Session 7: Storage

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The Focal Point on Integrated Research and Information for Hydrogen Safety

Storage

Hydrogen storage: recent improvements and gaps

- What has been done in the last three to four years (progress) ?
- What is planned for near term research direction (working topics)?
- What are the needs/gaps that need to be filled by future research (new directions) ?

Storage

Hydrogen storage overview

- To achieve the required performance (autonomy, gravimetric & volumetric storage capacity), 4 storage solutions:
  - **Gaseous compressed storage**

  - **Cryo-compressed form (low T~40K, high P~30 MPa)**

  - Liquefied storage (-253°C)
  - Solid form in hydrides

Compressed hydrogen storage technologies

Type I

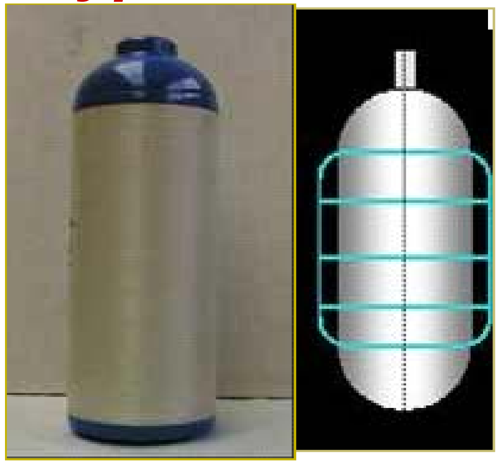
Metal

Up to 50 MPa H_2

< 1 kg H_2 for 70 kg (1 wt%)

Industrial & medical gases

Type II



Thick metal liner hoop wrapped with a fiber-resin composite

Up to 85 MPa

Poor weight performance

Transportable cylinders

Stationary applications such as fueling station buffer can reach 1000 bar

Type III

Metal liner fully-wrapped with a fiber-resin composite

Up to 70 MPa

~ up to 5 wt% of H2 stored

Automotive (GNV, CH_2V), stationary, mobile

Type IV

Non load sharing liner fully-wrapped with a fiber-resin composite
(mostly polymer)

Up to 70 – 100 MPa

~ up to 6 wt% of H2 stored

Automotive, stationary, mobile

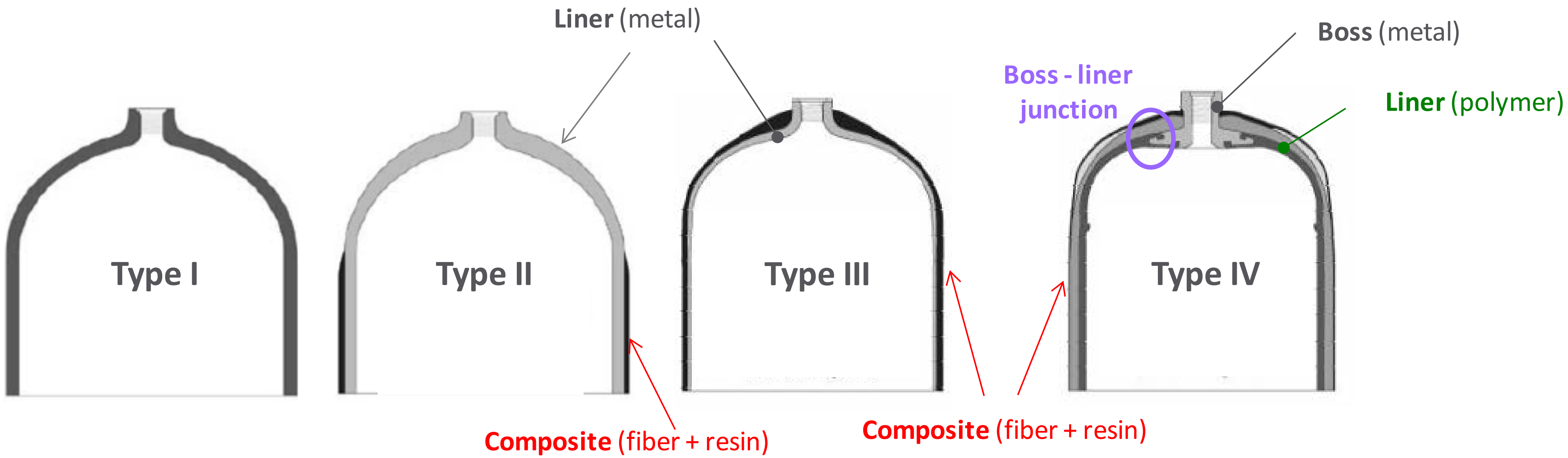
Storage

Compressed hydrogen storage – Progress &Gaps (General)

