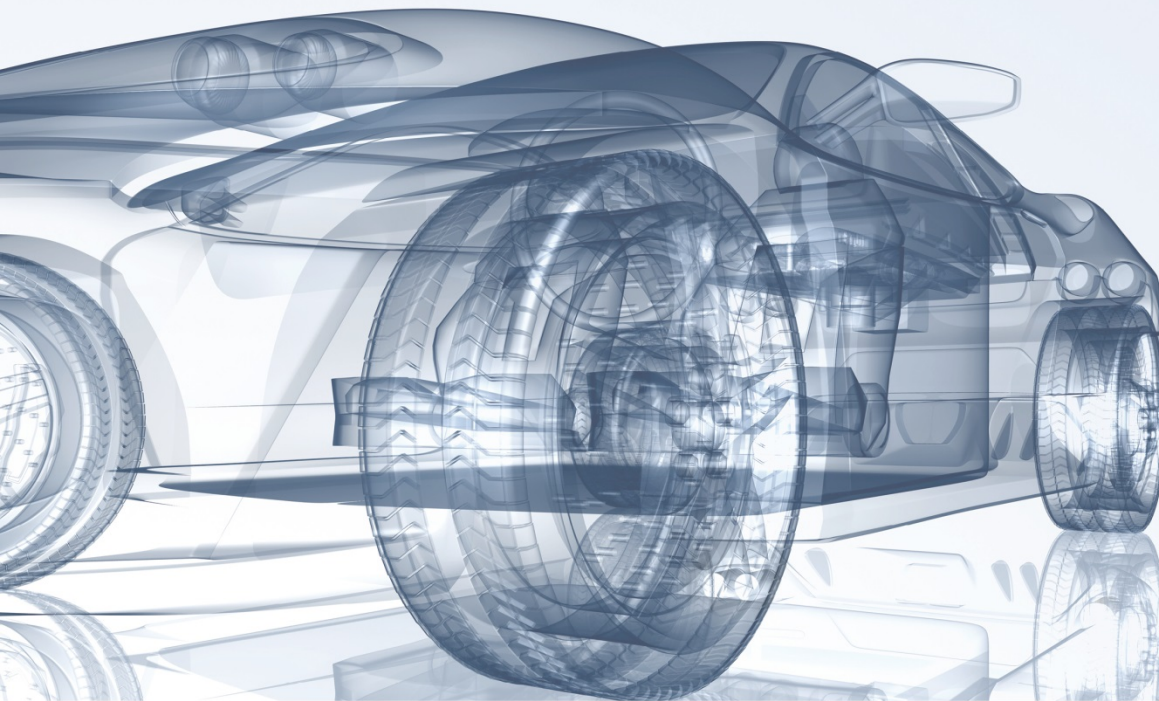


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Crash Safety of Fuel Cell Electric Vehicles

Rainer Justen, Prof. Dr. Rodolfo Schöneburg, Dr. Andreas Dehn, Stefan Boneberg | Daimler AG

