



STORHY
Train-IN 2006

Session 2.3: Pressure Storage Systems I

Dr. S. Rau, J.S. Colom

25th – 29th September 2006
Ingolstadt



2.3 Pressure Storage Systems



CV – Dr. Steffen Rau

Address:

Dynetek Europe GmbH
Breitscheider Weg 117a
40885 Ratingen, GERMANY



1986-1996: Study of Mechanical Engineering with specialisation in plastics processing at Aachen University of Technology (RWTH Aachen) followed by work as scientific assistant at the Institute of Plastics Processing (Institut für Kunststoffverarbeitung (IKV)) of Aachen University of Technology
1997-2000: Plant engineer at Mannesmann Cylinder Systems GmbH in Dinslaken; development and production of composite pressure vessels for breathing air systems, industrial gas applications and CNG powered vehicles.
2001-today: Technical Director and Authorized Representative of Dynetek Europe GmbH in Ratingen; development and production of composite pressure vessels for industrial gas applications as well as for CNG and hydrogen powered vehicles

CV – J.S. Colom

Address:

AIR LIQUIDE CRCD

1, chemin de la Porte des Loges
78354 Jouy-en-Josas, FRANCE

Tel : +33 (0)1 39 07 62 34

Fax : +33 (0)1 39 07 63 11

jayasitra.Colom@airliquide.com



2002 : Master's degree in General Engineering (Ecole des Mines de Nancy, France)

Energy and Gas Applications

2003-2005 : AIR LIQUIDE – Research Engineer (CRCD, France)

High pressure tank filling technologies

Metal hydride storage systems

2006 : AIR LIQUIDE – Project Coordinator (CRCD, France)

H₂ storage & distribution issues

2.3 Pressure Storage Systems



- Lectures on Compressed H₂ Storage Technology, [Dr. S. Rau](#), [J.S. Colom](#)

Abstract:

The first part will focus on cylinders for storage of compressed gaseous hydrogen. This includes different designs, manufacturing technologies, performance, and testing to ensure safety respectively to achieve a certification based on actual standards.

The second part will focus on the high pressure cylinder integration issues in a car. Associated devices and components, examples of architecture and storage concepts will be described. The refueling process for high pressure cylinders on-board vehicles is also a critical aspect of the application. Stakes and challenges of refueling will be addressed.

Table of Content

- Introduction to hydrogen storage systems
- Cylinder designs
- Cylinder manufacturing technologies
- Cylinder performance, testing and safety
- Integration of high pressure storage systems in cars
- Refueling issues

Hydrogen storage system design



STORHY
Train-IN 2006



Table of Content

- Introduction to hydrogen storage systems
- **Cylinder designs**
- Cylinder manufacturing technologies
- Cylinder performance, testing and safety
- Integration of high pressure storage systems in cars
- Refueling issues

Cylinder desings



• Typical weight range for 200 bar cylinders

700 bar Requirements



Today, in fuel cell cars a stored hydrogen mass of 4 kg is considered to be sufficient for a driving range of 640 km (400 miles). This range fulfills the requirements of several OEM's to support the commercialisation of fuel cell vehicles.

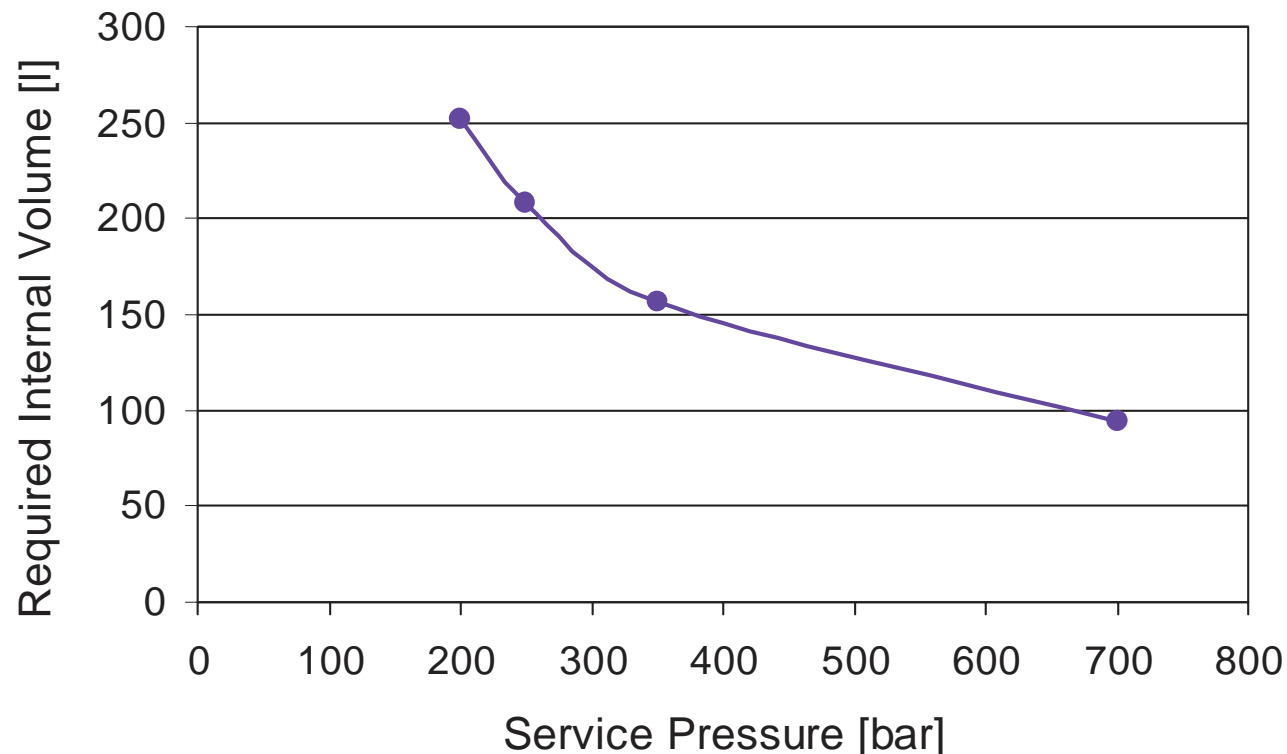
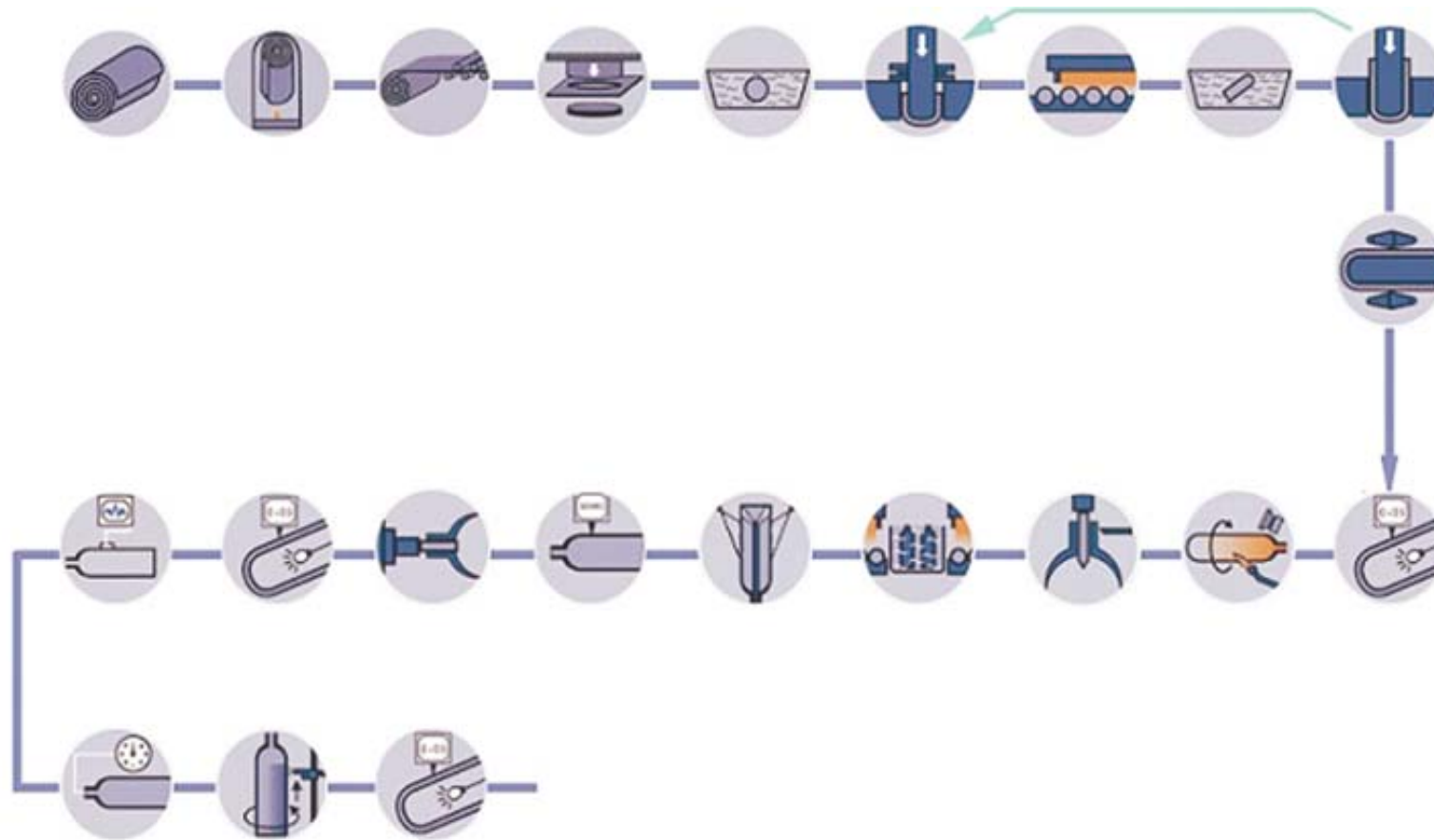