- Commercial products are available and experience is currently built (operations, manufacturing, standards, etc)

		Technology maturity	Cost performance	Weight performance
stationnary	Type I	Pressure limited to 50 MPa, ++	++	-
	Type II	Pressure not limited, +	+	0
fuel tanks	Type III	Difficulty to pass cycling requirements for more than 45 MPa	-	+
	Type IV	For 100 MPa max, first commercial series (-), liner behavior in gas to be further studied	-	++

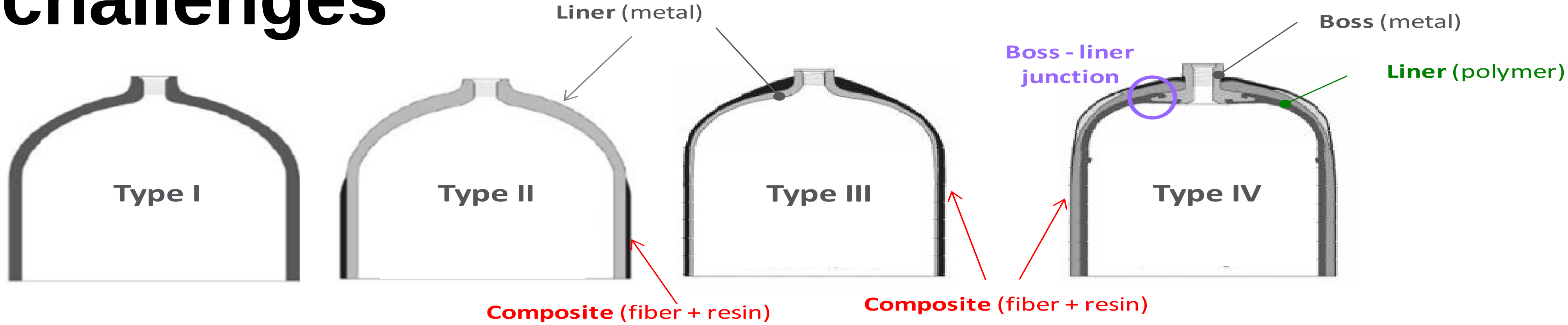
Compressed hydrogen storage – Design & manufacturing – most common materials



- Polymer liner: polyethylene or polyamide based polymer
- Metal parts: aluminum 6061 or 7060, steel (inox or Chrome Molybdenum)
- Composite: carbon, glass and/or aramid fibers embedded in a resin: most often carbon fibers/epoxy resin

Storage

Compressed hydrogen storage – Overview of materials issues and R&D challenges



- **General R&D Gaps**
- Ageing models for lifetime assessment of materials & structure
- Need NDT for ensuring constant manufacturing quality and e.g. required performance (number of cycles, tightness, etc)
- Recycling

- H_2 embrittlement (causes loss of fracture toughness) – H_2 enhanced fatigue
- Premature failure in fatigue (due to HE and/or cycling, in particular at HP)

- Gas permeation – Liner collapse
- Mechanical loads and durability – Criteria for liner materials selection
- Heat management during filling

- Tightness of boss – liner junction
- Bonding material selection & qualification (if any)

- Effects on damage & lifetime of static & cyclic pressure, temperature, environment, accidental loads (impact, fire)

See following slides and Materials Compatibility Session for info on identified gaps

Storage

Compressed hydrogen storage – Materials – Polymer parts – Gas permeability

- Polymer liner can deform permanently during (fast) emptying of the pressure vessels due to fast desorption of H_2 solved in the liner and composite at interfaces => Safety issue: is there a risk of leak with further pressure cycles ?

→ On-going study of key parameters influencing liner collapse and long-term effect on polymer liner lifetime in French Funded project Colline.

→ For a given liner material, occurrence depends on working pressure, minimal pressure in the cylinder (i.e. Residual Pressure Valve) & emptying speed

→ RPV seems mandatory to limit the phenomenon => beware of maintenance phase !

→ Identified Gaps : Need for ageing models considering liner collapse and other mechanical loads and influencing operating parameters => Definition of test protocols to define material selection test and criteria to qualify the solution for H_2 HP cylinder.