EVS30 Symposium

Stuttgart, Germany, October 10, 2017



1 The new GLC F-CELL Plug-In

2 Challenges for Crash Safety

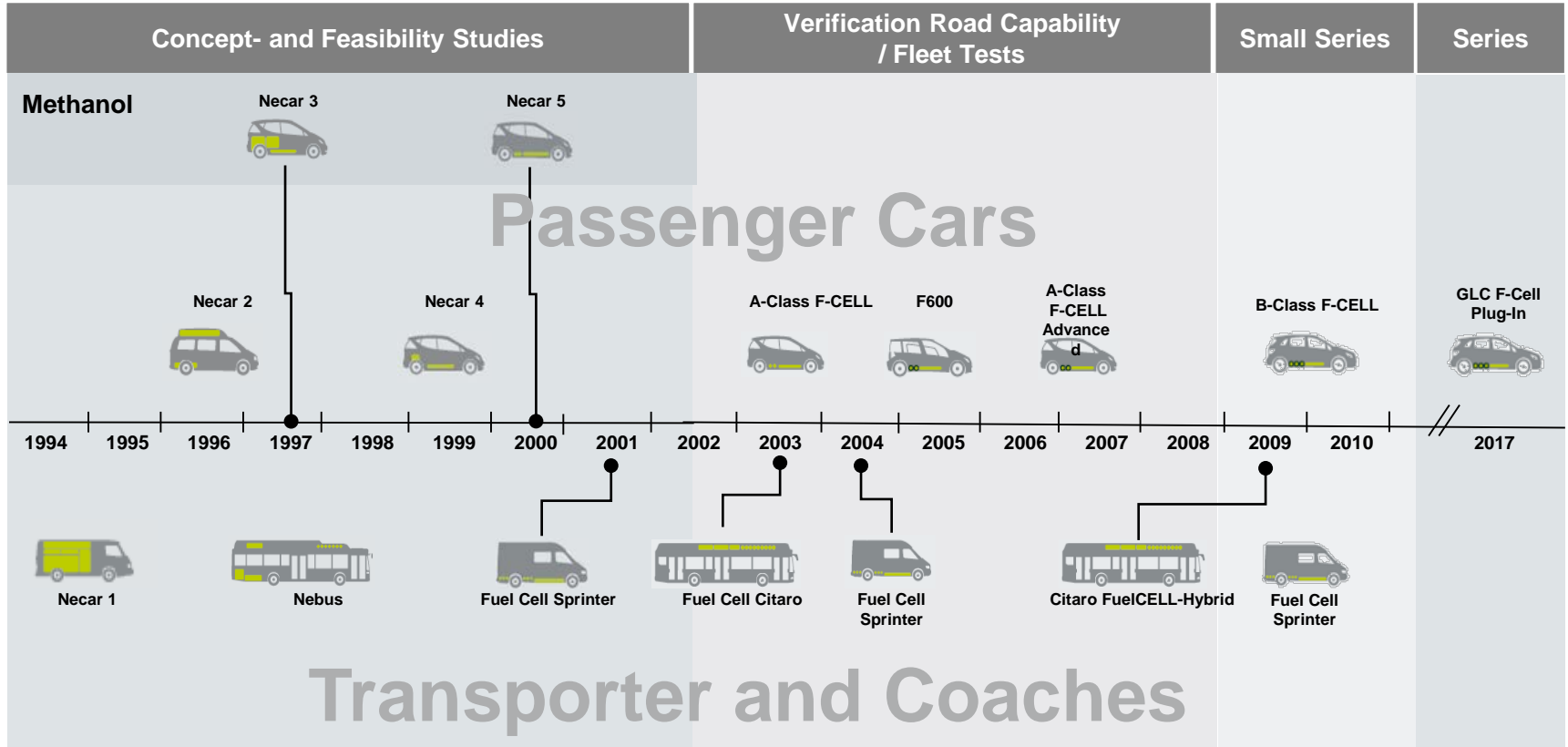
3 Safety Standards

4 Safety Concepts

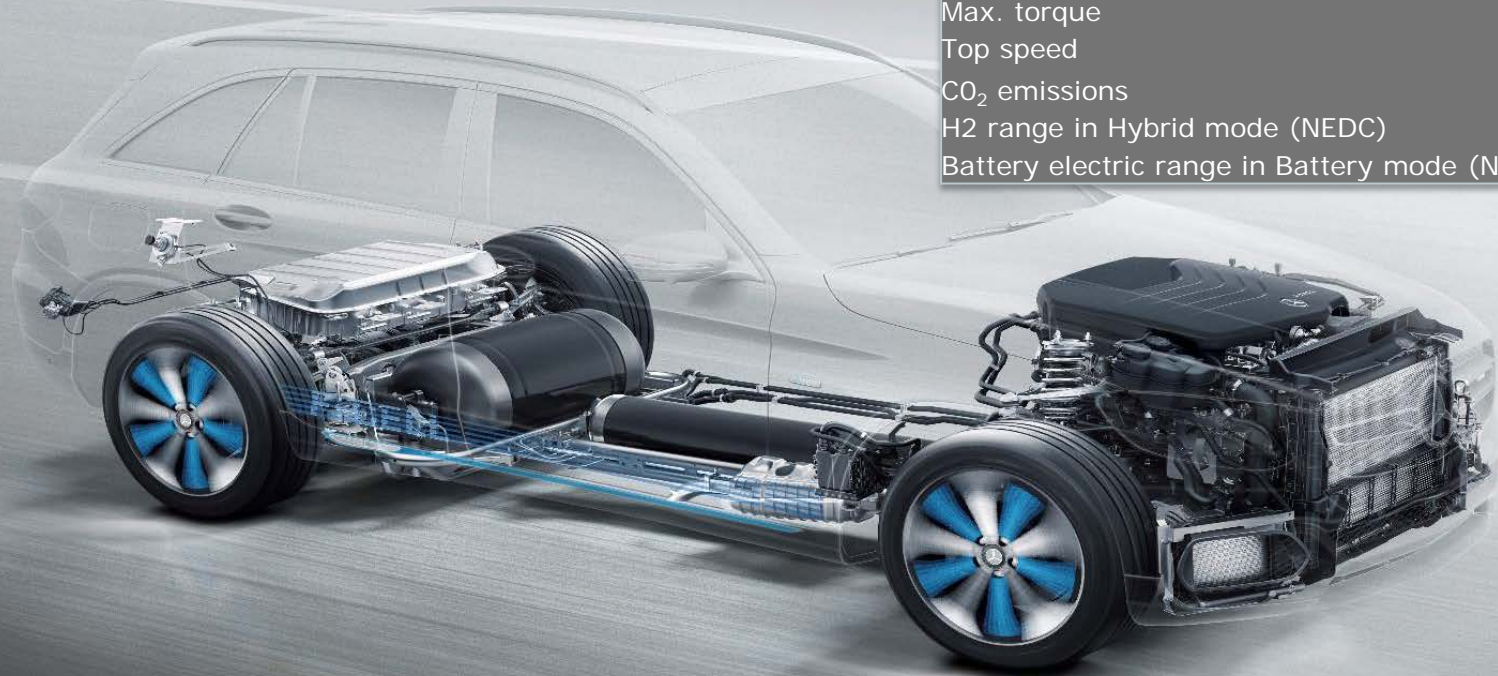
A close-up photograph of a car's front grille. The grille has a dark, diamond-patterned mesh. A prominent blue horizontal bar runs across the middle of the grille. On this bar, there is a blue badge with the white text 'F-CELL'. The car's body is a light color, possibly silver or white, and is visible on the right side of the frame.

