Safety Implications of Hydrogen Applications for Rolling Stock

El hidrógeno como agente de cambio del sector ferroviaro al net zero

Webinar – July 9th, 2024

TÜV SÜD

Add value.
Inspire trust.

TÜV SÜD
At a glance

150+
Years of safety, security and sustainability

100 %
Independent and impartial

70,000
System certificates

1,000+
Locations worldwide

1-Stop
Solutions provider

550,000
Product certificates

26,000+
Employees

50,000
Personnel certificates

€ 2.9 bn
in annual revenue

Our accreditations and recognitions for Rail

INSPECTION BODY

- **DIN EN ISO/IEC 17020 Type A**
- For infrastructure, energy, signalling, IT security, functional safety/automation and rolling stock
- In Europe, Korea and China

TESTING BODY

- **DIN EN ISO/IEC 17025**
- **UIC 541-00 and 541-05** for wheel slide protection tests and to supervise in-service test
- **CAN/CGSB 43.147-2005, CSA B625-08** for container test
- **Machinery Directive Annex 4** for safety components
- ISO/IEC 17025 for **CNAS fire lab**

CERTIFICATION BODY

- DIN EN ISO/IEC 17065
- For ECM certification for Rolling Stock

NOTIFIED BODY

- **EU Directive 2008/57/EC and (EU) 2016/797**
- Associated partner of **EBC**

DESIGNATED BODY

- DeBo in Germany, Austria, Norway, Finland, Switzerland, Denmark, Netherlands, Luxembourg, Italy, Poland

ASSESSMENT BODY

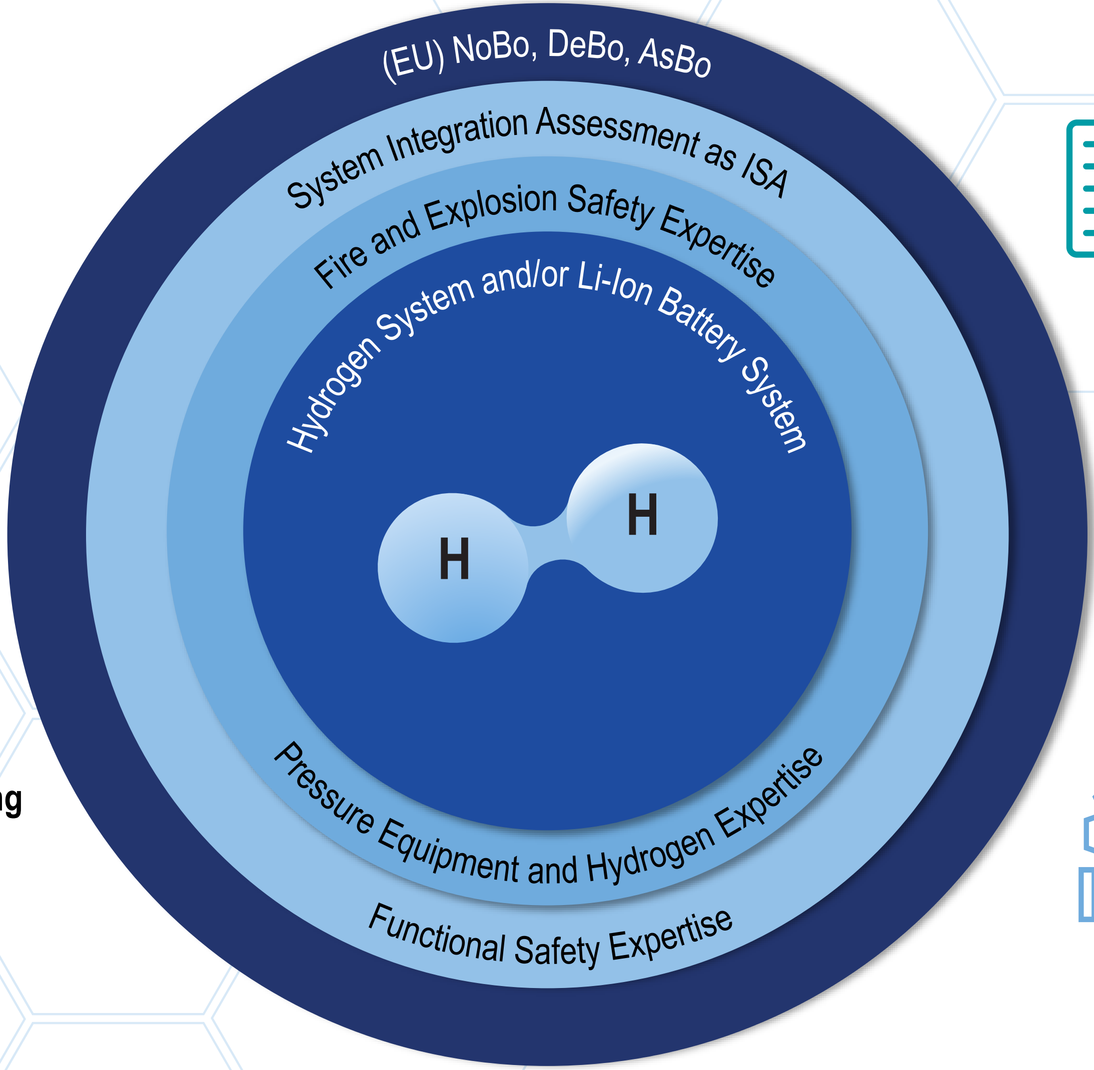
- **EU Regulation 402/2013/EU and (EU) 2015/1136**
- AsBo in EU and Switzerland

- EBA approved experts, including ECM
- BOStrab
- OIF (Italien)

TÜV SÜD’s Hydrogen Competences

Rail assessment

- Rolling Stock Independent Safety Assessor (ISA) acc. to EN 5012x
- Notified Body (NoBo),
- Designated Body (DeBo),
- Assessment Body (AsBo)



Specific hydrogen services

- H_2-Component inspection, homologation and/or CE-certification
- H_2-Infrastructure inspection and certification
- Environmental and railway suitability testing

Battery and H_2-Component testing

- Battery abuse testing
- Battery performance testing
- Hydrogen component testing
- Certification

Additional services

- Training, seminars and workshops
- Moderation of risk analyses

TÜV SÜD's Hydrogen Competences
Project Experience

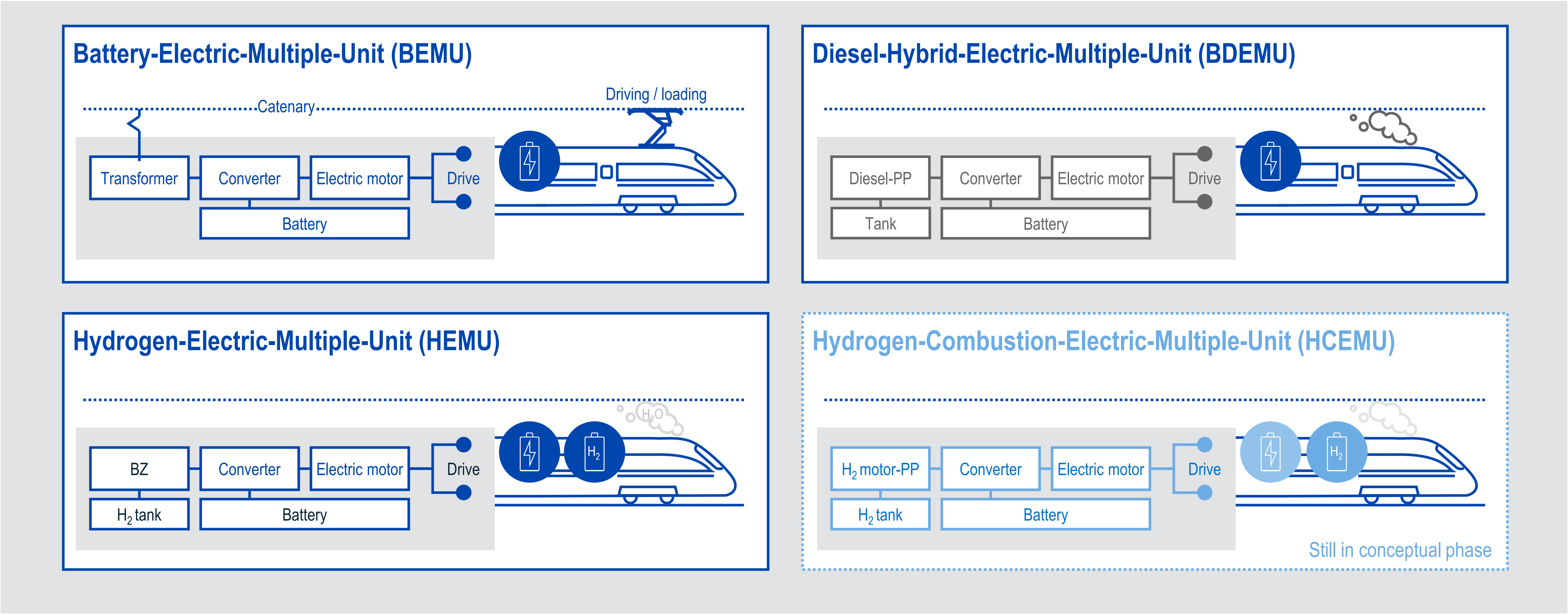
- Starting with the Alstom Coradia iLINT, TÜV SÜD Rail assessed the safety of the hydrogen and traction battery technology during development as ISA and EU Assessment Body
- Further assessment assignments followed, partly with subsystem assessment, filling station and process validation as well as maintenance infras-tructure and process assessments, among others:
  - FLIRT3 SBCTA ZEMU
  - CAF CIVIA H2 (FCH2RAIL)
  - LINSINGER MG11 H2
  - SIEMENS Mireo Plus H
  - Hyundai Rotem H2-Tram