X-Ray tomography of a polymer liner pressure vessel

See also
Materials Compatibility session

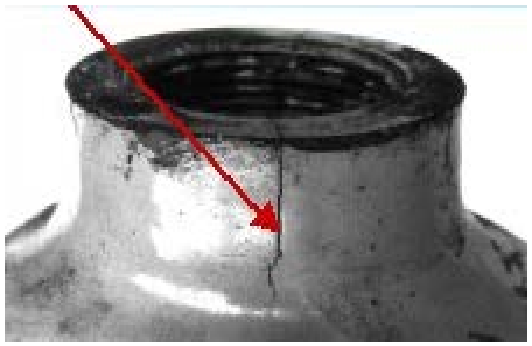
Storage

Compressed hydrogen storage – Materials – Composite structure

- Ageing and failures modes in carbon fiber composite materials are different from metals

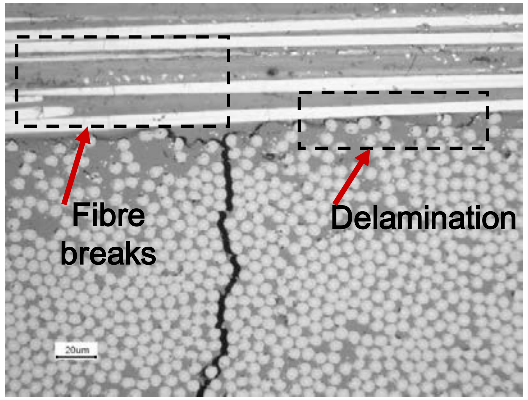
METAL

- Failure via cracks initiation and propagation



CARBON FIBER COMPOSITE

- Failure via fiber breaks, delamination, matrix cracks



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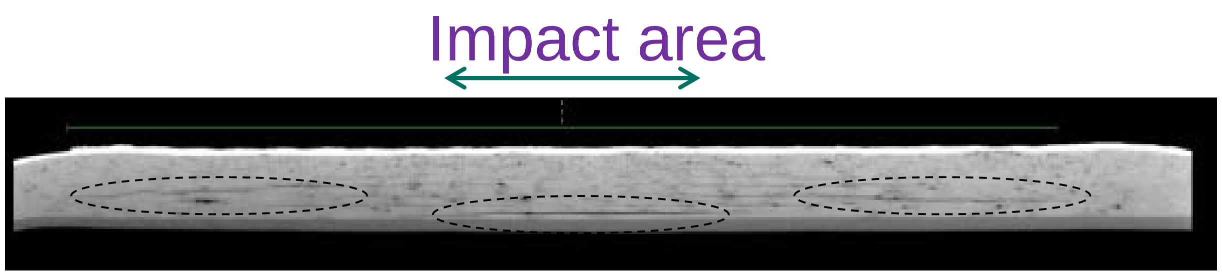
Compressed hydrogen storage – Materials – Composite structure - impact

- Mechanical impacts on composites pressure vessels cause damages on the surface and in the structure

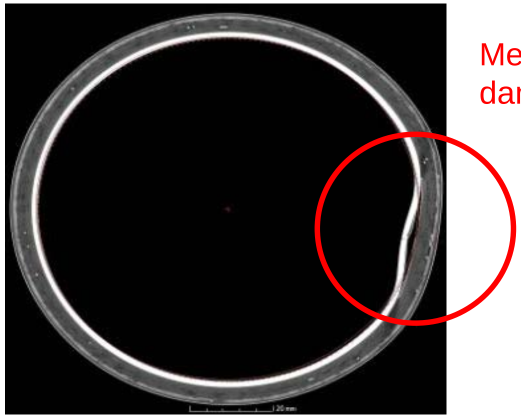
Impact visualisation on the glass fiber layer of a pressure vessel

X-Ray tomography of damages in the composite after the impact



➔ Tests protocols to correlate external visual inspection to damage in structure and loss of performance
➔ Non Destructive Testing techniques are under development (acoustic emission, ultrasonic, X Ray tomography, …) – Hypactor European funded project

Identified Gaps: modelling damage induced by impacts and lifetime assessment (including metal liner) - structural health monitoring