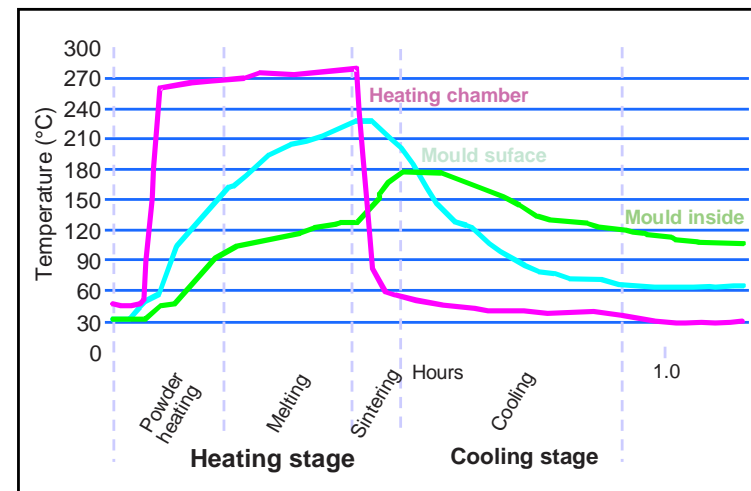
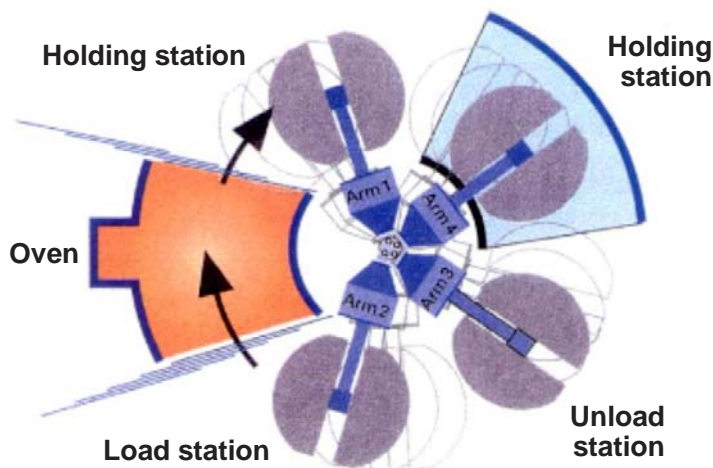
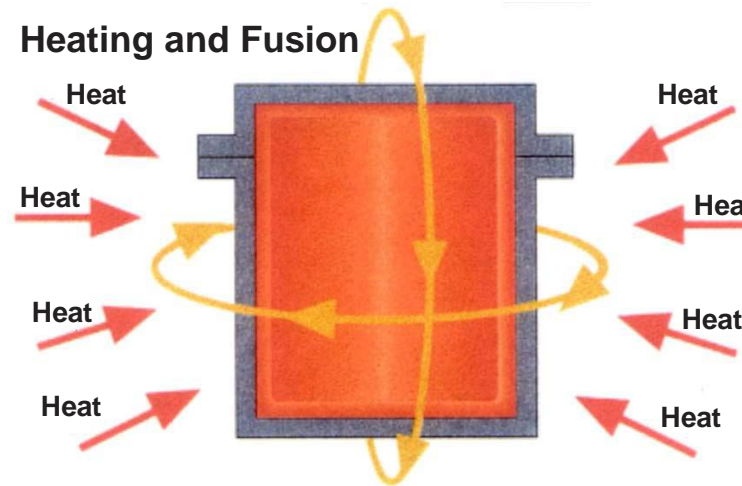
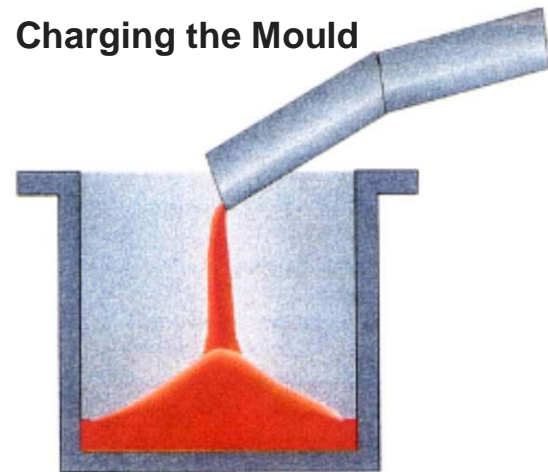
Table of Content

- Introduction to hydrogen storage systems
- Cylinder designs
- **Cylinder manufacturing technologies**
- Cylinder performance, testing and safety
- Integration of high pressure storage systems in cars
- Refueling issues



Liner Production Cycle From Steel Plate

Polymer Liner Production by Rotational Moulding





Fiber Raw Material



Impregnation Bath/ Epoxy Resin



Filament Winding



Curing Oven

Filament Winding Video 1



Filament Winding Video 2



Volumetric Expansion Test

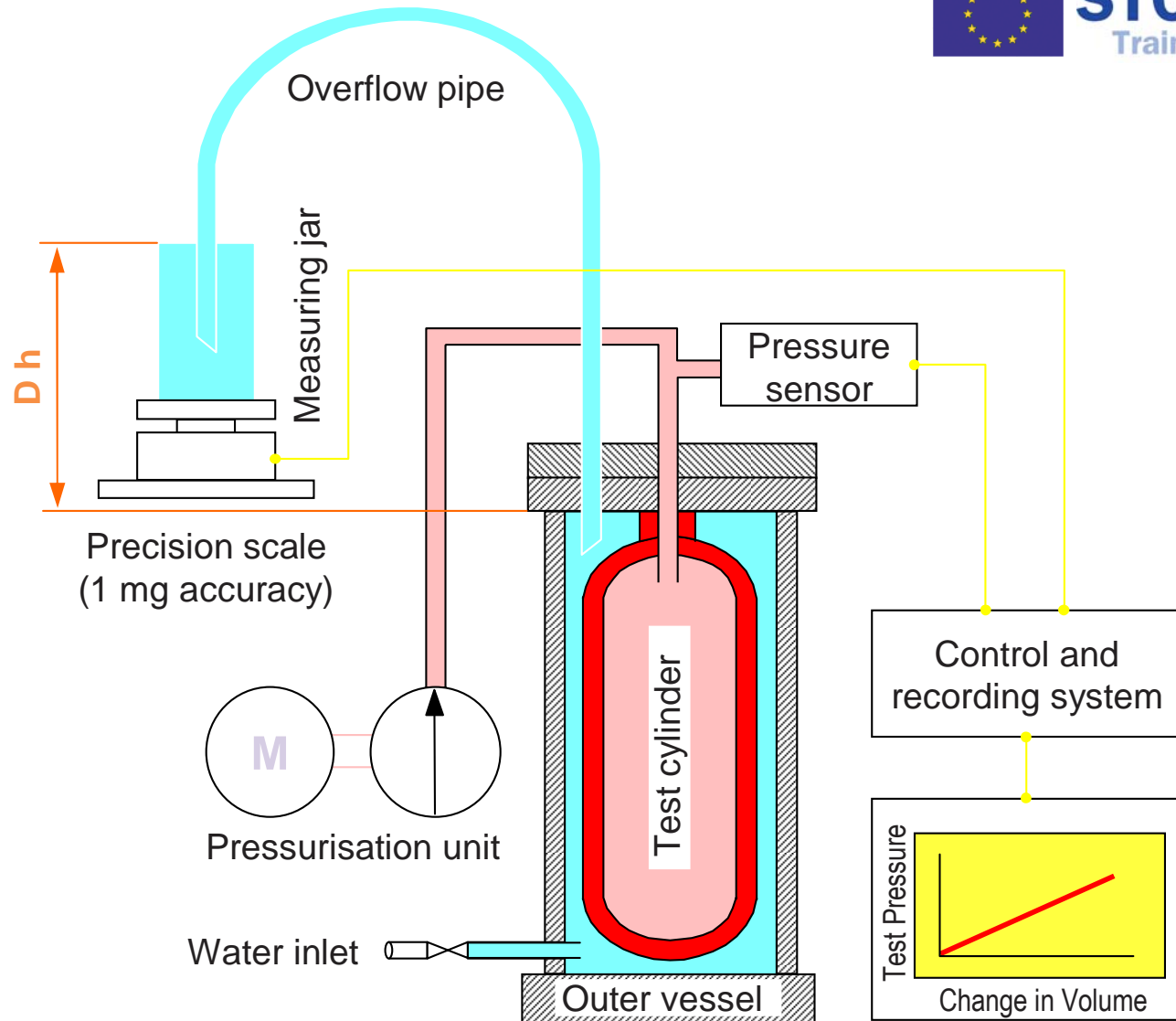
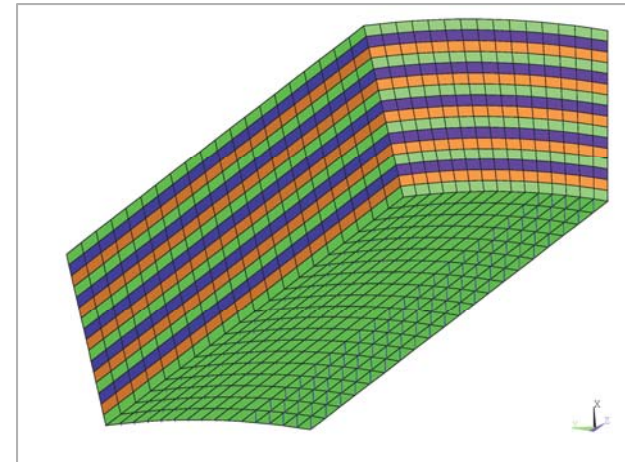
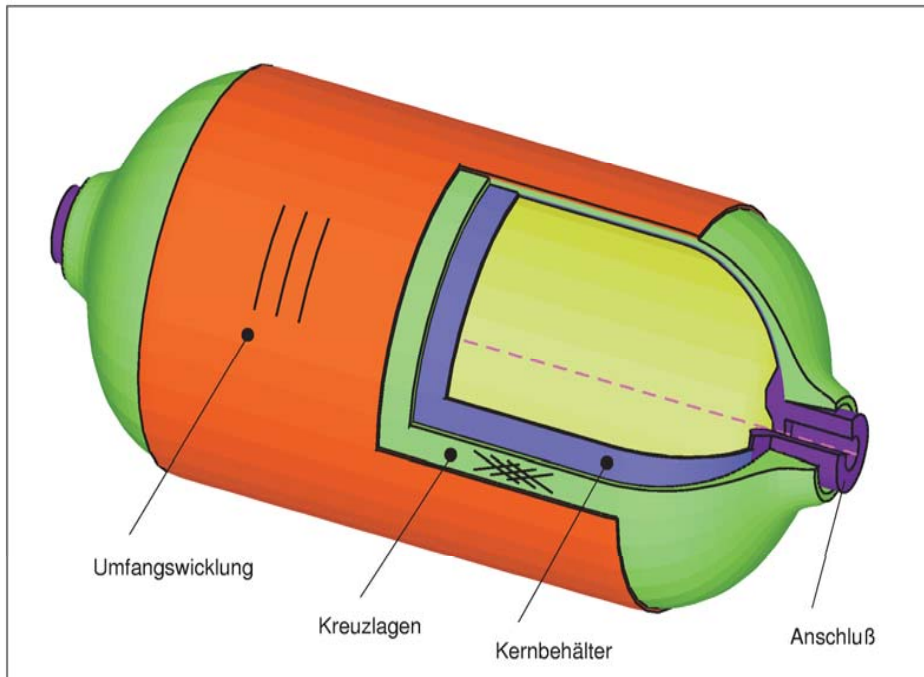