Project Images

Content

Introduction

State of the art in the railway industry



Introduction
Qualitative comparison of technologies

Propulsion Technology	Fuel	Technological readiness	Range	Emissions (in the overall balance)	Economical efficiency
EMU (Catenary)	Electric	Proven	Limited by electri-fication of net	**Emission free** (depending on generated power)	**Best** (on the long term)
BEMU (Battery and Catenary)	Electric	In service for some years	50 to 100 km	**Emission free** (depending on generated power)	**Good** (on short non-electrified tracks)
DEMU (Fossil Fuel Combustion)	Fossil	Proven	> 1,000 km	**High**	**Medium** (expecting oil prices to rise in future)
	Synthetic	Under development	> 1,000 km	**Minor local emissions** (depending on generated power)	**Low** (high energy consumption)
HEMU (Hydrogen Fuel Cell)	Hydrogen / electric	In service / bi-mode under development	600 to 1,000 km	**Emission free** (depending on generated power / H_2 production)	**Medium to good** (on long non-electrified tracks, expecting H_2-prices to drop)
HCMU / HCEMU (Hydrogen Combustion)	Hydrogen	Under development	500 to 1,000 km	**Minor local emissions** (depending on generated power / H_2 production)	**Medium to good** (on long non-electrified tracks)

Source: TÜV SÜD Rail

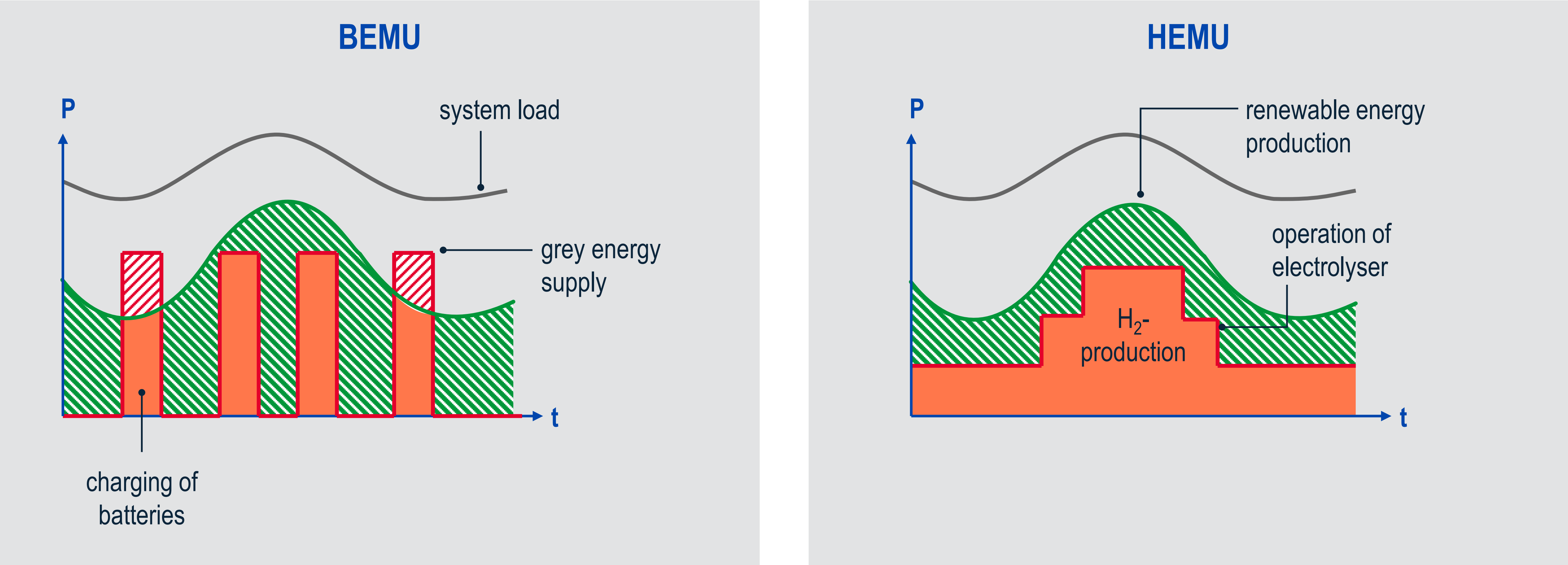
Introduction
Comparison of power efficiency

	Energy production	From energy production to vehicle storage system		From vehicle storage system to wheel	
Reference-EMU	mixed / renewable simultaneously	**Power grid** Transmission / transformation 50 Hz to 16,7 Hz if required/ supplied via overhead contact line		**Vehicle** Transformer / Converter / Engine	$\varepsilon_{\text{el'RE to BEV}}$ = 72 %
		$\varepsilon_{\text{transmission}}$ = 90 %		$\varepsilon_{\text{tank to wheel}}$ = 80 %	
BEMU	mixed / renewable simultaneously	**Power grid** Transmission / transformation 50 Hz to 16,7 Hz if required/ supplied via overhead contact line		**Vehicle** Charging / Discharging / Converter / Engine	$\varepsilon_{\text{el'RE to BEV}}$ = 65 %
		$\varepsilon_{\text{transmission}}$ = 90 %		$\varepsilon_{\text{tank to wheel}}$ = 72 %	
HEMU / HCEMU	mixed / renewable simultaneously	**Power grid** Transmission / AC-DC-Converter	**Hydrogen** Production / Storage / Logistic / Refuelling	**Vehicle** Fuel cell / Converter / Engine H_2-PowerPack / Stromrichter / Motor	$\varepsilon_{\text{el'RE to BEV}}$ = 25 – 31 % FCS 21 – 25 % HyCE
		$\varepsilon_{\text{transmission}}$ = 90 %	$\varepsilon_{\text{transmission}}$ = 55 – 67 %*	$\varepsilon_{\text{tank to wheel}}$ = 51 %	
SYN	mixed / renewable simultaneously	**Netz** Übertragung / AC-DC-Gleichrichter	**SYN-Erzeugung** Elektrolyse / Synthese / Betankung	**Vehicle** Combustion Engine / Generator / Converter / Engine	$\varepsilon_{\text{el'RE to BEV}}$ = 15 – 18 %
		$\varepsilon_{\text{transmission}}$ = 90 %	$\varepsilon_{\text{transmission}}$ = 40 – 47 %*	$\varepsilon_{\text{tank to wheel}}$ = 42 %	

Source: VDI/VDE-Study „Wasserstoff für den Schienenverkehr“ – September 2022
*If the waste heat is utilised, e.g. through district heating or vehicle-side heating, efficiency can be increased to 80 to 90%.