F-CELL

Mercedes-Benz History of F-Cell Vehicles



Technical Specification GLC F-Cell Plug-In

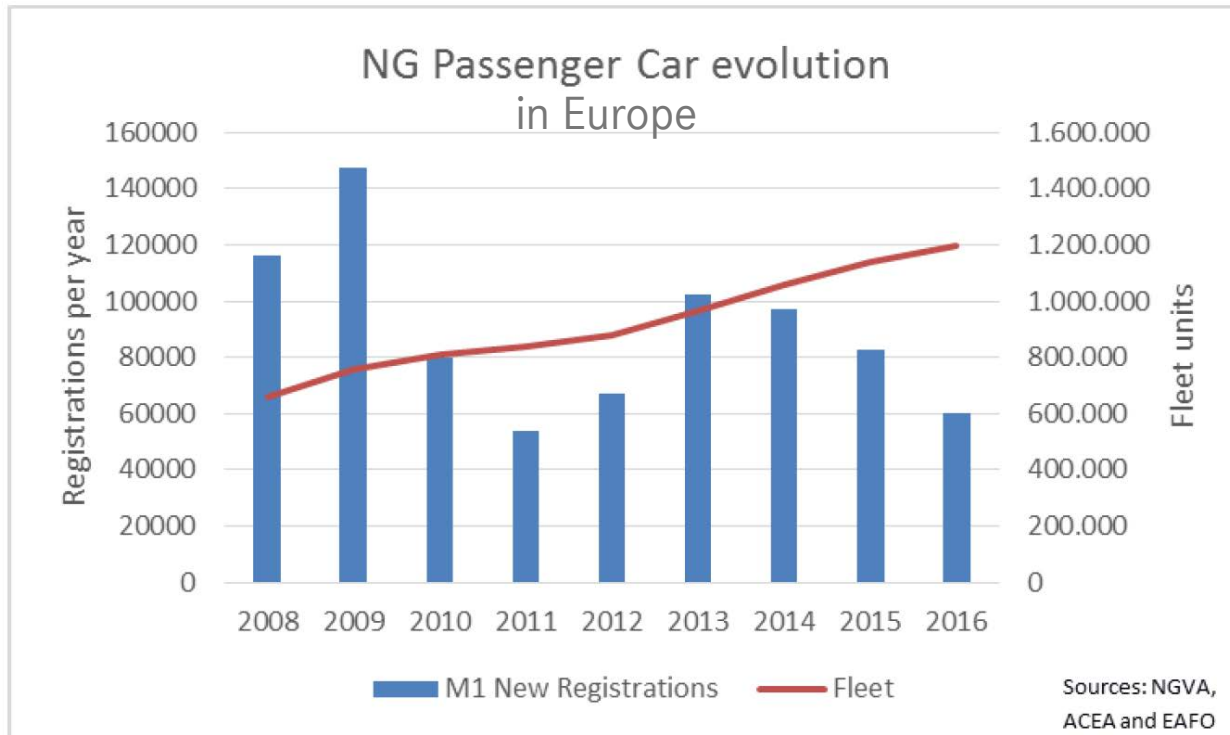


Performance Data Vehicle*

Rated output	kW	147
Max. torque	Nm	350
Top speed	km/h	160
CO ₂ emissions	g/km	0
H ₂ range in Hybrid mode (NEDC)	km	437
Battery electric range in Battery mode (NEDC)	km	49

* Preliminary estimation (not yet confirmed by type approval)

In general gas powered vehicles on a comparable safety level with conventionally fueled vehicles

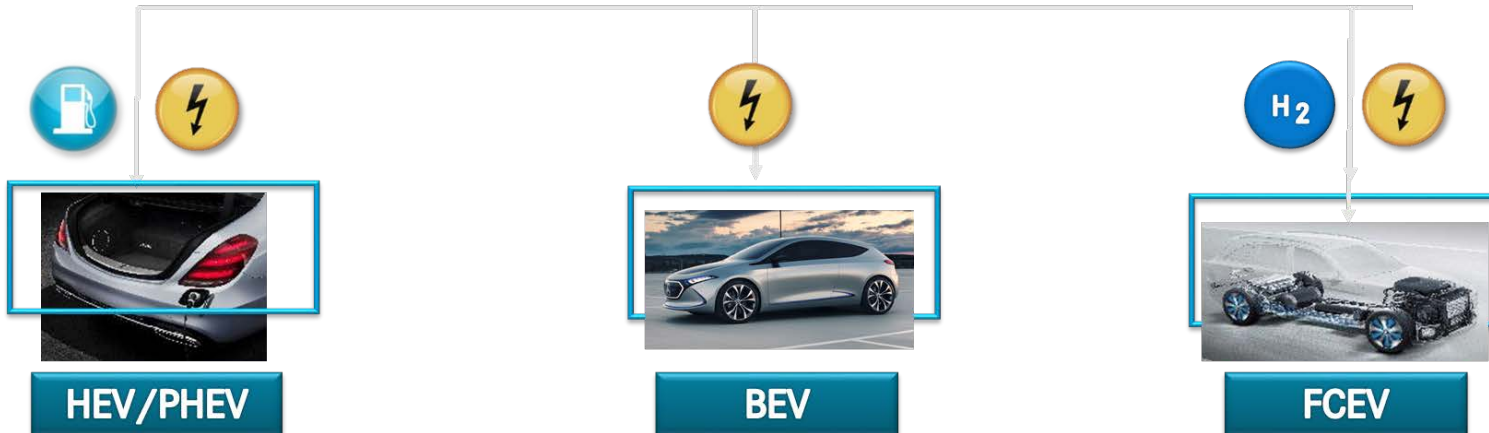


- Nearly 1.3 million NGVs (LPG and CNG) in Europe
- Globally > 15 million NGVs (www.iangv.org)
- Main regions South America, Iran, India, Pakistan
- No significant difference in accidents static compared with conventional vehicles
- Failures of gas tanks only noted in less particular cases