Table of Content

- Introduction to hydrogen storage systems
- Cylinder designs
- Cylinder manufacturing technologies
- **Cylinder performance, testing and safety**
- Integration of high pressure storage systems in cars
- Refueling issues

1st Design Step: FEA and verification



Safety: Testing of CH₂ Cylinders



- tests of raw material
- corrosion test
- hydraulic pressure test
- **burst test**
- cycle test (ambient temperature)
- cycle test (extreme temperature)
- leak before break test
- chemical exposure test
- bonfire test
- penetration (bullet) test
- composite flaw tolerance test
- accelerated stress rupture test
- impact damage (drop) test
- leak test
- permeation test
- boss torque test
- hydrogen cycle test

Test Requirements:

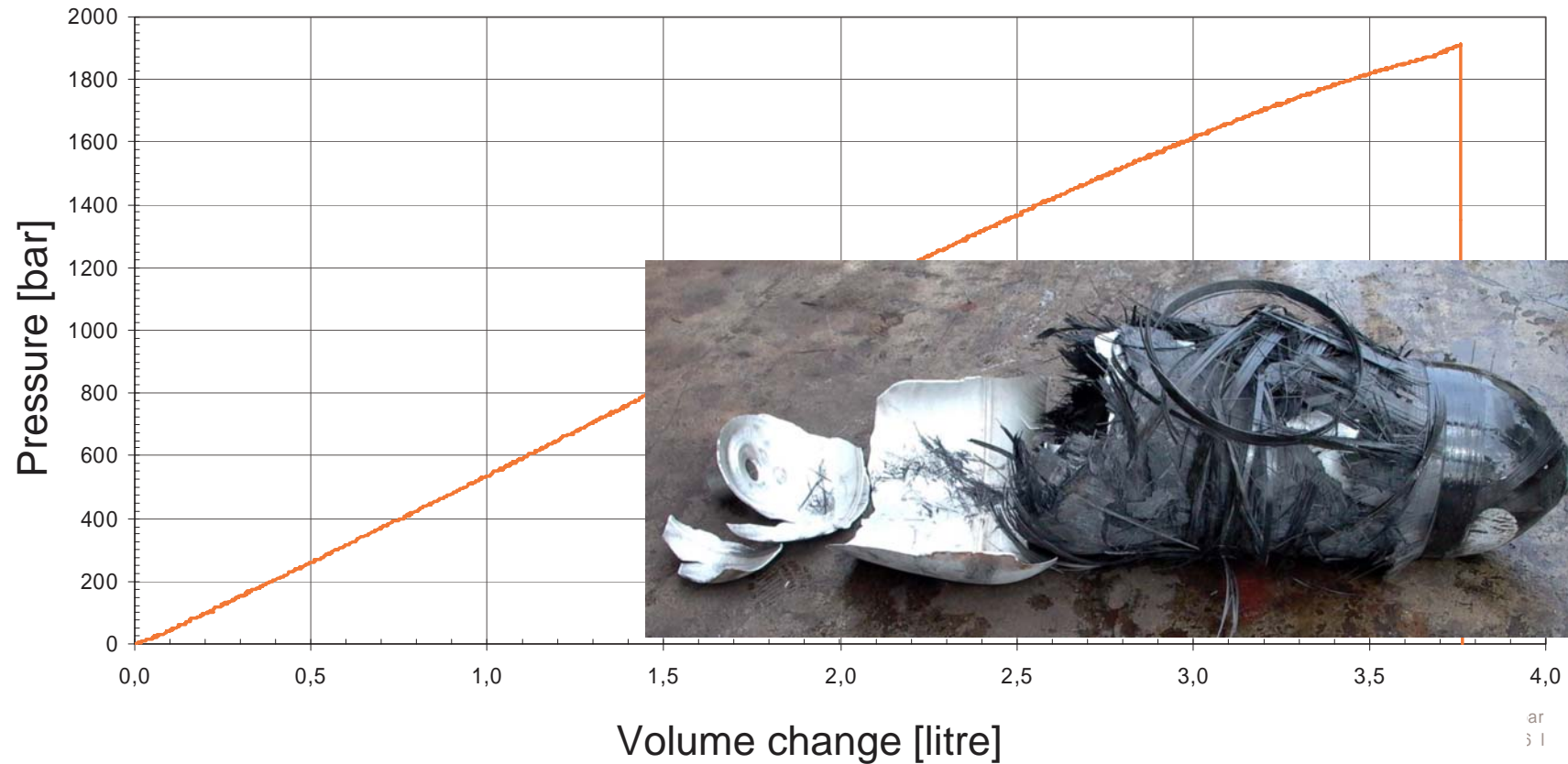
- Pressurised with liquid till burst with rate $< 1.4 \text{ MPa/s}$
- burst pressure
 $> 2.35 \times \text{working pressure}$ and
 $> \text{minimum design burst pressure}$

Only Type 4 Cylinders

Safety: Burst Test



Serial no. VC23



Safety: Testing of CH₂ Cylinders



- tests of raw material
- corrosion test
- hydraulic pressure test
- burst test
- cycle test (ambient temperature)
- cycle test (extreme temperature)
- leak before break test
- chemical exposure test
- bonfire test
- penetration (bullet) test
- composite flaw tolerance test
- accelerated stress rupture test
- impact damage (drop) test
- leak test
- permeation test
- boss torque test
- hydrogen cycle test

Test Requirements:

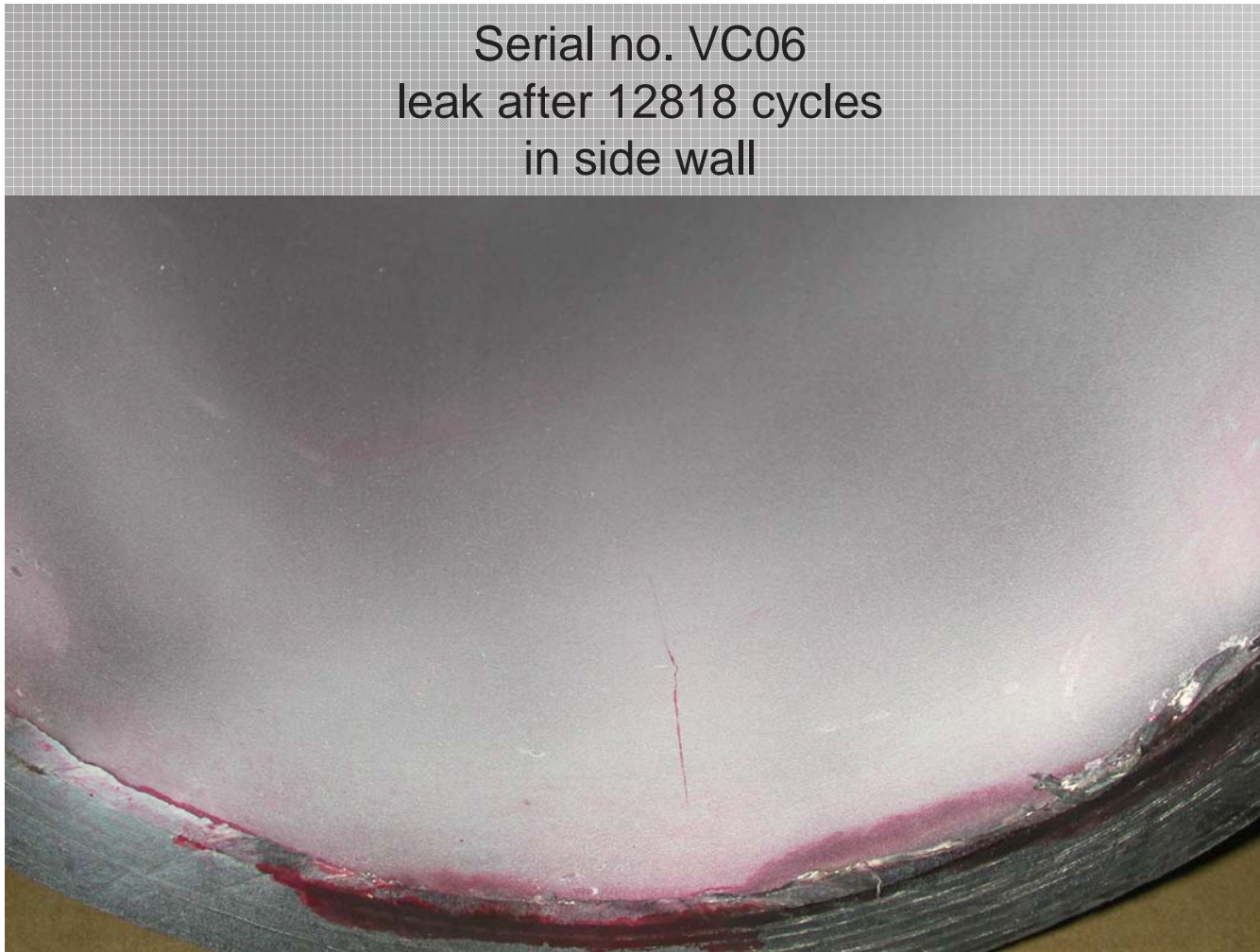
- Pressurised with liquid from 2 MPa to 1.25 x working pressure
- 3 x number of filling cycles or max. 15,000
- NO leak