Introduction

Why Hydrogen for Rail?



— Power demand BEMU or electrolyser Reference of non-renewable energy renewable energy

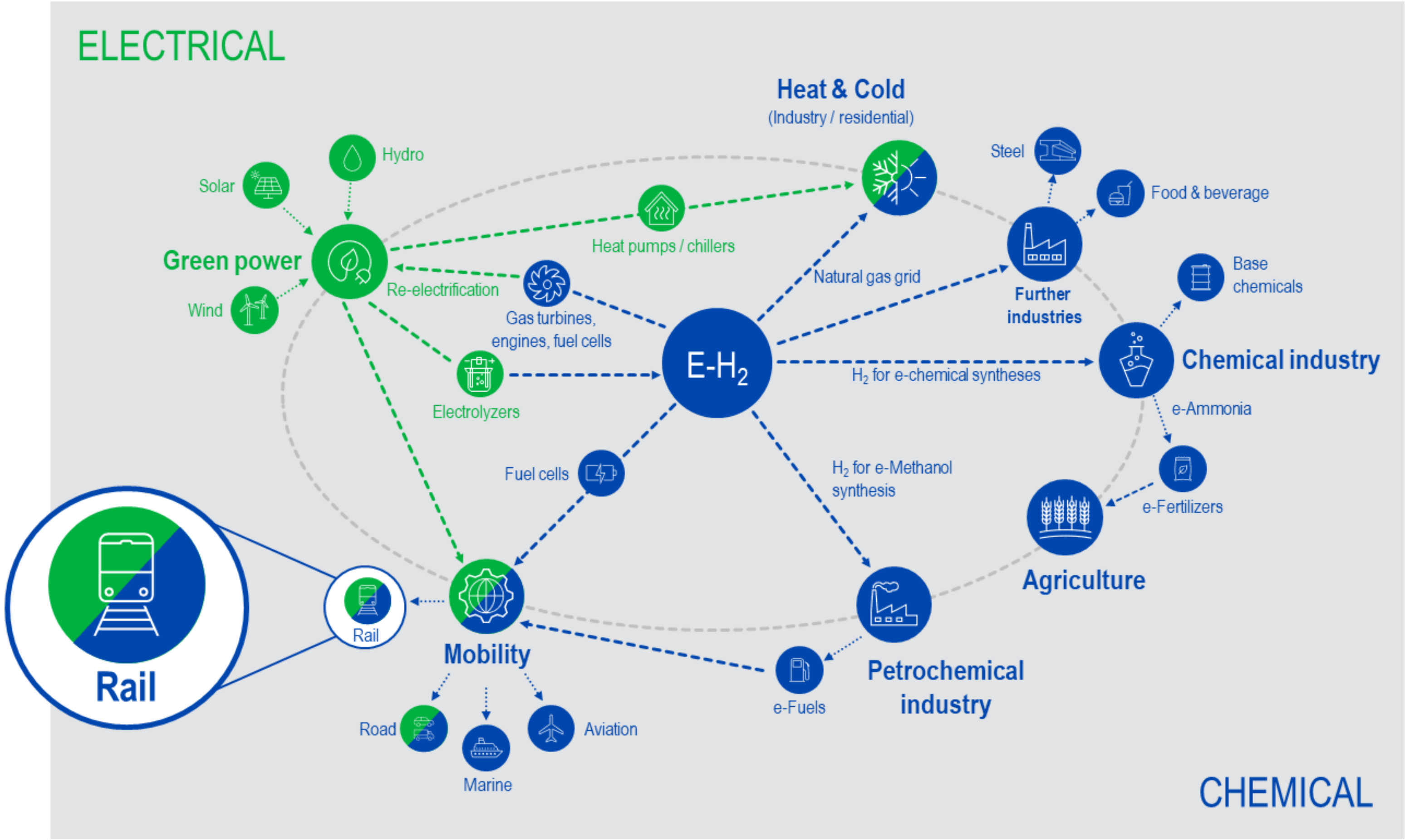
Source: VDI/VDE-Study „Wasserstoff für den Schienenverkehr" – September 2022

Introduction

Railways with Hydrogen Propulsion will remain a niche

- Imagining a future fossil free economy the mobility sector, especially the road and rail-sectors, will make use of both energy carriers:
  Electrical or **Hydrogen** or both
- Compared to the market size of road, marine and aviation, hydrogen trains will remain a niche with regards to total production numbers
- Hence, synergies between the sectors, especially heavy-duty road and rail application must be used and further developed!

→ Railway manufacturers will not reinvent the wheel but deliver a railway-specific safety evidence!