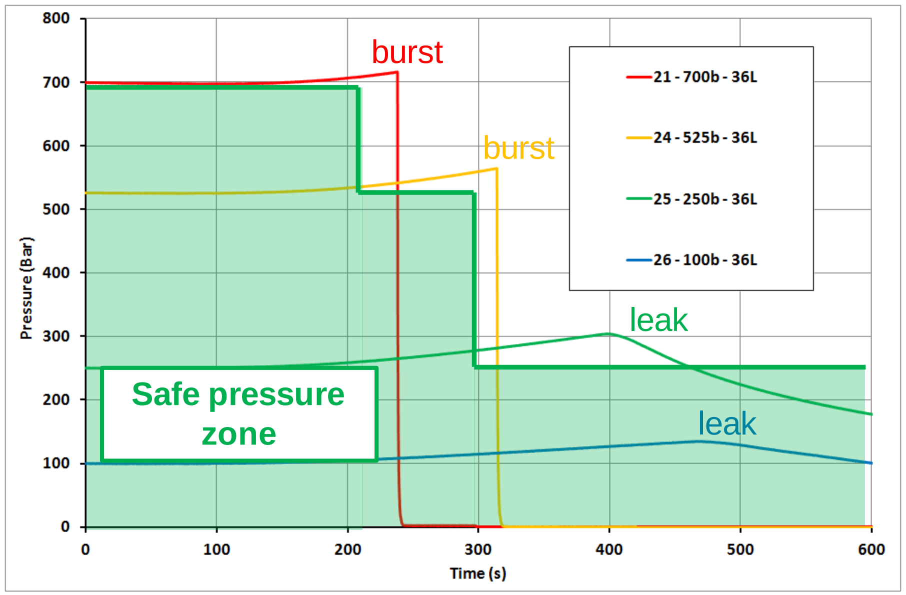
X-Ray tomography of a type III cylinder after impact

Storage

Compressed hydrogen storage – Materials – Composite structure – fire resistance

- The main mechanism responsible for burst is the composite degradation in fire and not the pressure increase like for metal cylinders
- Polymer liner cylinder can leak due to liner melting
- The time to burst in fire depends on the design
- Models have been developped and validated to estimate time to burst in fire
- Representative Bonfire test protocol has been defined
- Fire protection strategy has been proposed to prevent burst

FireCOMP



Identified gap: need for new cylinder & fire solutions design for smart and reliable fire detection and protection
(TPRD, protections, fire detections, heat conduction to promote liner melting, etc)

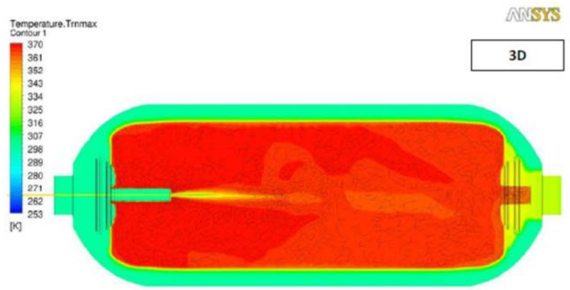
Storage

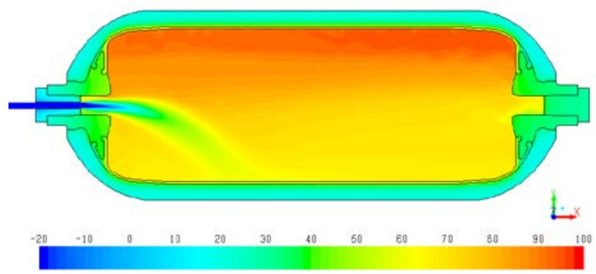
Compressed hydrogen storage – Fast filling of composite pressure vessels

- Development of modelling tools to calculate gas and materials during filling of cylinders (3D gas dynamic, average homogeneous temperature)

=> on-going definition of alternative fuelling protocols with optimized gas pre-cooling