Only Type 4 Cylinders

Safety: Cycle Test 2 MPa to 87.5 MPa



Serial no. VC06
leak after 12818 cycles
in side wall



Safety: Testing of CH₂ Cylinders



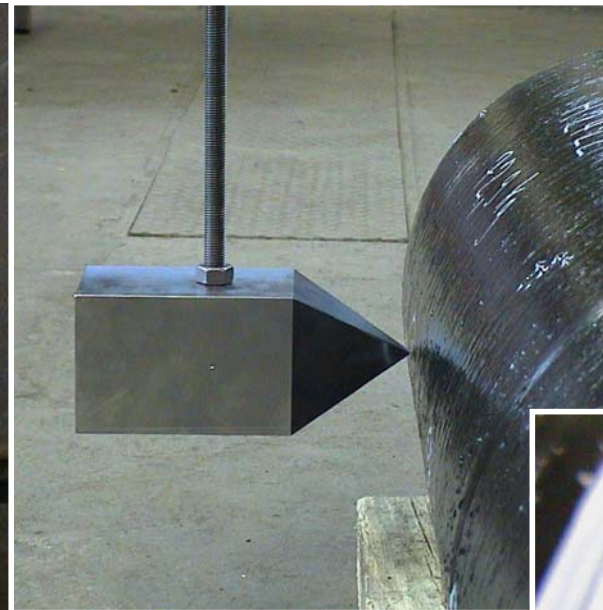
- tests of raw material
- corrosion test
- hydraulic pressure test
- burst test
- cycle test (ambient temperature)
- cycle test (extreme temperature)
- leak before break test
- **chemical exposure test**
- bonfire test
- penetration (bullet) test
- composite flaw tolerance test
- accelerated stress rupture test
- impact damage (drop) test
- **leak test**
- **permeation test**
- **boss torque test**
- **hydrogen cycle test**

Test Requirements:

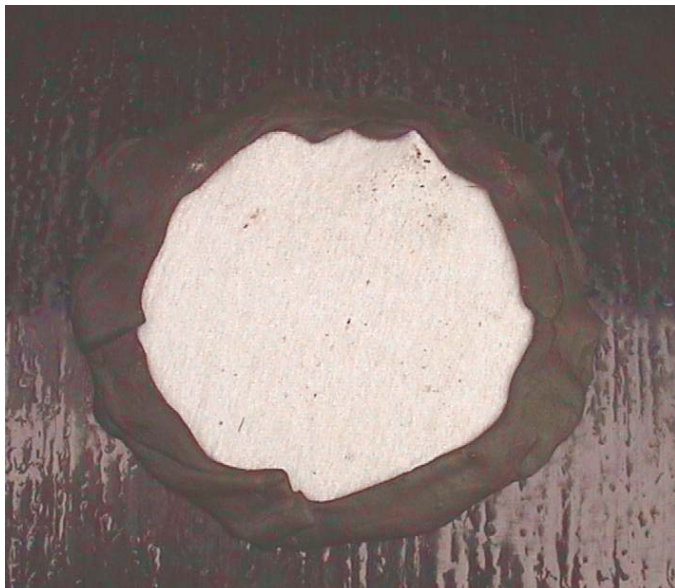
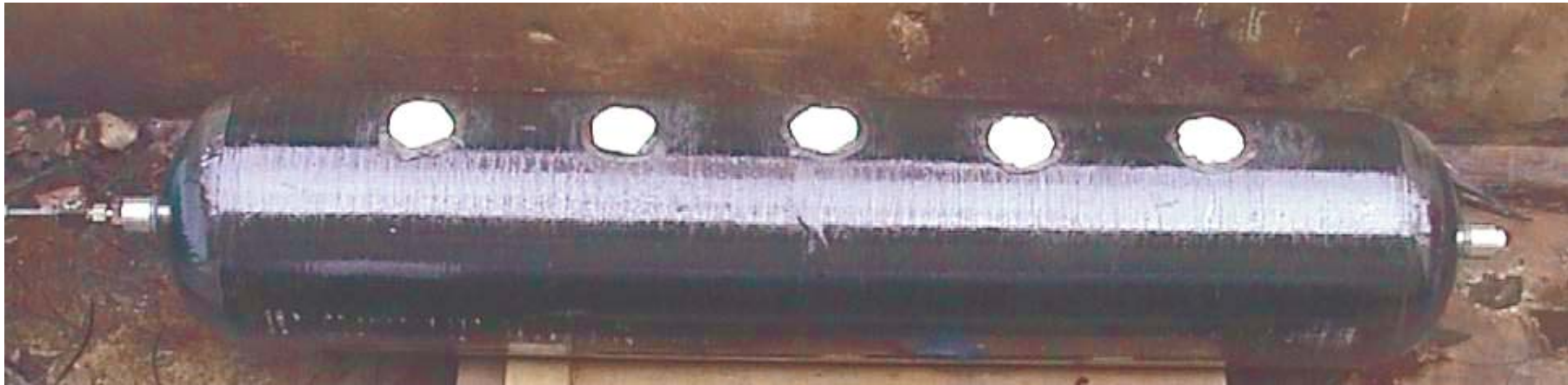
- preconditioned by impact
- exposure to five chemicals
- 5000 cycles to 1.25 x working pressure
- 24 h @ 1.25 x working pressure
- burst pressure
> 1.8 x working pressure

Only Type 4 Cylinders

Safety: Chemical Exposure Test – Impact by Pendulum



Safety: Chemical Exposure Test – Impact by Pendulum



Exposure to five chemicals:

1. Sulphuric acid - 19% solution by volume in water
2. Sodium hydroxide - 25% solution by weight in water
3. Methanol/gasoline - 5/95 % concentration
4. Ammonium nitrate - 28% solution by weight in water
5. Windshield washer fluid (50% by volume solution of methyl alcohol and water)

Testing:

- 5000 cycles to 1.25 x working pressure
- 24 h @ 1.25 x working pressure
- Burst pressure > 1.8 x working pressure

Safety: Testing of CH₂ Cylinders

- tests of raw material
- corrosion test
- hydraulic pressure test
- burst test
- cycle test (ambient temperature)
- cycle test (extreme temperature)
- leak before break test
- chemical exposure test
- bonfire test
- penetration (bullet) test
- composite flaw tolerance test
- accelerated stress rupture test
- impact damage (drop) test
- leak test
- permeation test
- boss torque test
- hydrogen cycle test

Test Requirements:

- Pressurised with H₂ to working pressure
- Fire source length: 1.65 m
- NO burst but venting through the temperature triggered pressure relief device (TPRD)

Only Type 4 Cylinders



Safety: Bonfire Test Video



STORHY
Train-IN 2006

Play Video

Safety: Testing of CH₂ Cylinders



- tests of raw material
- corrosion test
- hydraulic pressure test
- burst test
- cycle test (ambient temperature)
- cycle test (extreme temperature)
- leak before break test
- chemical exposure test
- bonfire test
- penetration (bullet) test
- composite flaw tolerance test
- accelerated stress rupture test
- impact damage (drop) test
- leak test
- permeation test
- boss torque test
- hydrogen cycle test

Test Requirements:

- Pressurised with gas to working pressure
- Armour Piercing Bullet 7.62 mm
- Impact at an angle of 45°
- NO burst but venting through the entrance (and exit) opening

Only Type 4 Cylinders



Safety: Bullet Test Video



STORHY
Train-IN 2006

[Play Video](#)

Safety: Bullet Test Results (200 bar CNG cylinder)