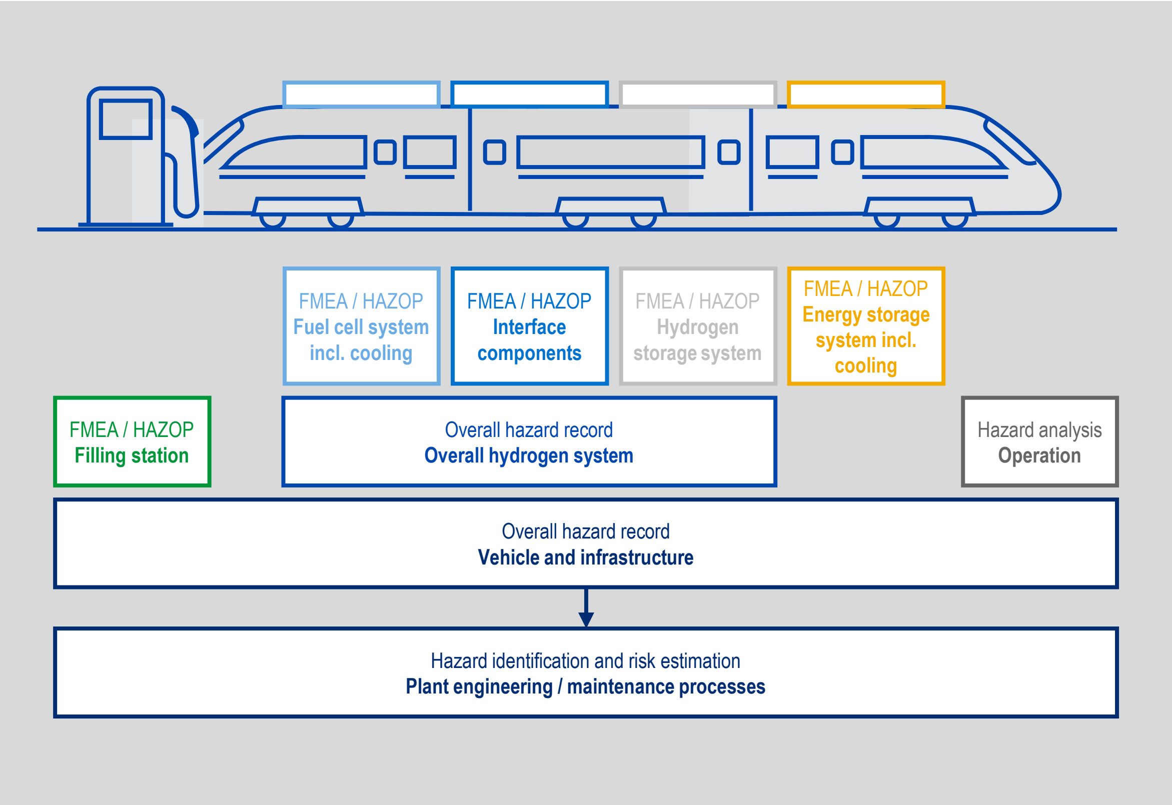


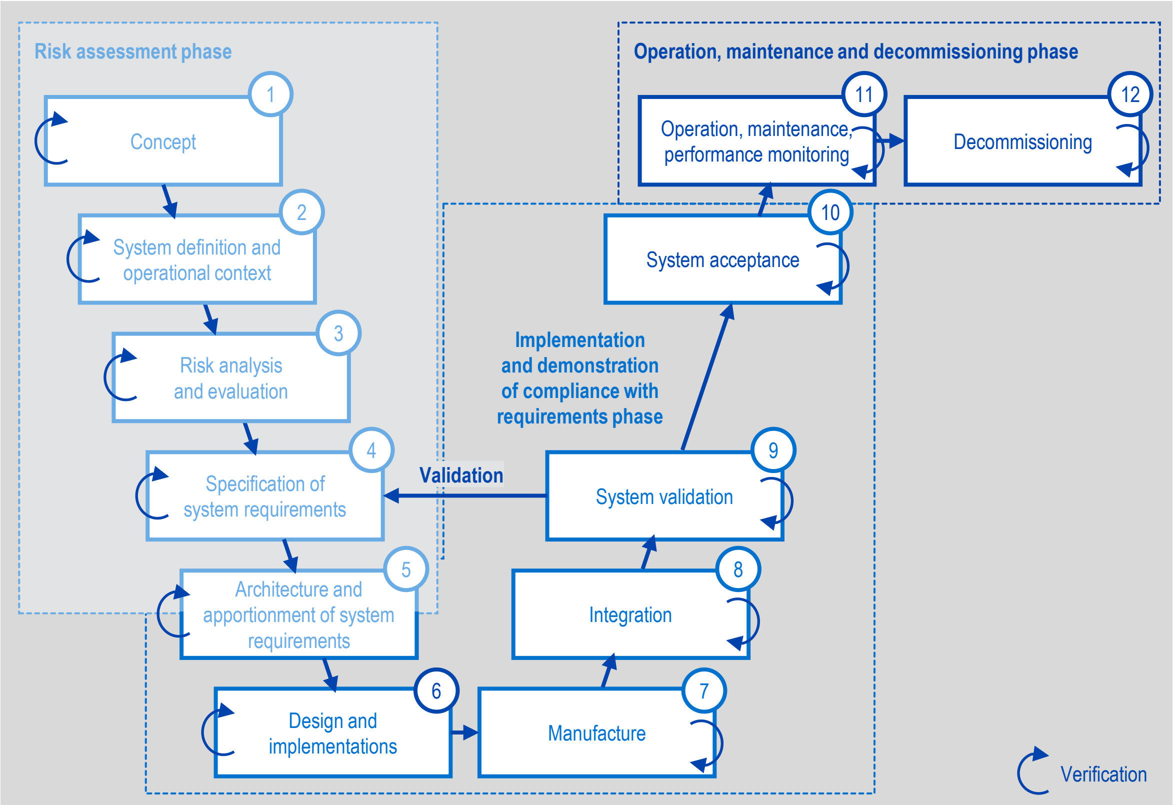
Content

Risk based approach

Requirements are derived from risk analysis – not standards

- The railway industry typically follows the system life cycle (V-model) acc. to EN 50126-1 (resp. IEC 62278) with regards to the different phases of product development including concept, design, validation as well as operation, maintenance and emergency handling
- In the risk assessment phase, the requirement specifications for relevant subsystems, their integration as well as operational aspects must be defined





Risk based approach
Choosing the right method is key

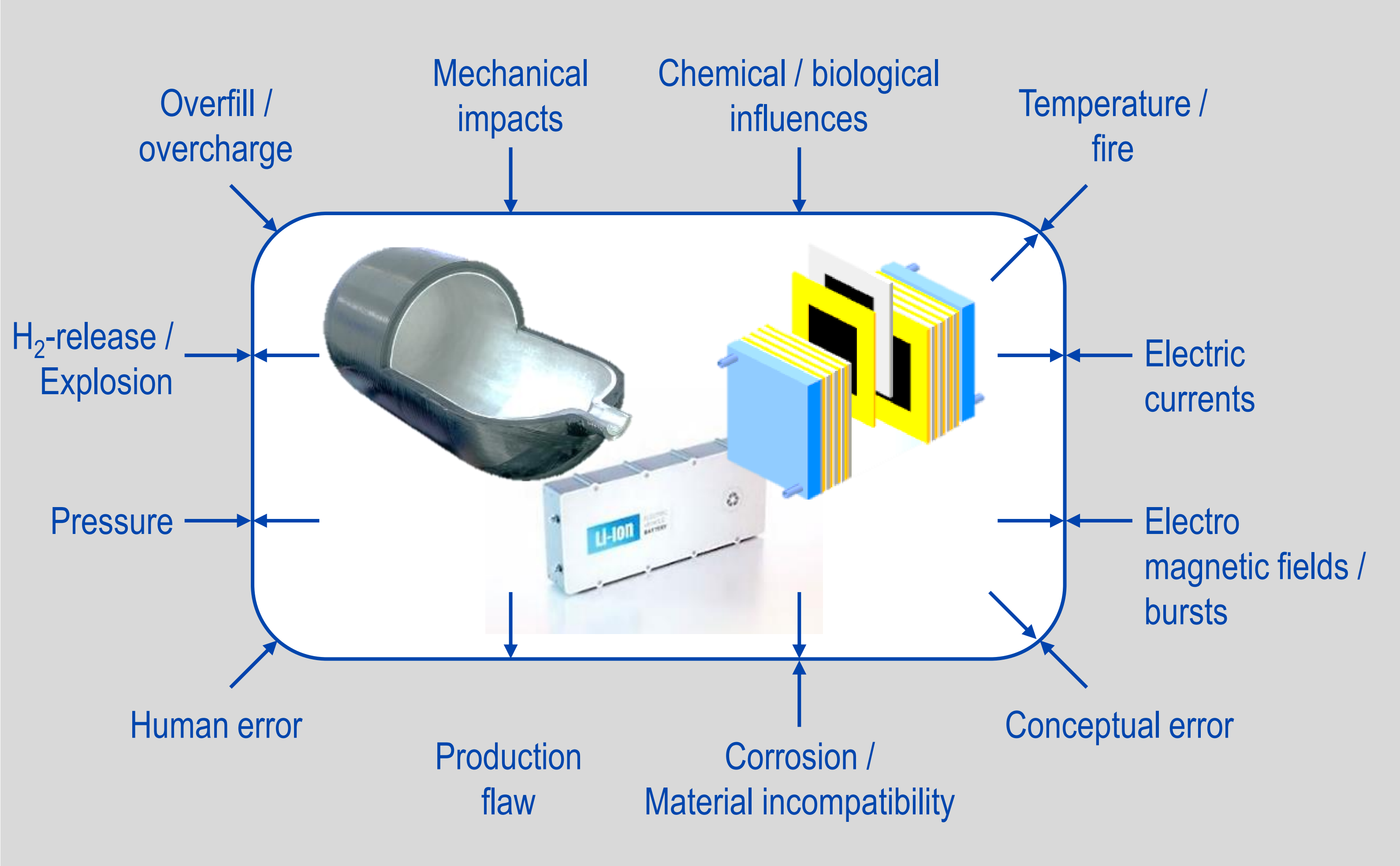
- Different risk analysis methods can be usefully applied depending on the level of knowledge of impacts and hazards
- For H_2 systems in rail vehicles, the effects of component failure in particular are partly unknown
  → Inductive / explorative analysis FMEA or HAZOP

Explosion hazard analysis acc. IEC 60079-10-1 is mandatory and must be combined with a risk analysis to determine and avoid potential sources of secondary releases

Effect of component failure		Hazard causes: Known	Hazard causes: Unknown
	Known	Description of the system behaviour	Deductive analysis (failure tree analysis)
	Unknown	Inductive analysis (FMEA)	Explorative analysis (HAZOP)