HyTransfer



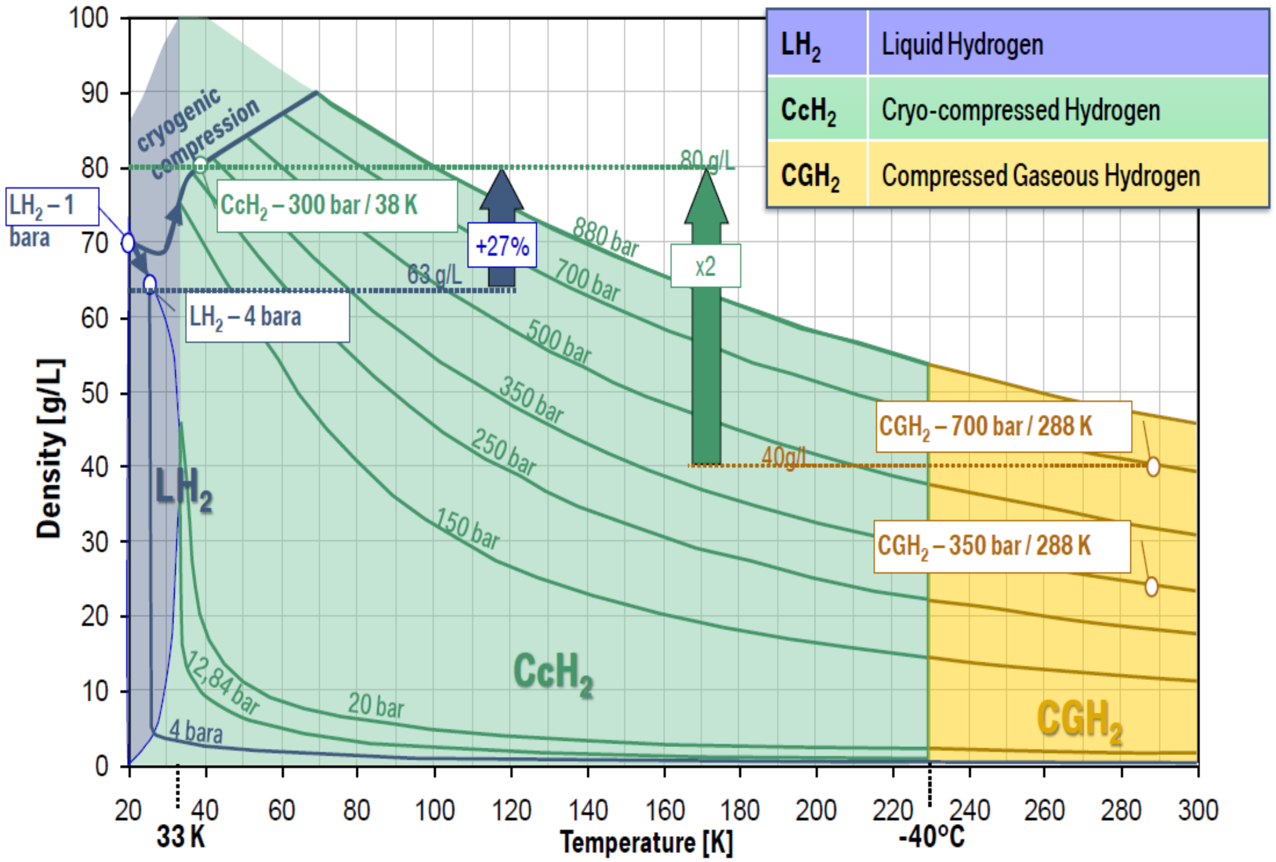


Identified gaps: what is the effect of overheating on materials and structures performance and lifetime (temperature higher than 85°C in gas and or materials) ? => Safety issue underlined by ISO TC 197 studies (refueling station risk assessment) + possible occurrence for extreme hot case filling scenarios

Storage

Cryo-Compressed hydrogen storage

- New technology under development for on-board storage in vehicles
- Minimize boil-off loss while retaining high system energy density
- Requires high pressure and insulated pressure vessel



Source: BMW

Storage
Cryo-compressed
Additional questions to be addressed

1. What has been done in the three to four years (progress)?

Design and operation of demonstrator prototypes in different vehicle architectures
3 CcH2-vehicles (total 23000 km on public roads, 110 filling cycles)
3 CGH2-vehicles (total 25000 km on public roads, 361 filling cycles)
Operation validated under hot and cold climate conditions.
Preparation for commercialization.

2. What is planned for near term research direction (working topics)?

Load carrying pressure vessels.
Design optimization of pressure vessel (e.g. cost, fibers, storage efficiency).
Investigation of fire resistance behavior of pressure vessels.
Next generation cryo-compressed hydrogen storage.

Storage
Cryo-compressed
Safety relevant research issues H2 storage

3. What are the needs / gaps that need to be filled by future research (new direction)?

CGH2-Storage

- Remote pressure relief.
- Burst impact mitigation.
- Investigation of pressure vessel components (e.g. resin, CFK, liner, insulation) during thermal events.
- Detection of local thermal events.
- State of health monitoring of pressure vessel (fatigue, after crash, thermal events, misuse).
- Extreme impact loads:
  - Event statistics.
  - Protection on vehicle side.
  - Pressure vessel robustness.
- Full range high precision pressure measurement.

CcH2-Storage (additionally)

- Improvement of insulation function.
- Hydrogen conversion system (for blow off hydrogen), improve availability and operating range.

Back up

Microsoft Office
Word Document

Prof. Dr. Jinyang Zheng

Adobe Acrobat
Document

Jan-Mark Kunberger