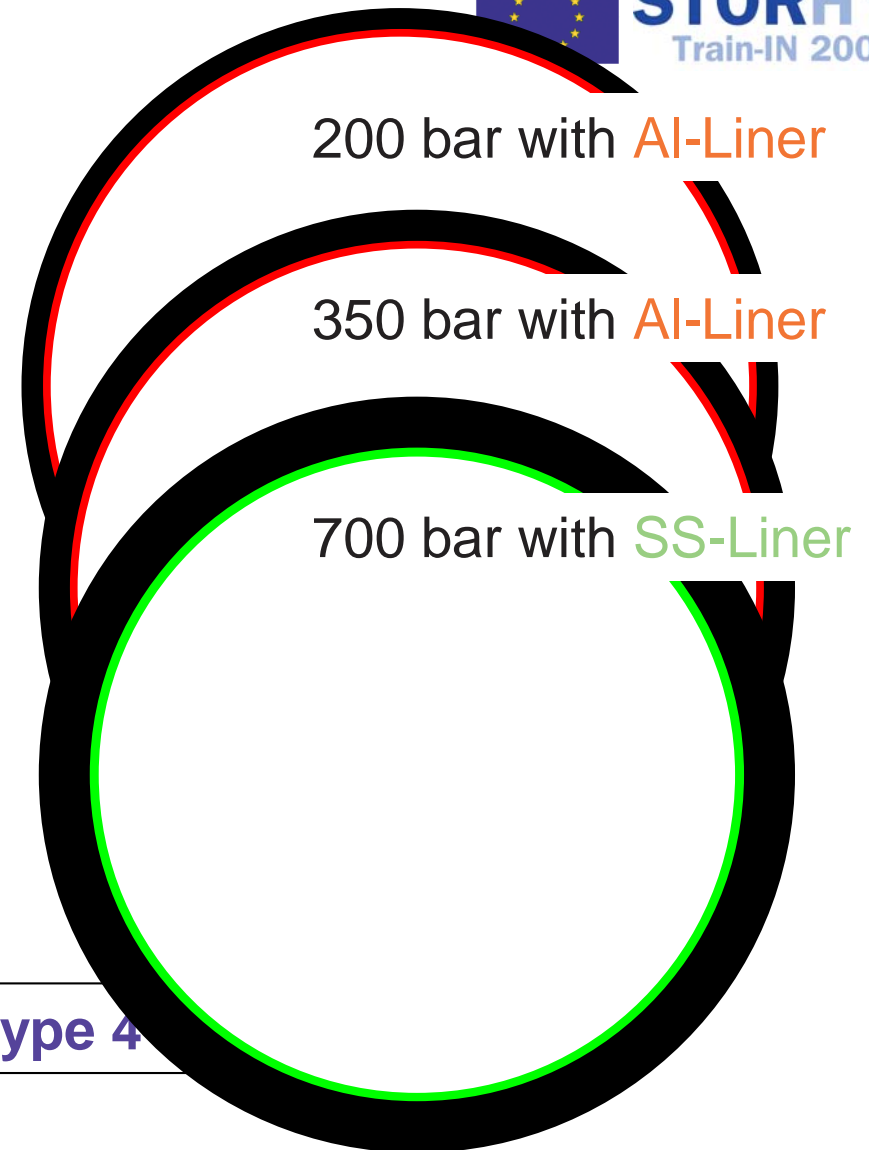


Safety: Testing of CH₂ Cylinders



- tests of raw material
- corrosion test
- hydraulic pressure test
- burst test
- cycle test (ambient temperature)
- cycle test (extreme temperature)
- leak before break test
- chemical exposure test
- bonfire test
- penetration (bullet) test
- composite flaw tolerance test
- accelerated stress rupture test
- impact damage (drop) test
- leak test
- permeation test
- boss torque test
- hydrogen cycle test

Only Type 4



Lectures on Compressed H₂ Storage Technology,



Result of design and testing:

**Type approval for the on-board storage of
compressed hydrogen in vehicles**

Table of Content

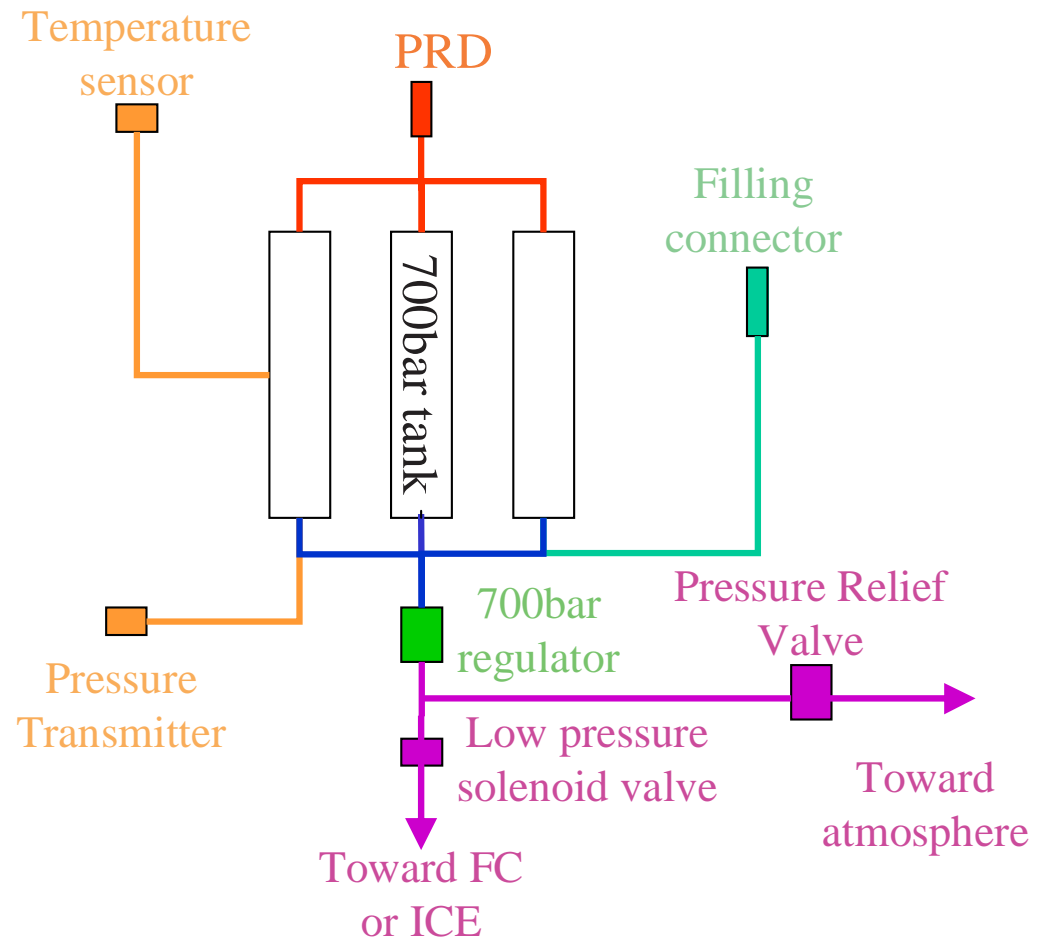
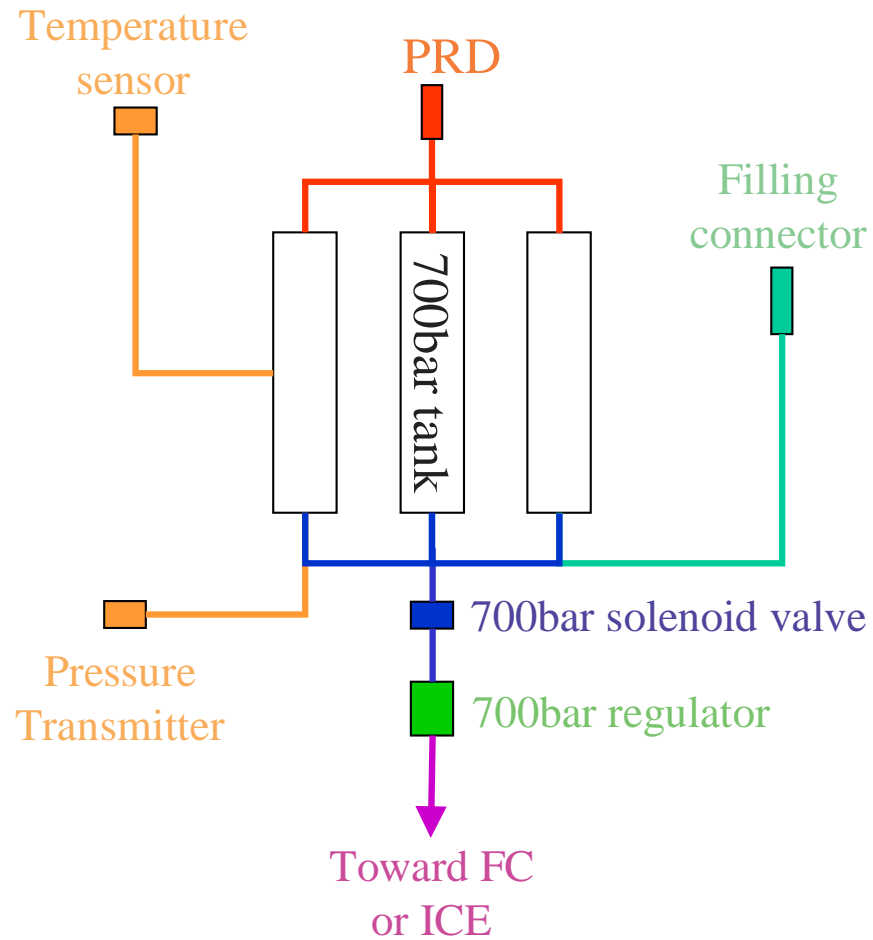
- Introduction to hydrogen storage systems
- Cylinder designs
- Cylinder manufacturing technologies
- Cylinder performance, testing and safety
- **Integration of high pressure storage systems in cars**
- Refueling issues

Integration challenges

- **700 bar components availability** : design adapted to vehicle requirements, optimisation (in-tank integration) and cost decrease
- **Crash protection** : localization of the tank in the car
- **Safety issues**
 - High pressure management in case of **fire**
 - **H₂ external leak** management system : detection / appropriate procedures definition
- **Monitoring** : safety, maintenance, control