Risk based approach

Many existing standards are suitable for mitigation



Applicable railway standards for mitigation

Mechanical impacts / shock and vibration:
EN 12663-1, EN 15227, EN 61373

Environmental impacts:
EN 50125-1, EN 50155

Fire safety:
EN 45545-x

Electrical protection:
EN 50124-1, EN 50153, EN 50343

EMC:
EN 50121-3-2

Functional safety:
EN 50126-x, EN 50128, EN 50129

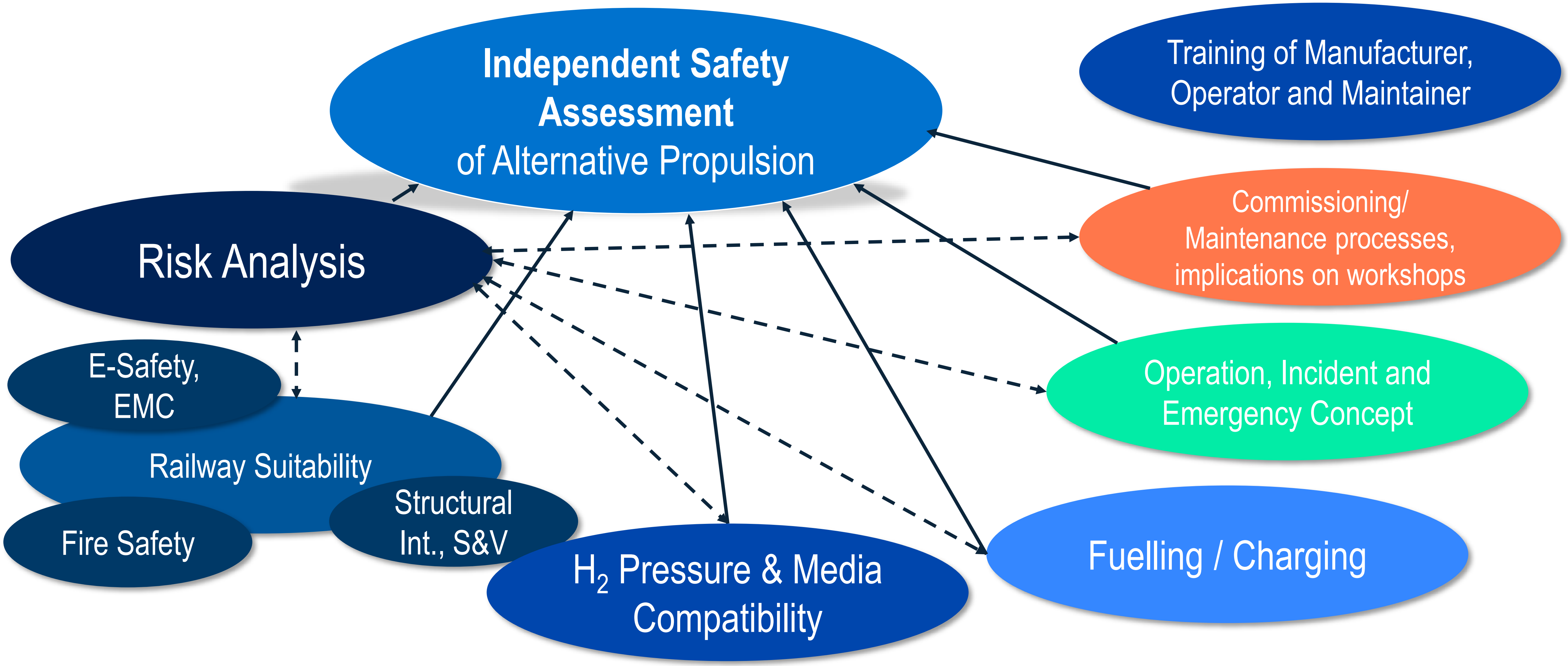
Traction batteries:
IEC 62928

Fuel cells:
IEC 63341-1 (draft)

H_2 storage:
IEC 63341-2 (draft)

→ Several rail specific ISO standards are under development

Risk based approach
Development accompanying assessment by TÜV SÜD




199M
H2
FCH2RAIL
Clean Hydrogen Partnership
Co-funded by the European Union

Content

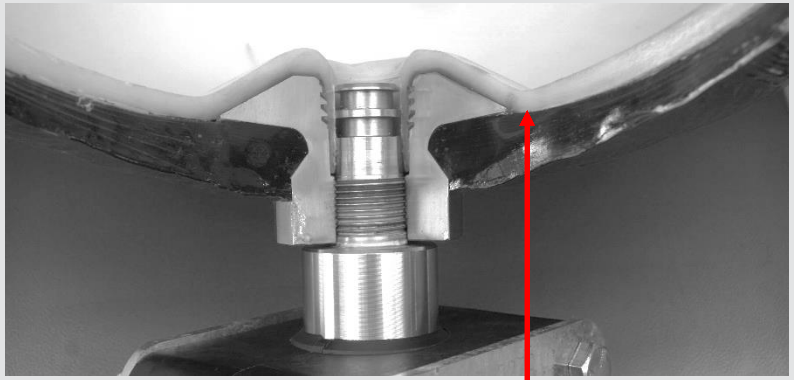
Safety implication examples

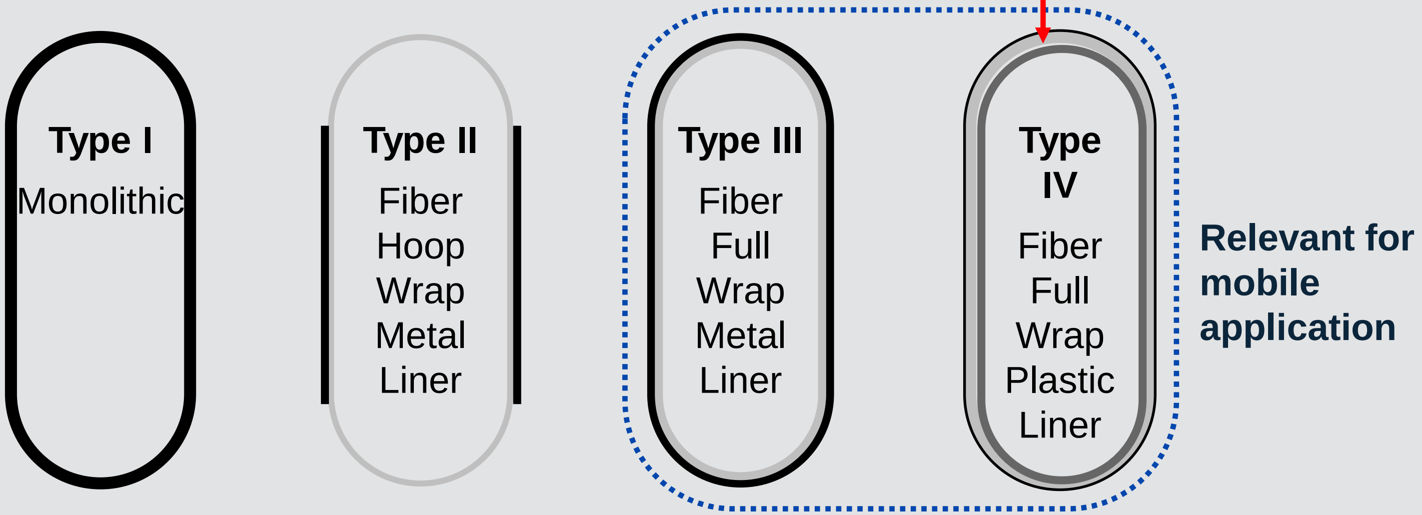
State of the are compressed hydrogen storage

Typical pressure levels:
200 / 350 / 700 bar

Materials:

- Monolithic steel vessel (Type 1)
- Composite vessel (Type 2 to 4) from CFRP / GFRP with permeation barriers from steel, aluminium or thermoplastics





Safety implication examples

Rail and road application have strong synergies

UNECE R134 CHSS type approval tests for road vehicles → acknowledged by IEC 63341-2 for rail application

Verification tests for baseline metrics

Baseline initial burst pressure

Baseline initial pressure cycle life

→ Min. burst pressure = 2,25 x nominal pressure → >788 bar (at 350 bar)

Verification tests for performance durability (test sequence)

Proof pressure

Drop (impact)

Surface damage

Chemical exposure + ambient temperature pressure cycling

High temperature static pressure

Extreme temperature pressure cycling

Residual proof pressure test

Residual strength burst test

Verification tests for expected on-road performance (test sequence)

