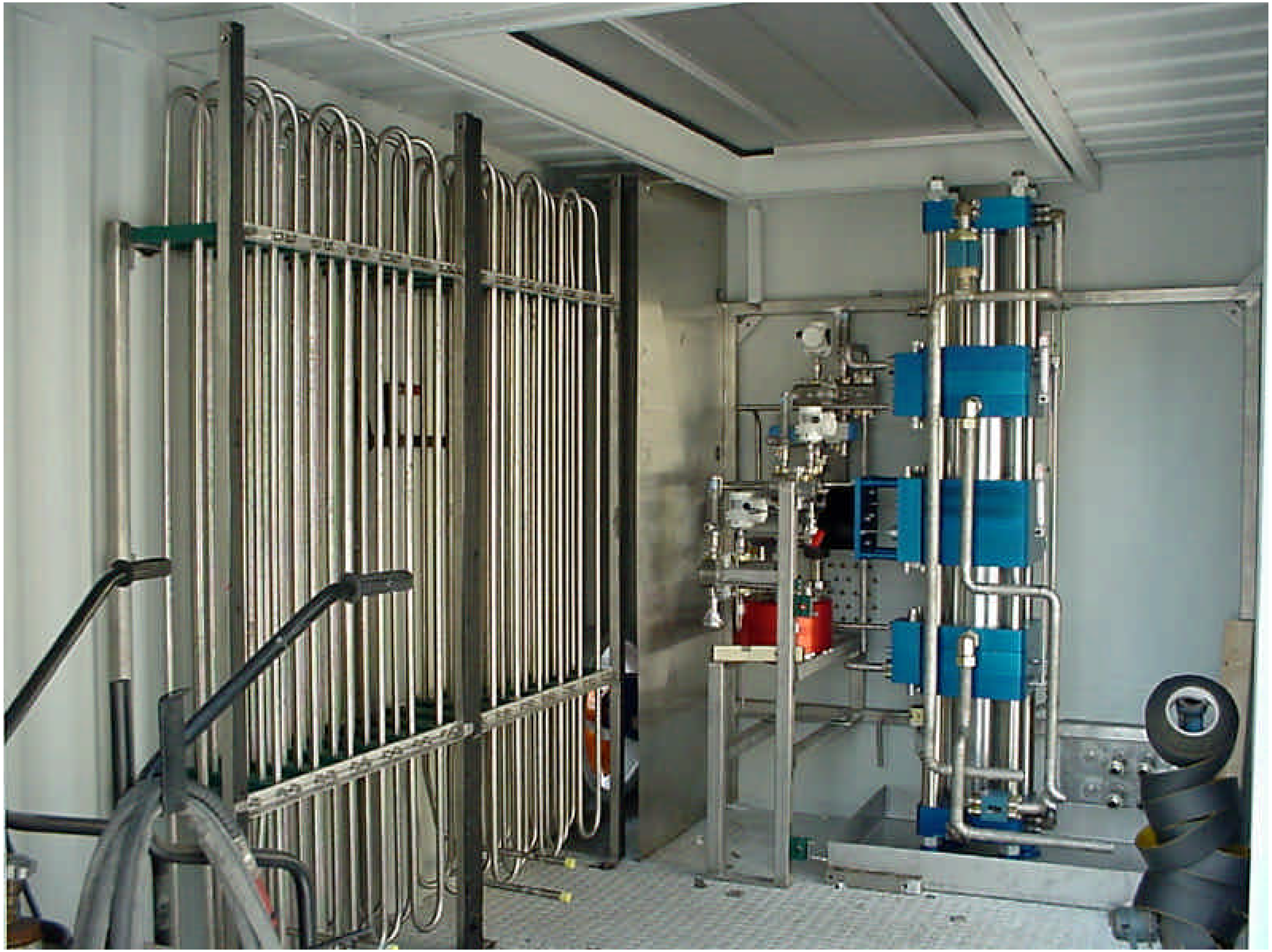
CGH_2 filling station - FC-bus with CGH_2 storage / filling process, MAN 2000 -