For more information, session 1.4

Integration architecture : examples



Two storage concepts



ON-BOARD STORAGE



High pressure tank is integrated in the car

Direct fueling in a fueling station



EXCHANGEABLE RACK



High pressure tank can be removed from the car



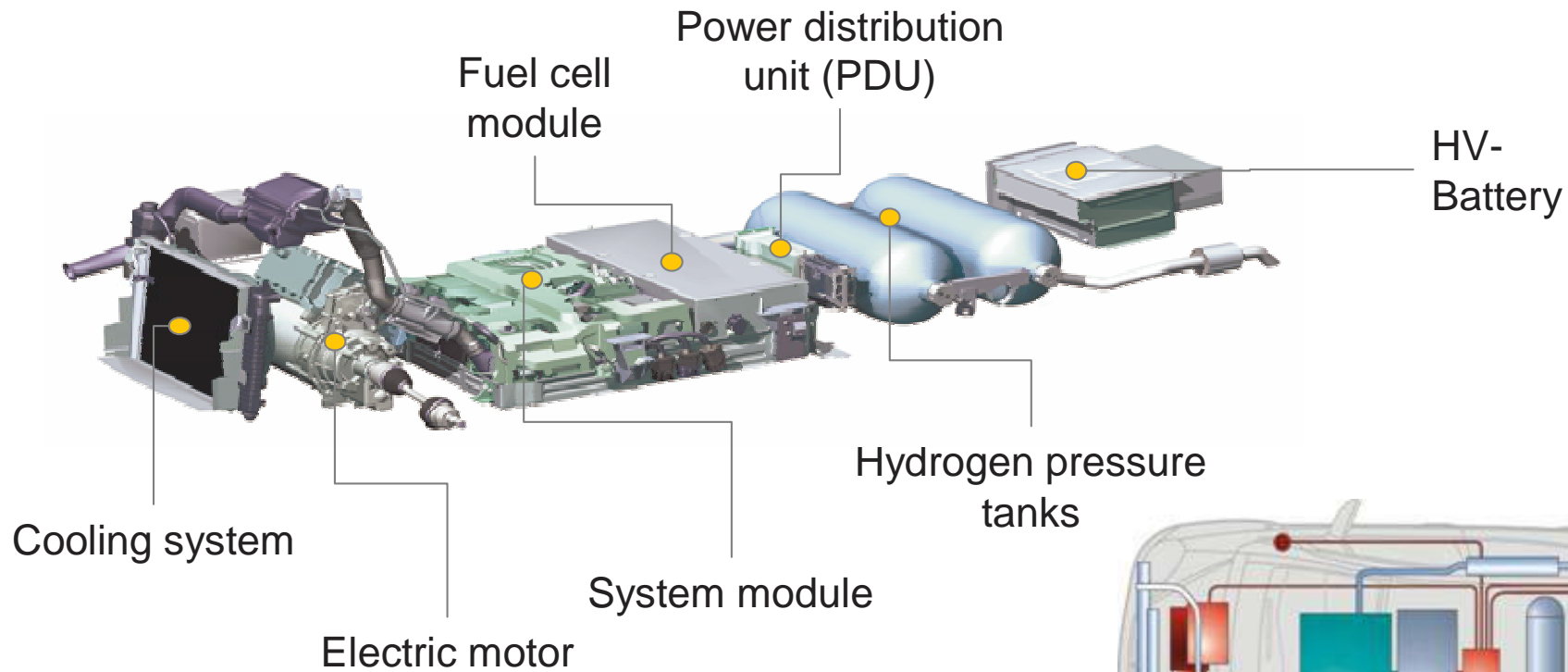
Remote fueling in a filling center

Two storage concepts

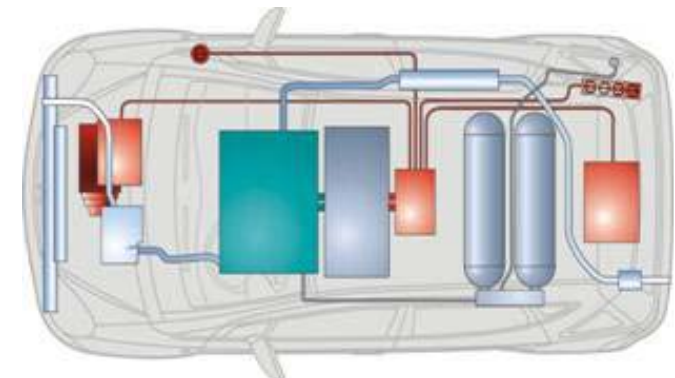


	On-Board storage	Exchangeable rack
Interest	<ul style="list-style-type: none"> • No change in fueling habits 	<ul style="list-style-type: none"> • Possibility to use the existing infrastructure
Main applications	<ul style="list-style-type: none"> • Large vehicles (cars, buses) • Long term solution 	<ul style="list-style-type: none"> • Small vehicles (scooter), captive fleet • Short term solution
Challenges	<ul style="list-style-type: none"> • Develop infrastructure • Fast filling (< 3min) 	<ul style="list-style-type: none"> • Resistant and light structure • Regulations adapted to the application

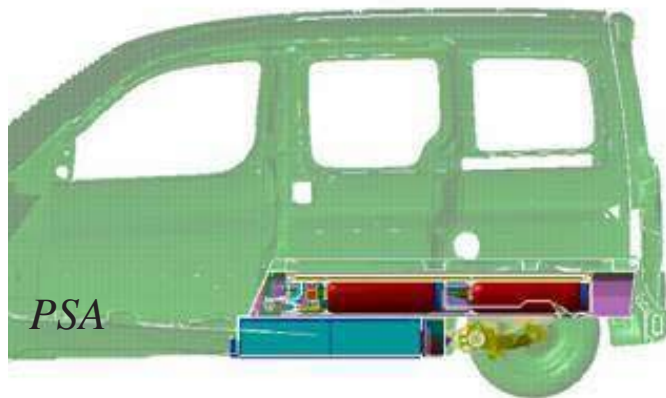
On-board storage : integration examples



Daimler Chrysler



Exchangeable rack : integration examples



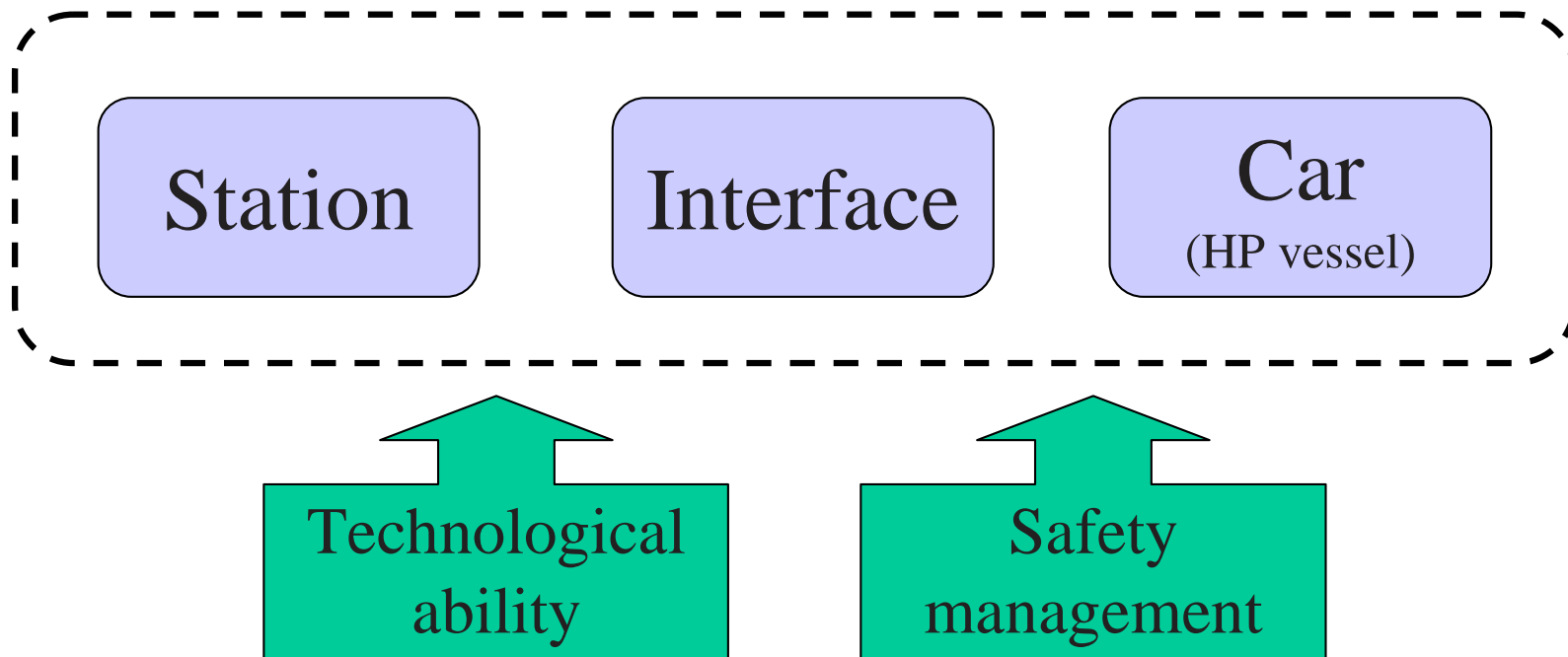
Due to crash issues, the swap-rack is mainly at the centre of the vehicle and at least kept away from the rear bumper.