Proof pressure

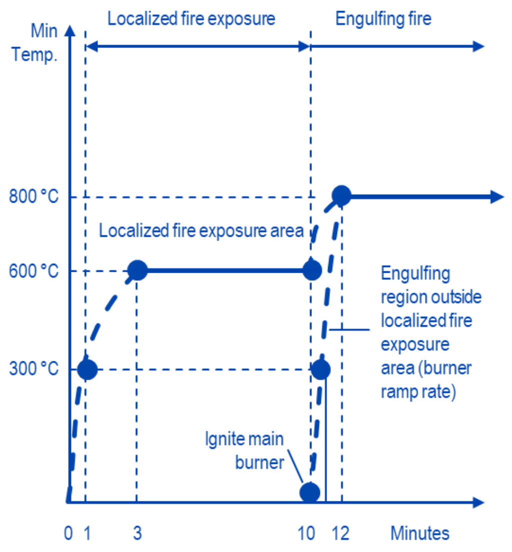
Ambient and extreme temperature gas pressure cycling test (pneumatic) I + II

Extreme temperature static gas pressure leak / permeation test (pneumatic) I + II

Residual proof pressure test

Residual strength burst test (hydraulic)

Verification test for service terminating performance in fire



Safety implication examples

Comparing road vehicle with rail vehicle operation

		
H_2-Storage capacity	LD: 10 – 40 kg, HD: <100 kg	**up to 300 kg**
Life duration	15 – 20 years	**min. 30 years**
Filling cycles over life duration	5.000 – 10.000	**up to 20.000**
Filling cycles dayly	LD: ~1x/week, HD: ~1x/day	**min. 1x/day**
Expected filling time	5 to 10 min	**15 bis 30 min**
Number of safety vavles	2 to 10	**up to 100**

Safety implication examples

Examples of generic risks for railway vehicles

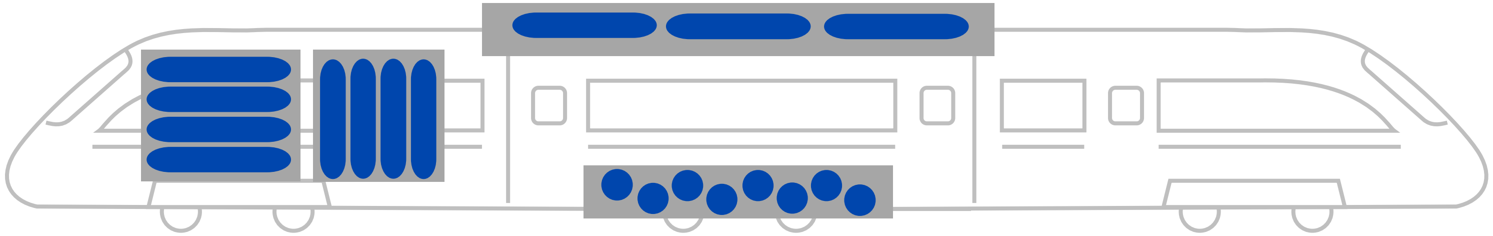
Top level railway specific risks with potentially catastrophic consequence:

Fire scenarios
beyond standard ignition models

Crash scenarios
beyond standard crash impulses

Electric arcing from catenary
non standardized scenario

The result of the risk analysis highly depends on the individual vehicle design,
especially the arrangement of the Compressed Hydrogen Storage System (CHSS) but also fuel cells and piping



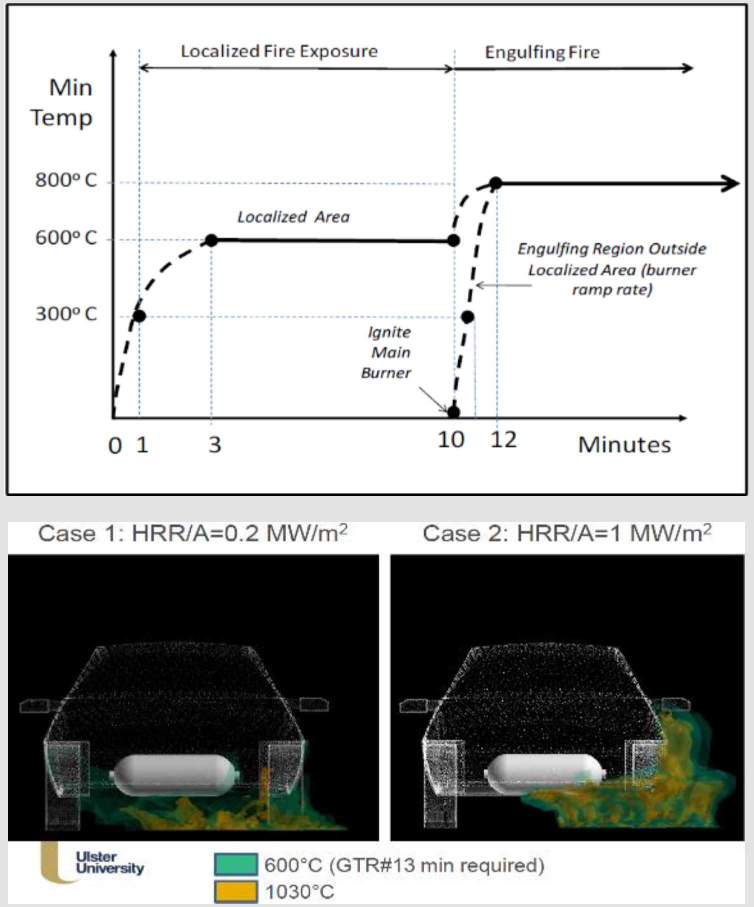
CHSS and components may be arranged:

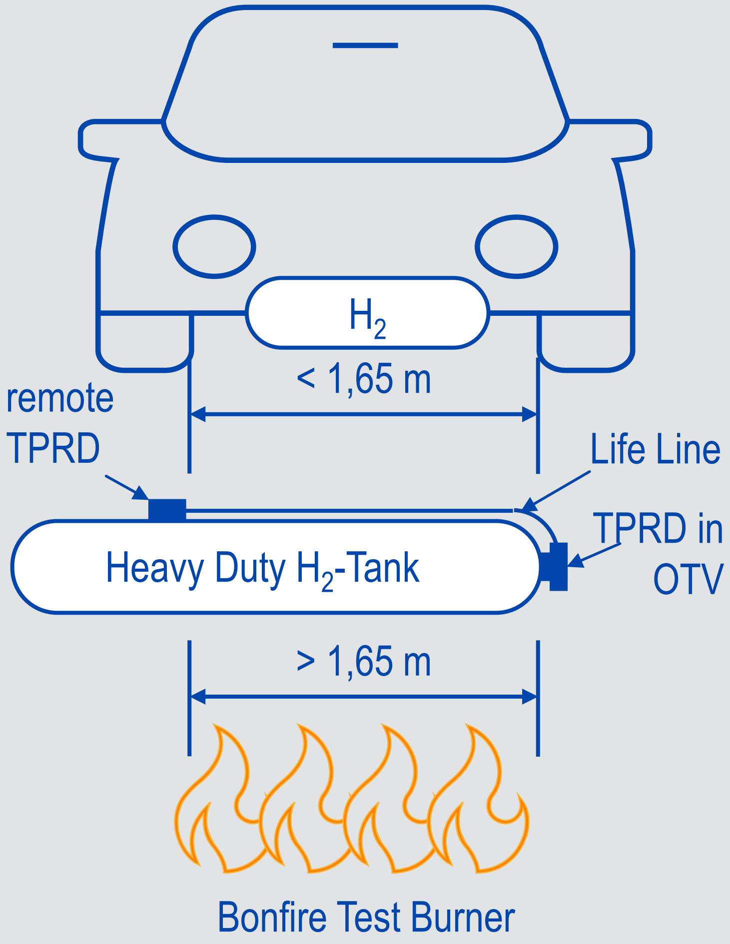
- Below the car body
- On the car body roof
- Inside the car body (vertical)
- Inside the car body (horizontal)

Safety implication examples

Fire and burst protection concept

- In a fire incident, the expected worst-case scenario is a liquid fire below the road vehicle, or the vehicle catching fire on its own ⟶ hydrogen tanks are directly exposed to flames with rapid heat impact
- For this reason, hydrogen pressure tanks are equipped with Thermal Pressure Relieve Devices (TPRDs) to prevent bursting from heat induced over pressure and structural degradation
- The number and placement of TPRDs is chosen to fulfil the automotive type approval test (bon fire test) → Longer tanks require more than one TPRD!