High Voltage Safety, Electric Shock

Fire of Electric Energy Storages

Explosion, Bursting
of Gas Tanks



Hydrogen Safety – Relevant Situations and Risks

Relevant Situations

Vehicle
Parking

Vehicle
Fire

**Vehicle
Crash**

Vehicle
Driving

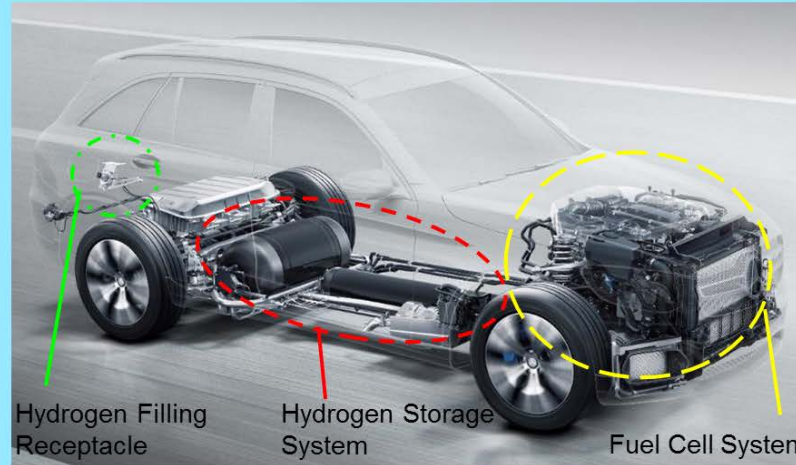
Risks

Hydrogen
accumulation
in garages

Burst of
container

Hydrogen
accumulation
in vehicle
compartments

Leaking Fittings
and Lines



Hydrogen Filling
Receptacle

Hydrogen Storage
System

Fuel Cell System

Hydrogen
release during
refueling

Leaking Fuel
Cell System

Leaking
Container






Hydrogen in
exhaust gas

Vehicle
Refueling

Vehicle
Service

Vehicle
Production

Regulatory Requirements and Standards for Fuel Cell Vehicles (Extract of relevant specifications)

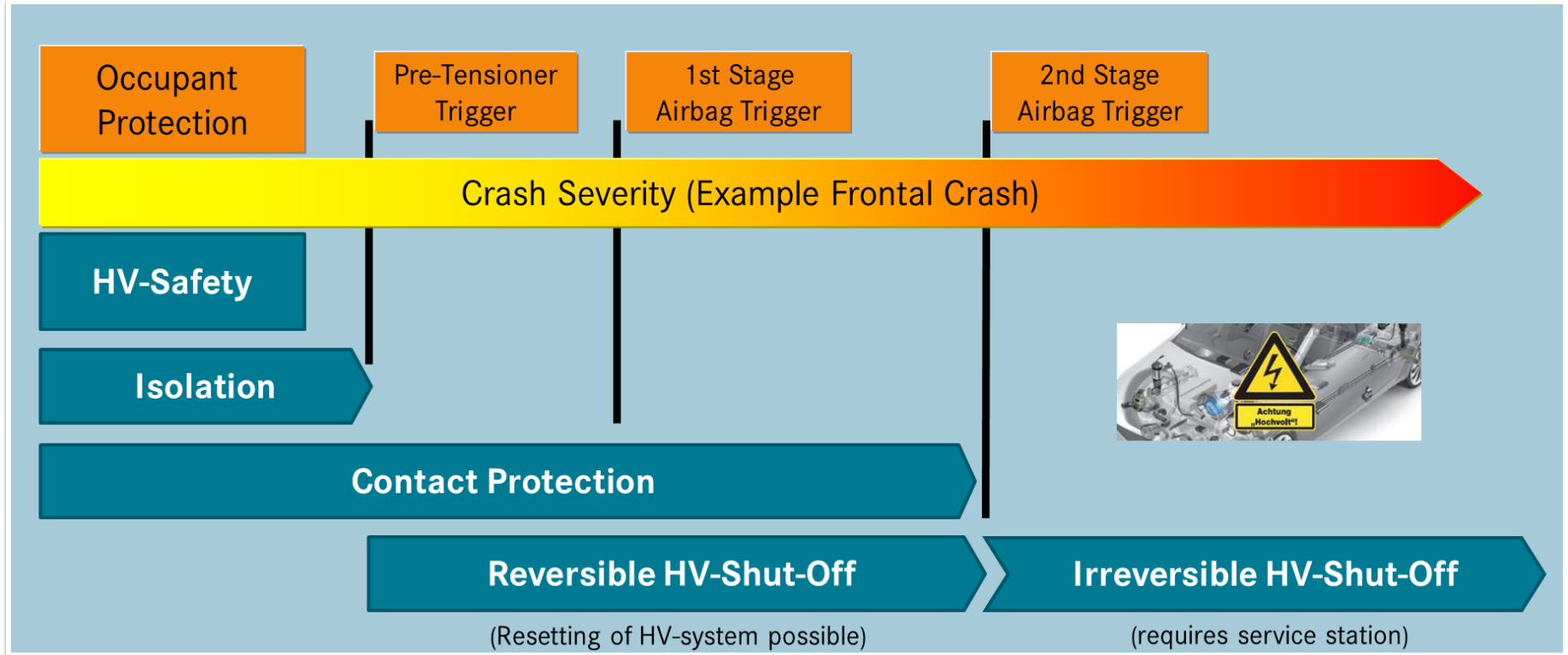
Market	Post-Crash	Component Level
ECE 	ECE R134: Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety-related performance of hydrogen-fueled vehicles (HFCV)	EG 79/2009: Provision (EG) No. 79/2009 of the European Parliament and the Board for approval of hydrogen driven vehicle types, and for the change of the guideline 2007/46/EG
USA 	FMVSS 303: Fuel System Integrity of Compressed Natural Gas Vehicles (CNG vehicles)	FMVSS 304: Compressed Natural Gas (CNG) Fuel Container Integrity
Japan 	Attachment 100: Technical Standard for Fuel Systems of Motor Vehicles fueled by compressed hydrogen gas	
GTR 	GTR13: Global technical regulation on hydrogen and fuel cell vehicles	
ISO 		ISO 23273 Fuel cell road vehicles – safety specifications – Protection against hydrogen hazards for vehicles fueled with compressed hydrogen