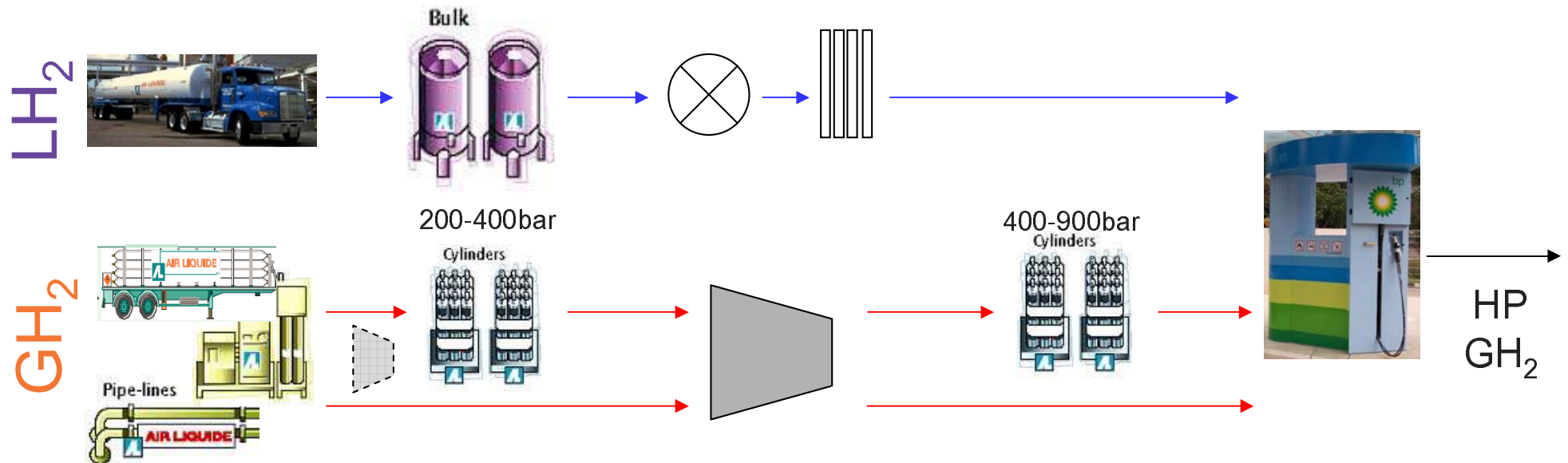
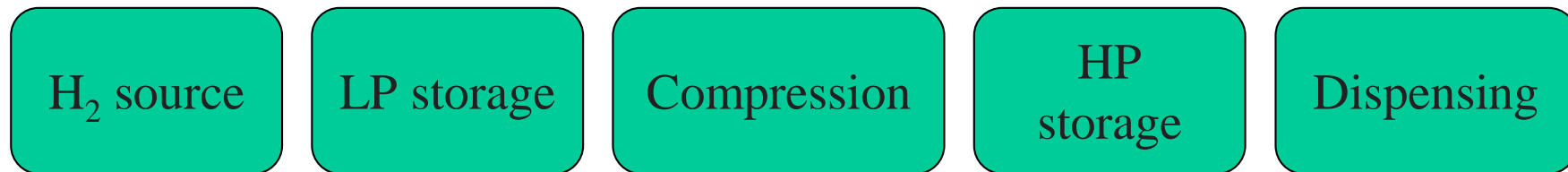
Table of Content

- Introduction to hydrogen storage systems
- Cylinder designs
- Cylinder manufacturing technologies
- Cylinder performance, testing and safety
- Integration of high pressure storage systems in cars
- **Refueling issues**

Objective : To supply high flow of high pressure hydrogen with high reliability



Station design : technologies

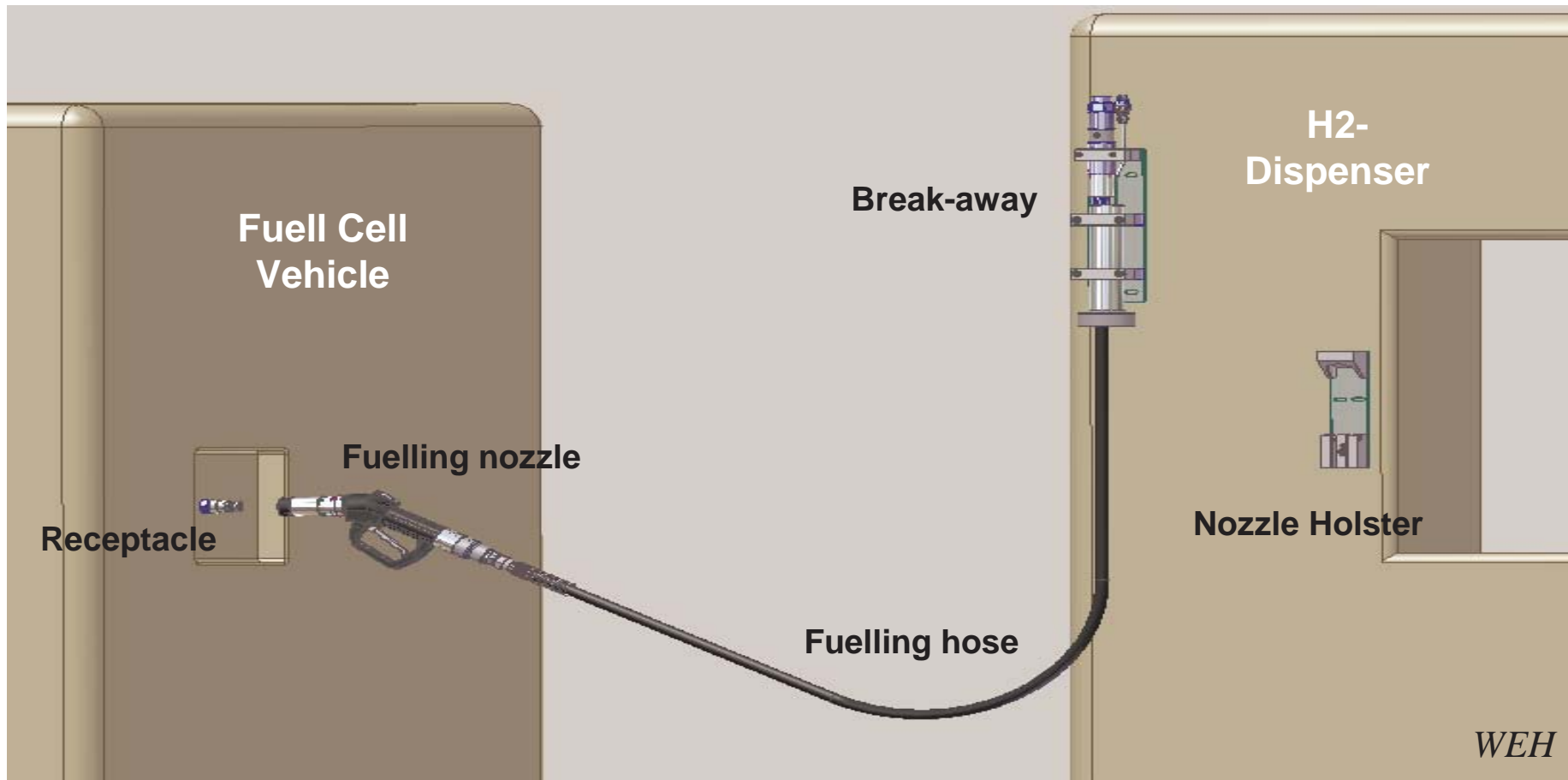


Design depends on H₂ source and station capacity

Main risks are relative to **H₂** and **high pressure**
 ⇒ **Leakages, Fire, Explosions**

	Passive device	Active device
Reduce occurrence	H ₂ / Fire detection device Pressure release device	Leak detection Electrostatic discharge
Reduce gravity	Protective wall	Safety distance

Interface station / vehicle



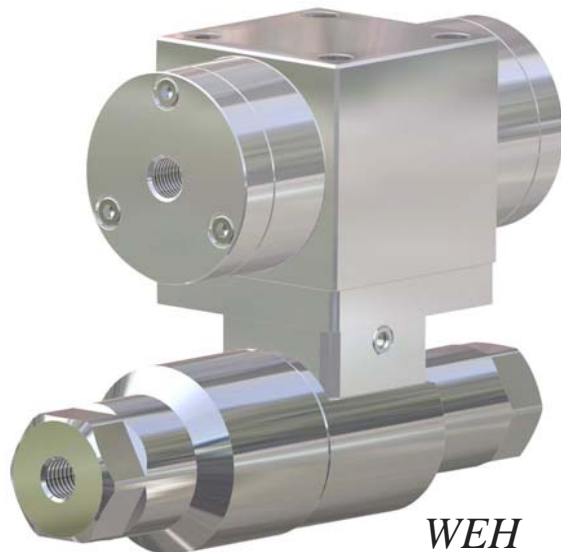
Fueling components : break-away system



**Break-away
coupling
for H₂ filling
stations for cars**

- **Function : separating the coupling in the event of an accidental deployment**

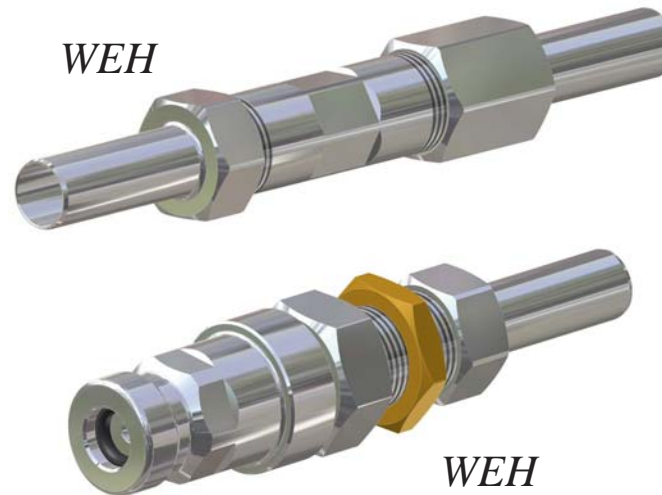
Fueling components : linear valve



**Pneumatically actuated
linear valve for use at
hydrogen filling stations**

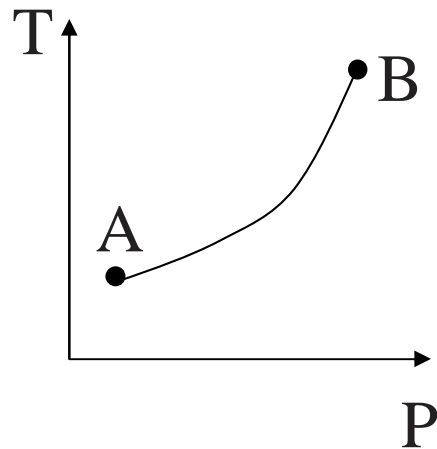
- **Function : to control the H₂ flow rate during filling**

Fueling components : nozzle and receptacle



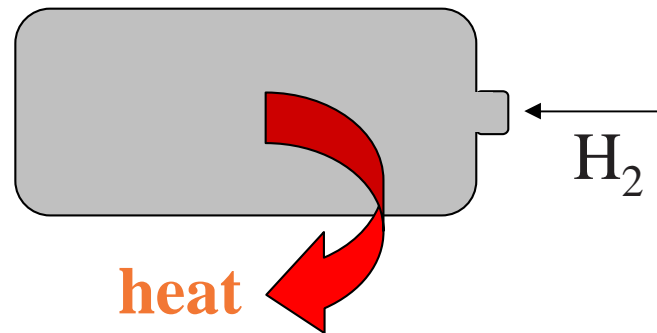
Pistol grip nozzle and corresponding receptacle