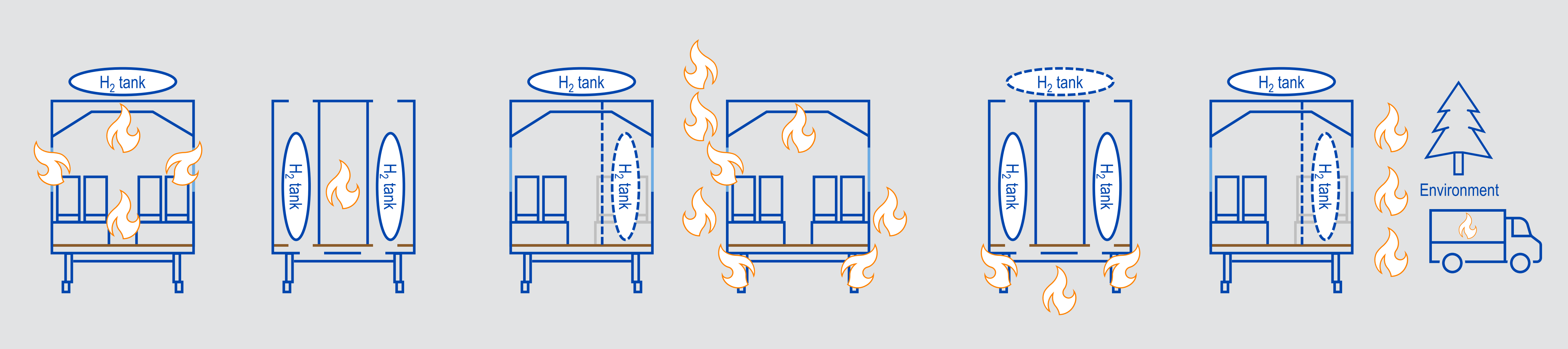


Quelle: SO 19881 und GTR13 Ulster University

Safety implication examples

Fire and burst protection concept

- Depending on the arrangement of the HFS and the potential fire scenario, a **specific radiative or convective heat impact** may be applied on the hydrogen tanks
- Depending on the design of the HFS compartment, the surrounding barriers would avoid a direct flame impact, at least for a significant amount of time → much longer compared to road vehicles!
- The fire and burst protection concept for railway vehicles must be reassessed, since the large number of TPRDs brings along a higher residual risk of failures, leakage and early activation without combustion of the vented hydrogen



Safety implication examples

Crash protection concept

Potential crash scenarios to be considered:

Impact
(on moving object)

Collision
(on rigid object)

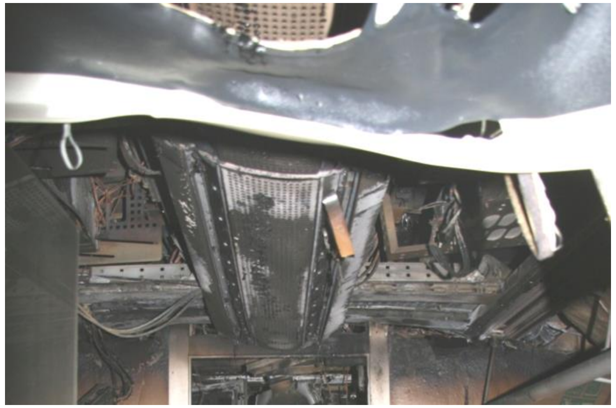
Slanting collision
(Flanking, bumping into an obstacle)

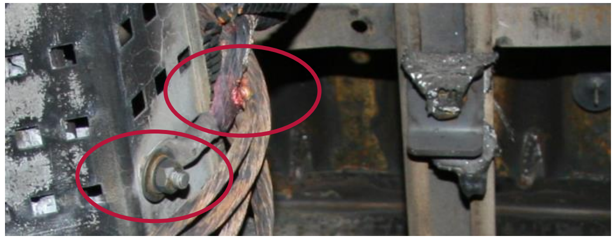
- Consequently, the vehicle may be climb up, roll over, sliding
- H_2 containers have been proven to have very high rigidity against mechanical impact / puncture
- More likely tube ruptures lead to valve closure (excess-flow-valves, solenoid valves)
- **Criticality → Remote TPRDs**
  with pressurized life-lines, which have no means for closure

Safety implication examples
Electric arcing from catenary

Arcing e.g. from 15 kV AC catenary on the vehicle with effect on the roof structure / components → Grounding concept!

Fire incident example:
Collision and emergency stop underneath a branch hanging in the catenary after a storm