Hydrogen as Alternative Fuel

filling stations - CNG fuel station -

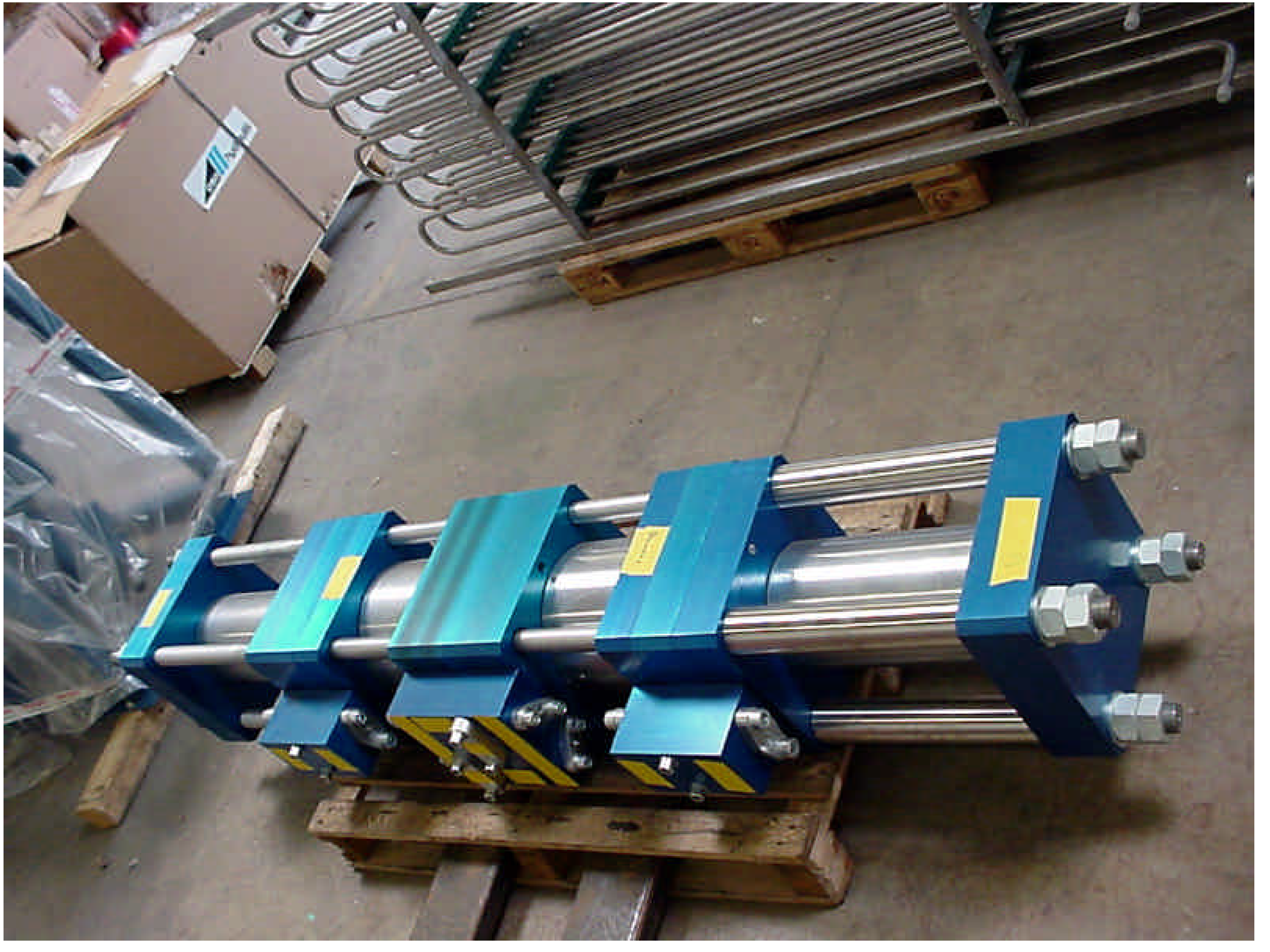
Hydrogen as Alternative Fuel

filling stations - CGH_2 filling station -



Hydrogen as Alternative Fuel