Post Crash Requirements for Fuel Cell, Electric and Hybrid Vehicles

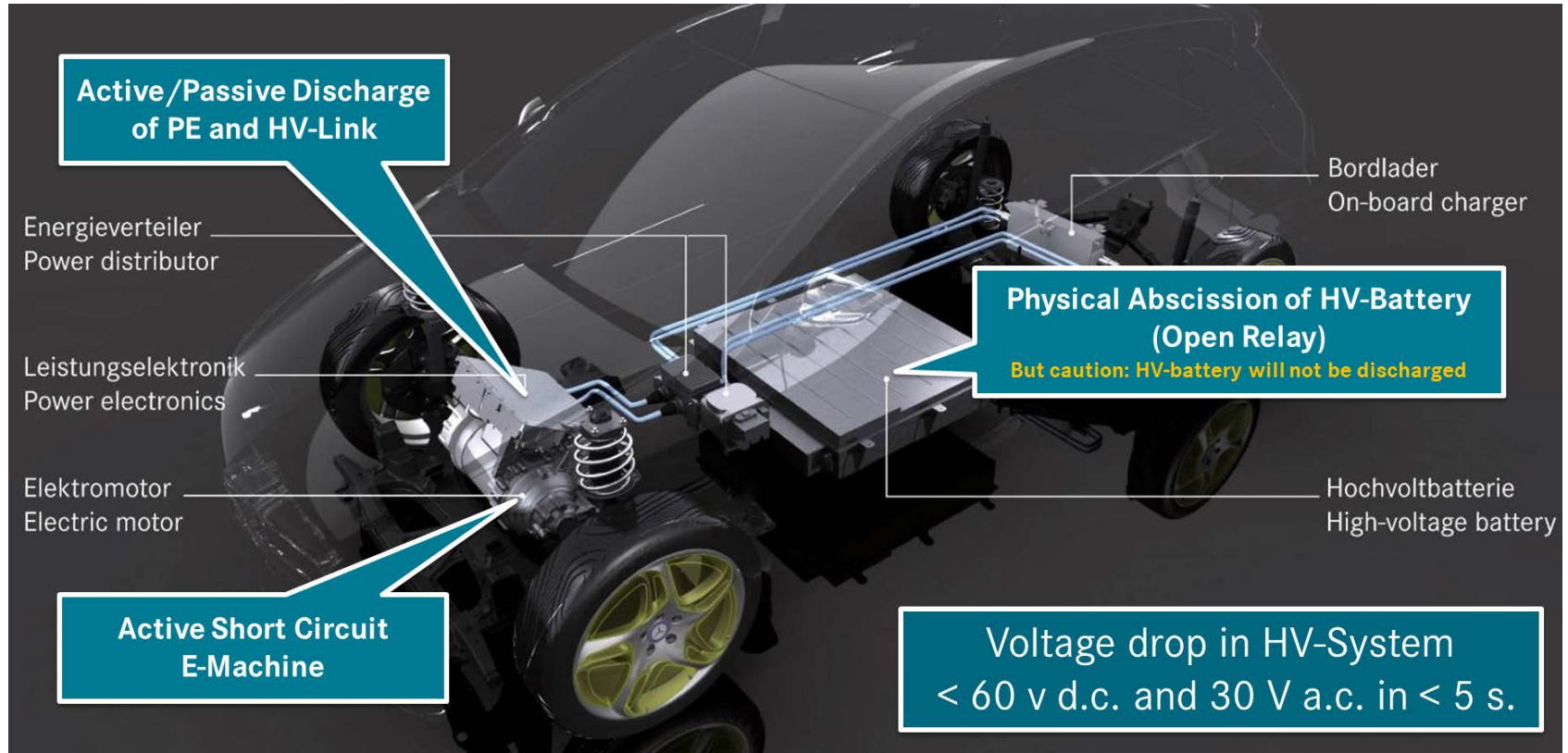
Fuel System Integrity*	Rechargeable Energy Storage System (RESS)*	High Voltage System*
<ul style="list-style-type: none">▪ Volumetric flow of hydrogen gas leakage < 118 NI/min▪ Concentration of hydrogen gas leakage < 4% in passenger and luggage compartments▪ Storage container shall remain attached to the vehicle at a minimum of one point	<ul style="list-style-type: none">▪ No explosion or fire of RESS▪ The RESS shall remain in their mounting points▪ RESS shall not enter the passenger compartment▪ No electrolyte spillage in passenger compartment (Outside passenger compartment < 5 l/7%)	<p>Optional:</p> <ul style="list-style-type: none">▪ El. Isolation > 100/500 Ω/V d.c./a.c▪ High Voltage < 60 V in < 5 sec▪ Electrical Energy < 0,2 J in < 5 sec▪ Physical protection IPXXB