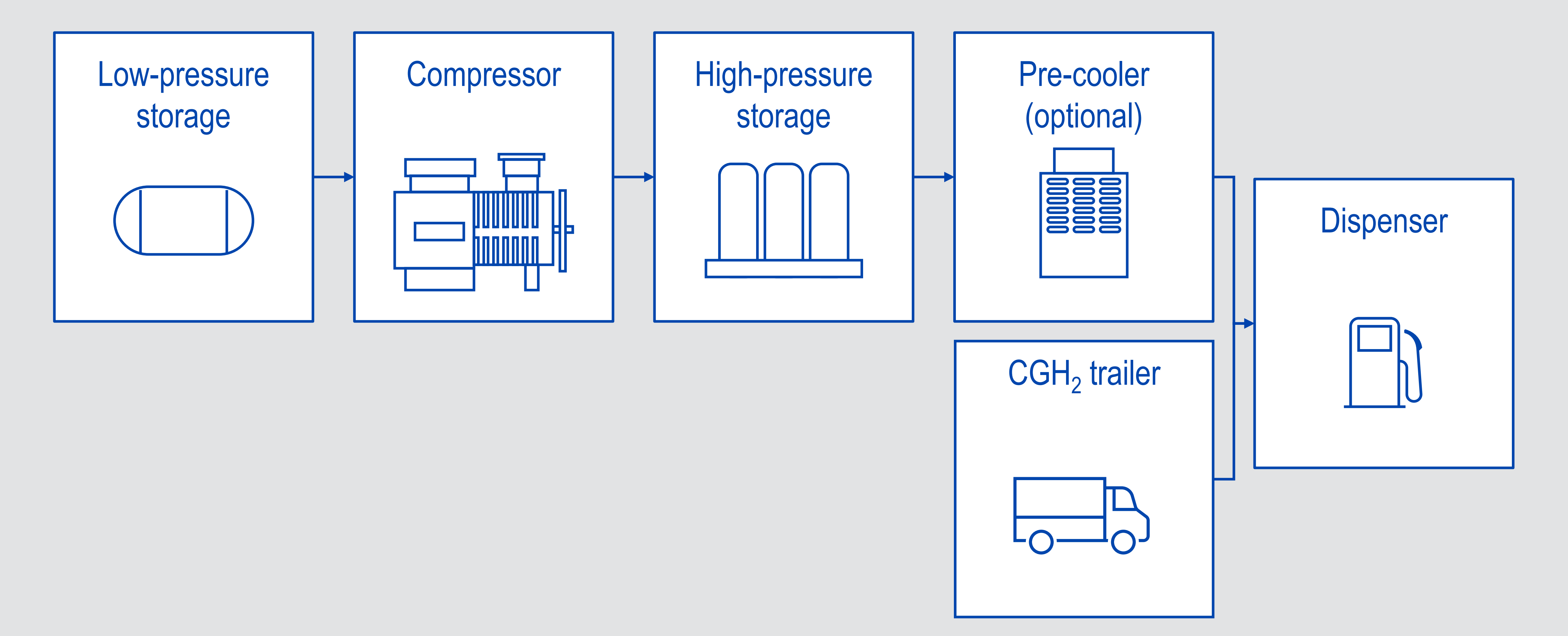




Content

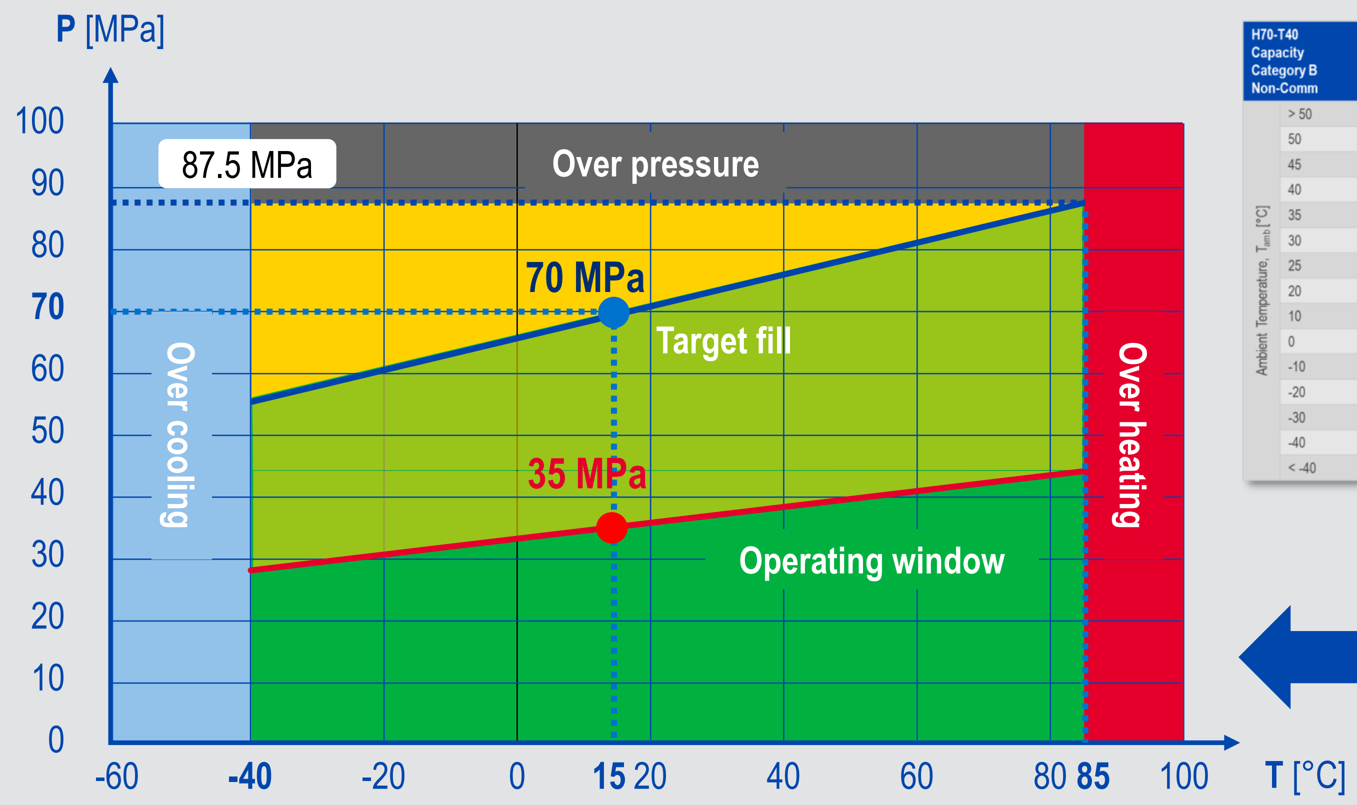
Hydrogen refuelling

Typical rail hydrogen refuelling station concepts



Hydrogen refuelling

Road vehicle filling ramps based on SAE J2601

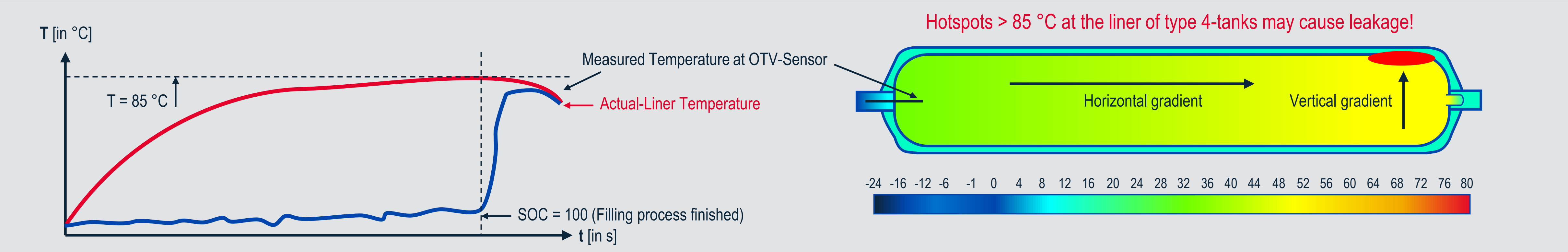


H70-T40 Capacity Category B Non-Comm		APRR [Mpa/min]	Initial Pressure, P_{targer} [Mpa]											
			Initial Tank Pressure, P_0 [Mpa]											
			0,5	2	5	10	15	20	30	40	50	60	70	> 70
Ambient Temperature, T_{amb} [°C]	> 50	No fueling	No fueling	No fueling	No fueling	No fueling	No fueling	No fueling	No fueling	No fueling	No fueling	No fueling	No fueling	No fueling
	50	5,1	77,8	77,6	77,3	76,9	76,6	76,2	75,5	75,3	74,7	73,9	72,8	No fueling
	45	8,1	76,3	77,2	76,9	76,5	76,4	76,2	75,6	75,3	74,7	73,9	72,7	No fueling
	40	11,5	73,2	75,6	76,8	76,3	76,4	76,2	75,6	75,3	74,6	73,9	72,7	No fueling
	35	12,4	72,9	75,3	76,4	76,0	76,1	75,9	75,3	75,1	74,5	73,8	72,7	No fueling
	30	15,3	70,6	73,9	75,8	75,2	75,4	75,1	74,3	74,1	73,3	72,4	71,3	No fueling
	25	18,5	69,0	72,8	75,1	74,5	74,7	74,3	73,3	73,0	72,0	71,1	No fueling	No fueling
	20	21,8	67,9	72,1	74,5	73,7	74,0	73,4	72,2	71,9	70,7	69,7	No fueling	No fueling
	10	28,0	66,3	71,1	74,1	73,2	72,4	71,6	70,9	69,6	68,4	66,9	No fueling	No fueling
	0	28,5	74,0	73,4	72,4	70,6	70,7	69,6	68,6	67,1	65,7	64,0	No fueling	No fueling
	-10	28,5	73,4	72,9	71,9	70,0	70,0	68,4	66,5	64,4	62,9	61,2	No fueling	No fueling
	-20	28,5	72,9	72,3	71,3	71,0	69,5	68,0	65,7	62,4	60,0	No fueling	No fueling	No fueling
	-30	28,5	72,1	71,6	70,6	70,4	69,0	67,4	65,2	61,8	58,7	No fueling	No fueling	No fueling
	-40	28,5	71,6	71,1	70,2	70,0	68,5	66,9	64,8	61,5	58,5	No fueling	No fueling	No fueling
	< -40	No fueling	No fueling	No fueling	No fueling	No fueling	No fueling	No fueling	No fueling	No fueling	No fueling	No fueling	No fueling	No fueling

Choice of filling ramp is done based on residual pressure and ambient temperature

Hydrogen refuelling
Safety implications for rail vehicles

- Gas warms up in the filling process due to the gas work (isenthalpic compression), gas dynamics (friction) and the Joule-Thomson effect
- This effect is intensified by:
  - a low residual pressure in large heavy duty tanks (e. g., below 50 bar)
  - a high gas temperature at the filling station (e. g., above 20 °C)
- Temperature sensors, which are usually part of the on-tank-valve (OTV), can neither measure the actual gas temperature nor the liner temperature due to turbulence and cooling effects of the incoming gas flow → no possibility to detect any abnormality during filling!
- Consequently, the hydrogen filling station is fully responsible for the safe filling of the rail vehicle
- However, this requires comprehensively validated filling curves (SAE J2601-5 is on a good way, but still requires validation, especially for ambient refueling)



Q&A

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