filling stations - CGH_2 filling station -

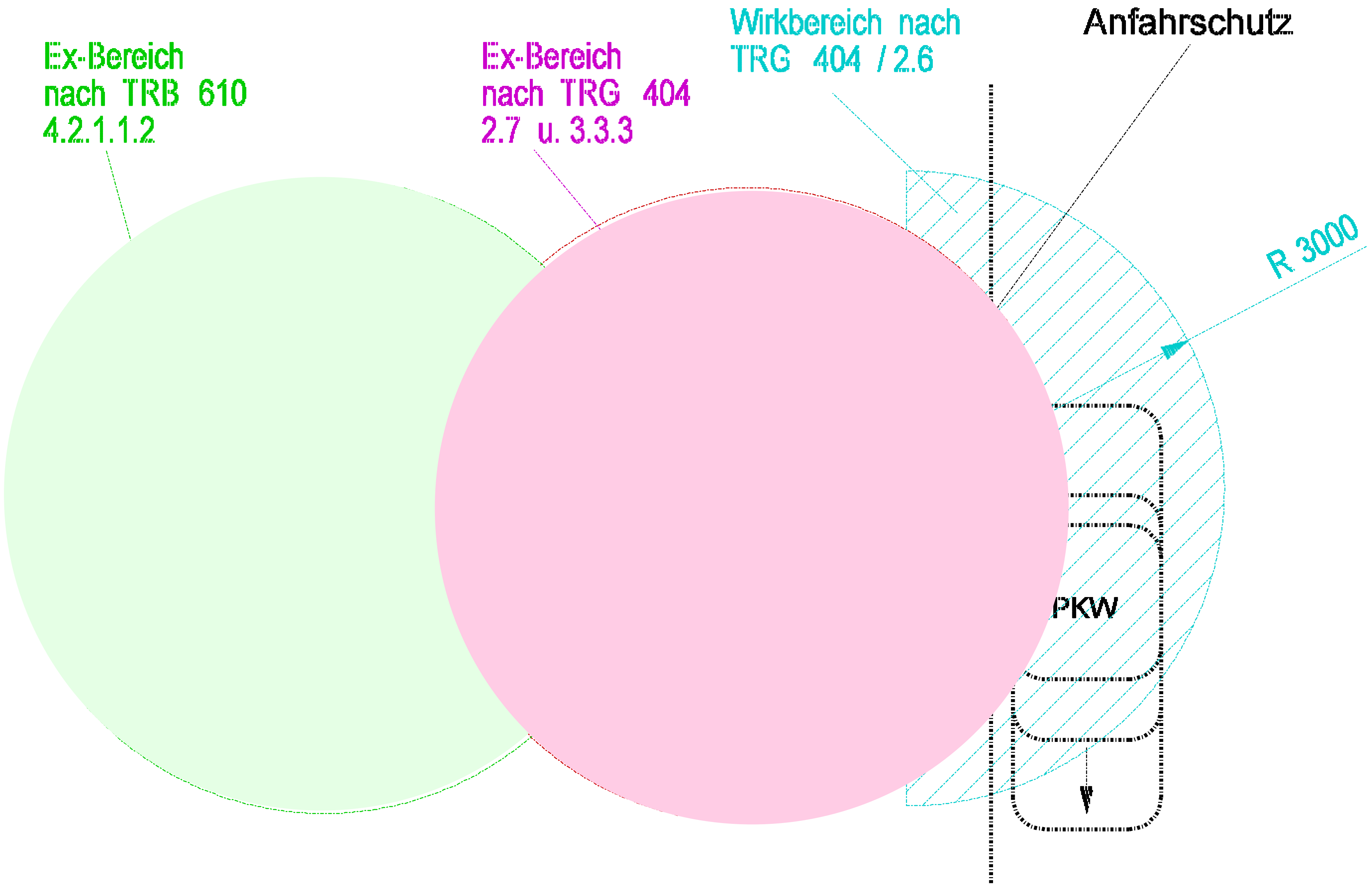


Hydrogen as Alternative Fuel

filling stations - CGH_2 filling station -

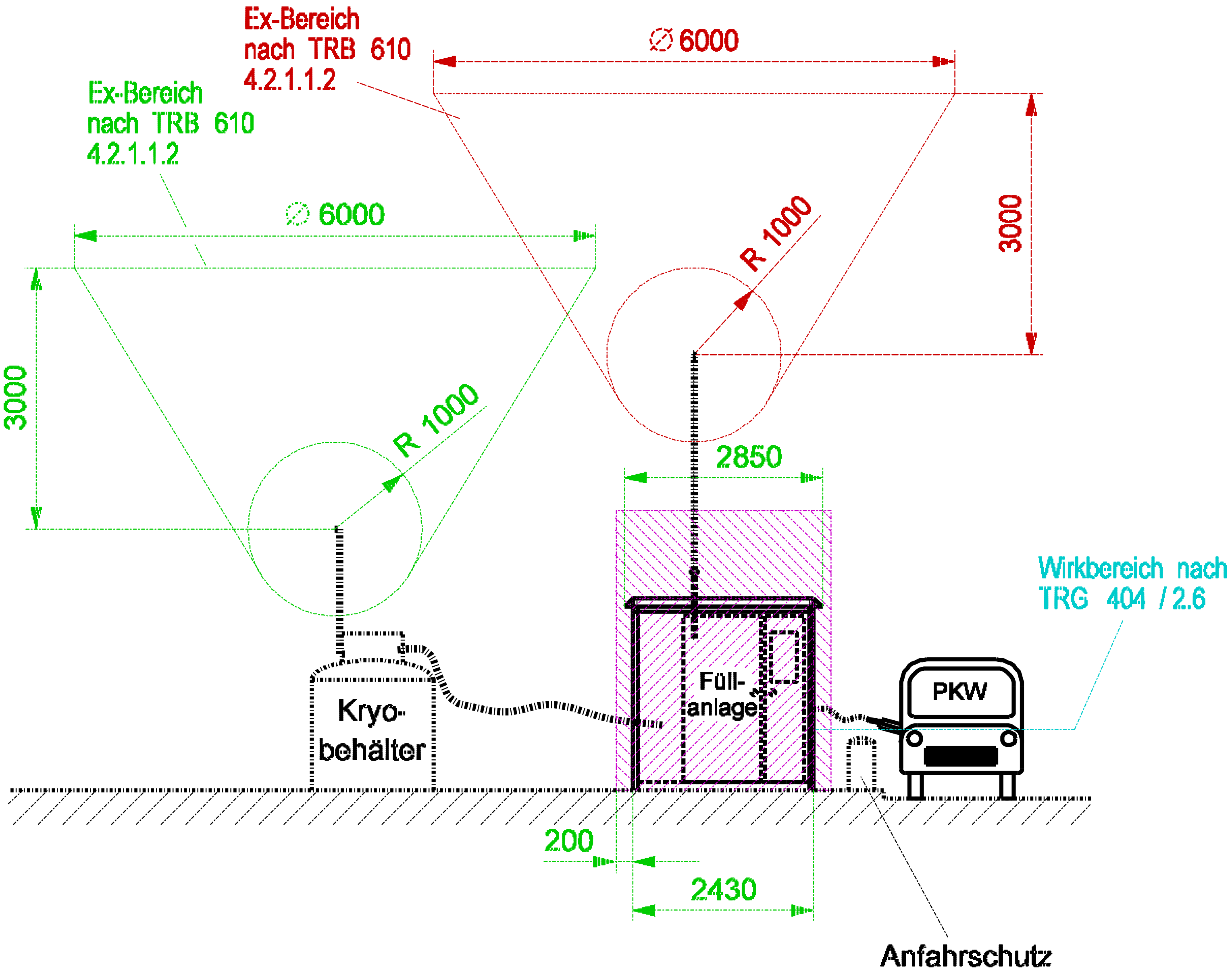
Hydrogen as Alternative Fuel