Theory :
“Isentropic compression”



$$T_B = T_A \times \left(\frac{P_A}{P_B} \right)^{\frac{\gamma-1}{\gamma}}$$

High pressure vessel

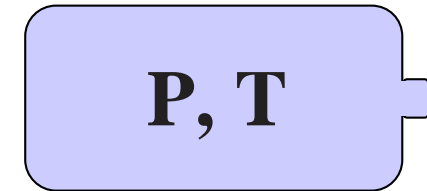
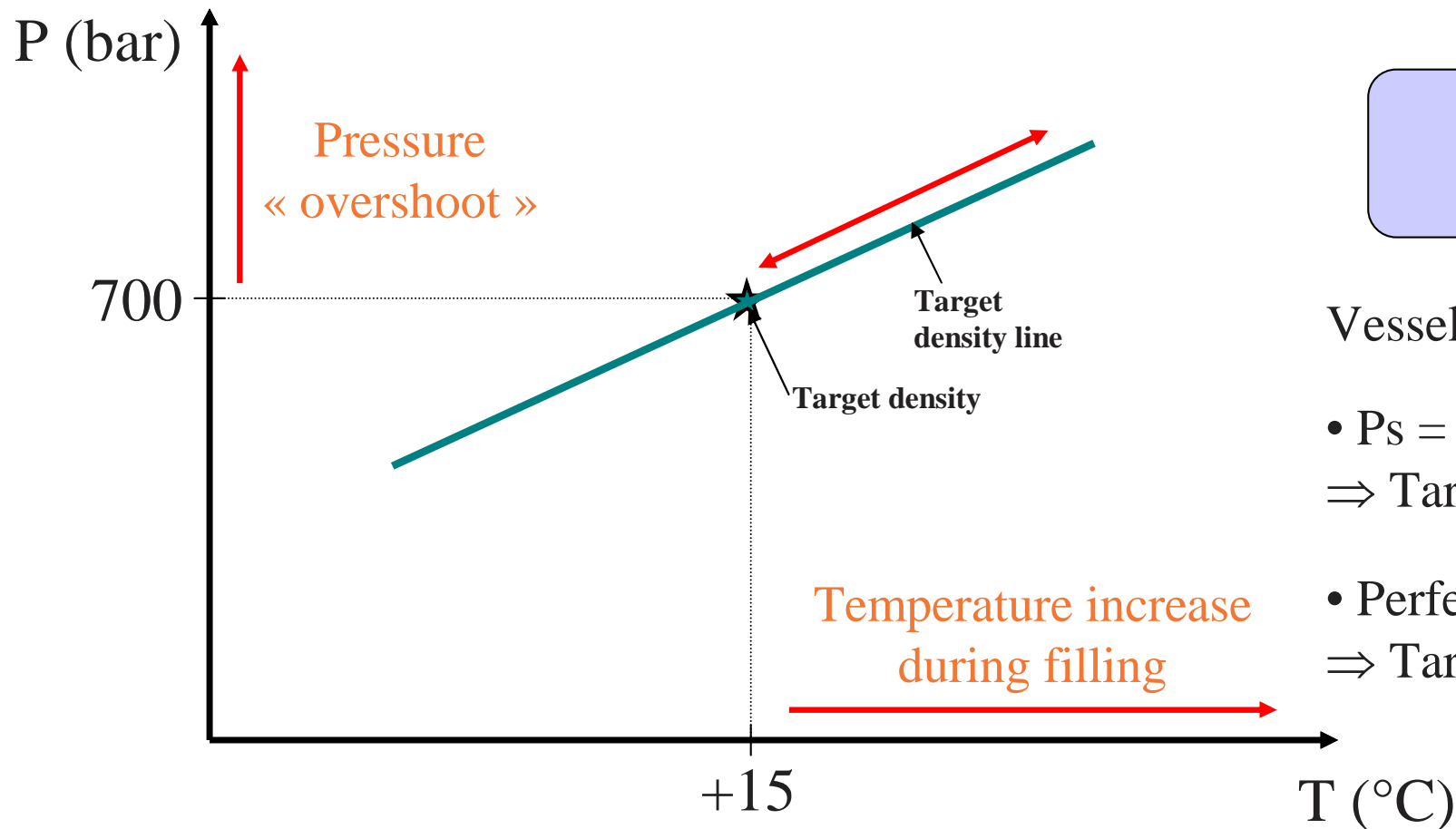


In practice
heat transfer
through tank
wall and
outside
environment

$$T_B = f(\Delta H_{in} + \Delta H_{comp} - \Delta H_{heat})$$

Fast filling results in a temperature increase in the tank

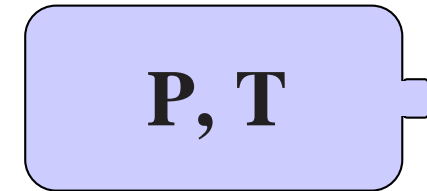
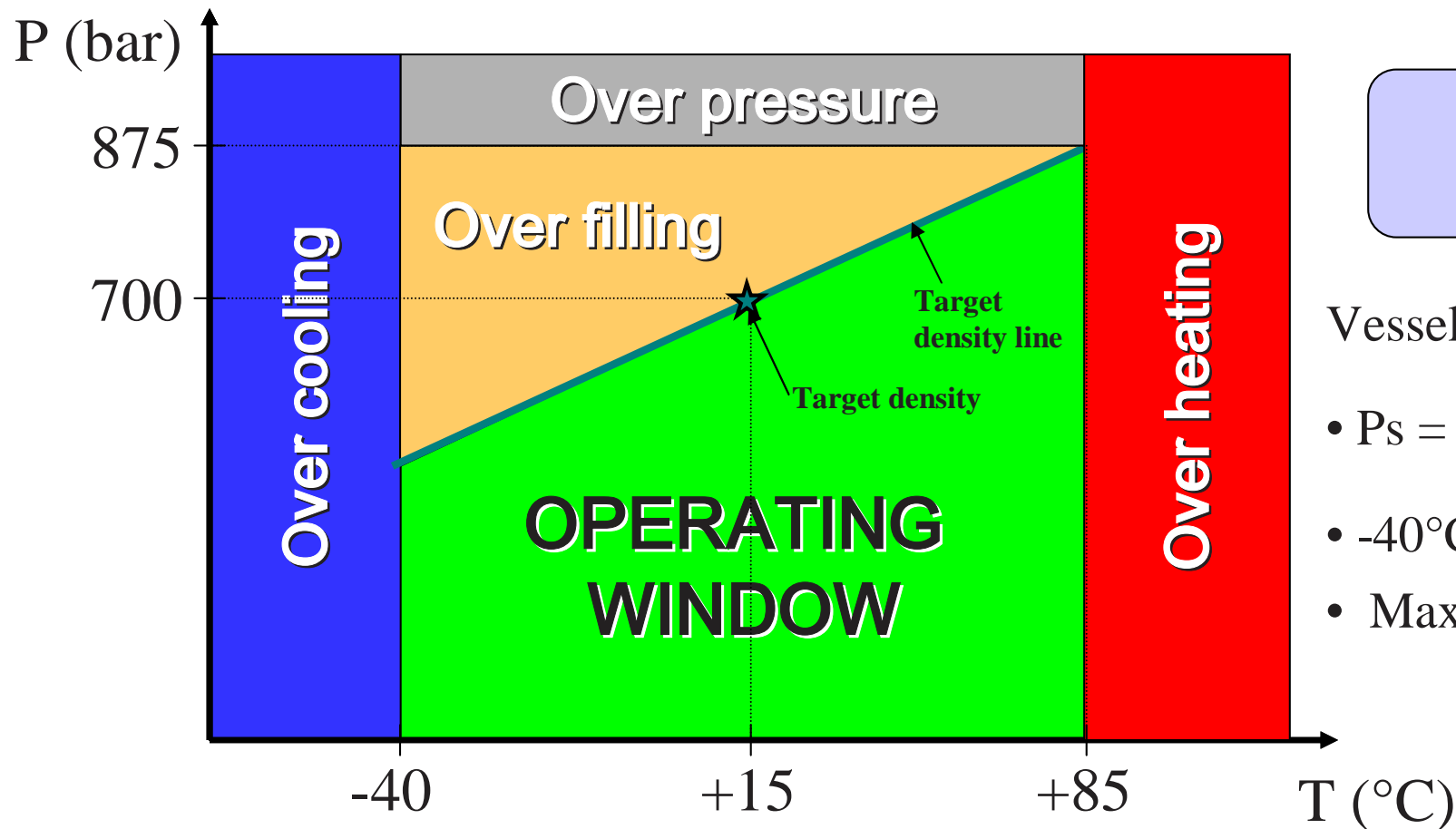
Filling : target density



Vessel specifications

- $P_s = 700\text{bar}$ at 15°C
 \Rightarrow Target density
- Perfect gas law
 \Rightarrow Target density line

Filling : vessel operating window



Vessel specifications

- $P_s = 700\text{bar}$ at 15°C
- $-40^\circ\text{C} / +85^\circ\text{C}$
- $\text{Max } P = 875\text{bar}$

Filling challenges



Objectives

- Target density
- Fast filling : < 3min

Constraints

- Maximum operating pressure
- Temperature limits

Challenges

- Control
 - Temperature
 - Density
- Optimum between high filling rate (target density) and fast filling (filling time)



Lectures on Compressed H₂ Storage Technology



STORHY
Train-IN 2006

Thank you for your attention



STORHY
Train-IN 2006

Session 2.3: Pressure Storage Systems I

Dr. S. Rau, J.S. Colom

25th – 29th September 2006
Ingolstadt