filling stations - safety areas (***top view***) -



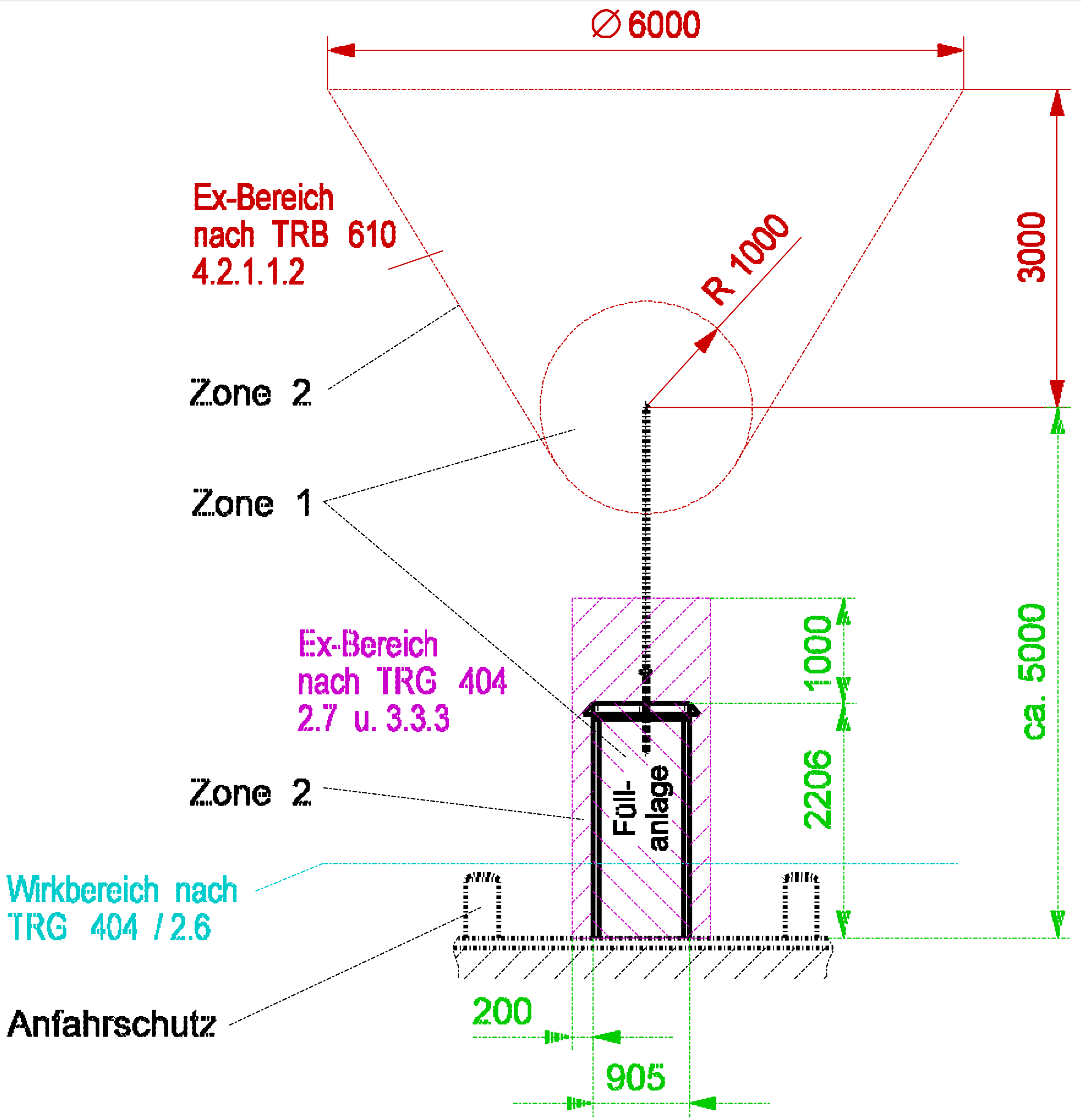
Hydrogen as Alternative Fuel

filling stations - safety areas (*side view*) -



Hydrogen as Alternative Fuel

filling stations - safety areas (*front view*) -



end

Thank you for your attention.

But there is a video about the Hydrogen Filling Station at the Airport Munich.

Do we have additional 98 seconds?

Hydrogen as Alternative Fuel

filling stations - the ROBOT application -

thank you