*Extract of relevant requirements from different legal standards (e.g. ECE, FMVSS, TRIAS, GB, GTR)

Mercedes-Benz Safety Concept Against Electrocution & Electric Shock After an Accident



HV-System Shut-Off



Crash related Hydrogen Safety Concept

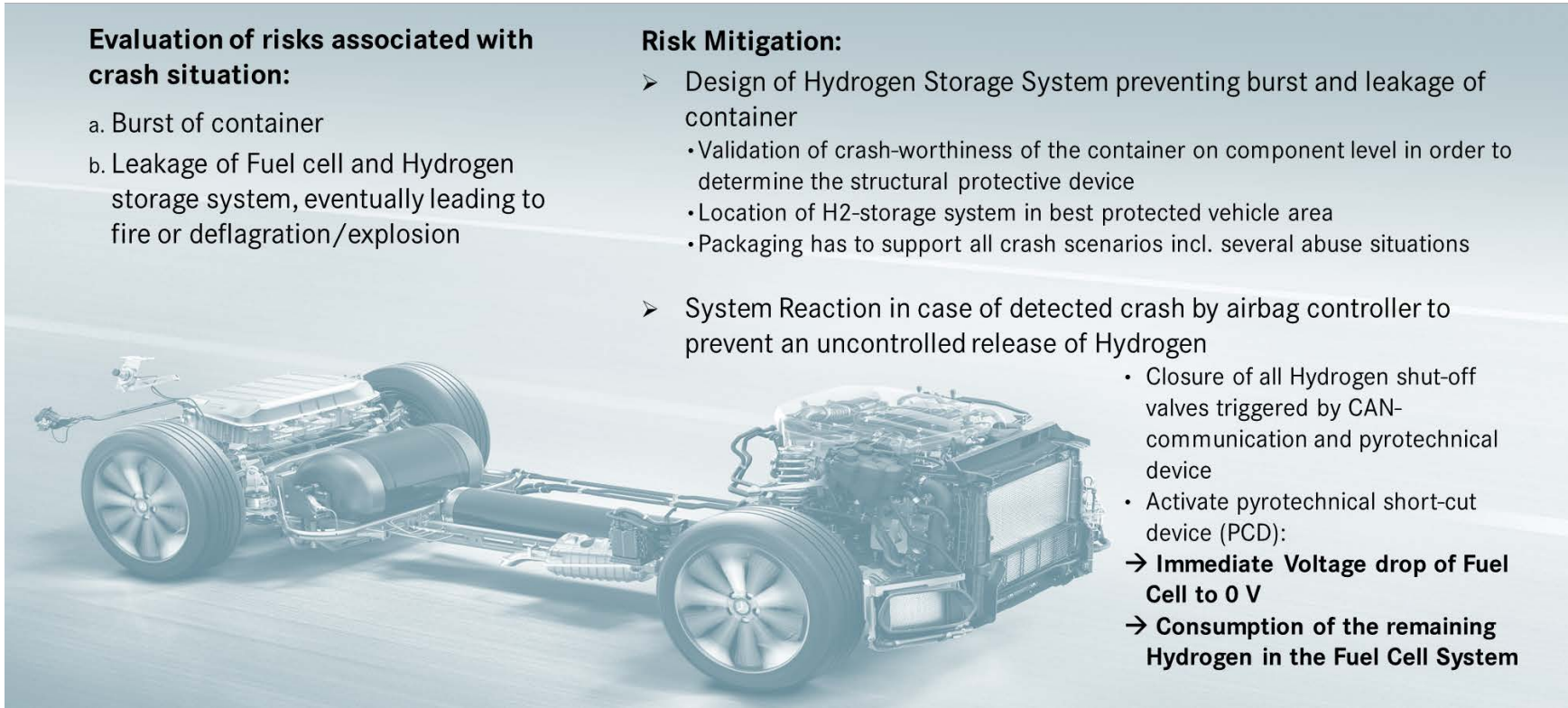
Evaluation of risks associated with crash situation:

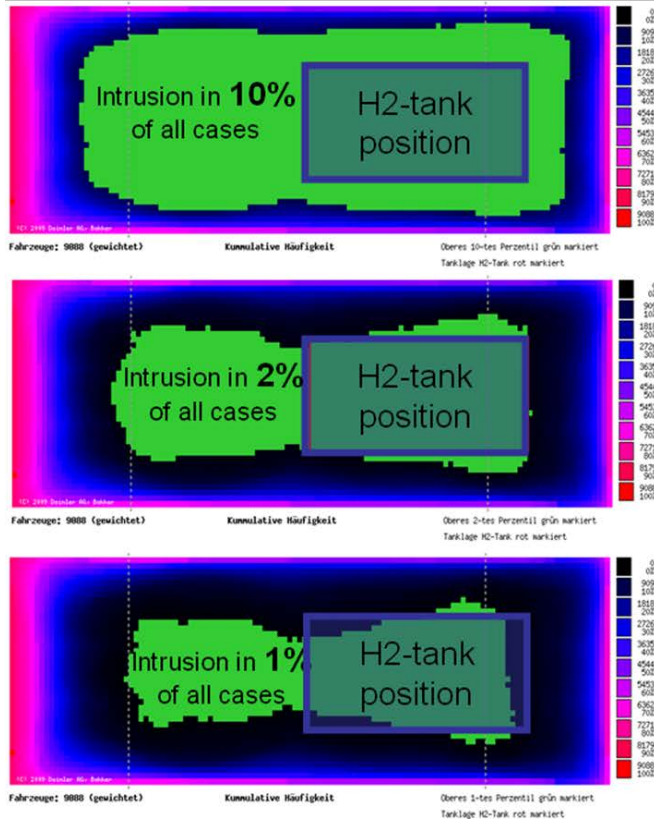
- a. Burst of container
- b. Leakage of Fuel cell and Hydrogen storage system, eventually leading to fire or deflagration/explosion

Risk Mitigation:

- Design of Hydrogen Storage System preventing burst and leakage of container
 - Validation of crash-worthiness of the container on component level in order to determine the structural protective device
 - Location of H₂-storage system in best protected vehicle area
 - Packaging has to support all crash scenarios incl. several abuse situations

- System Reaction in case of detected crash by airbag controller to prevent an uncontrolled release of Hydrogen
 - Closure of all Hydrogen shut-off valves triggered by CAN-communication and pyrotechnical device
 - Activate pyrotechnical short-cut device (PCD):
 - ➔ **Immediate Voltage drop of Fuel Cell to 0 V**
 - ➔ **Consumption of the remaining Hydrogen in the Fuel Cell System**

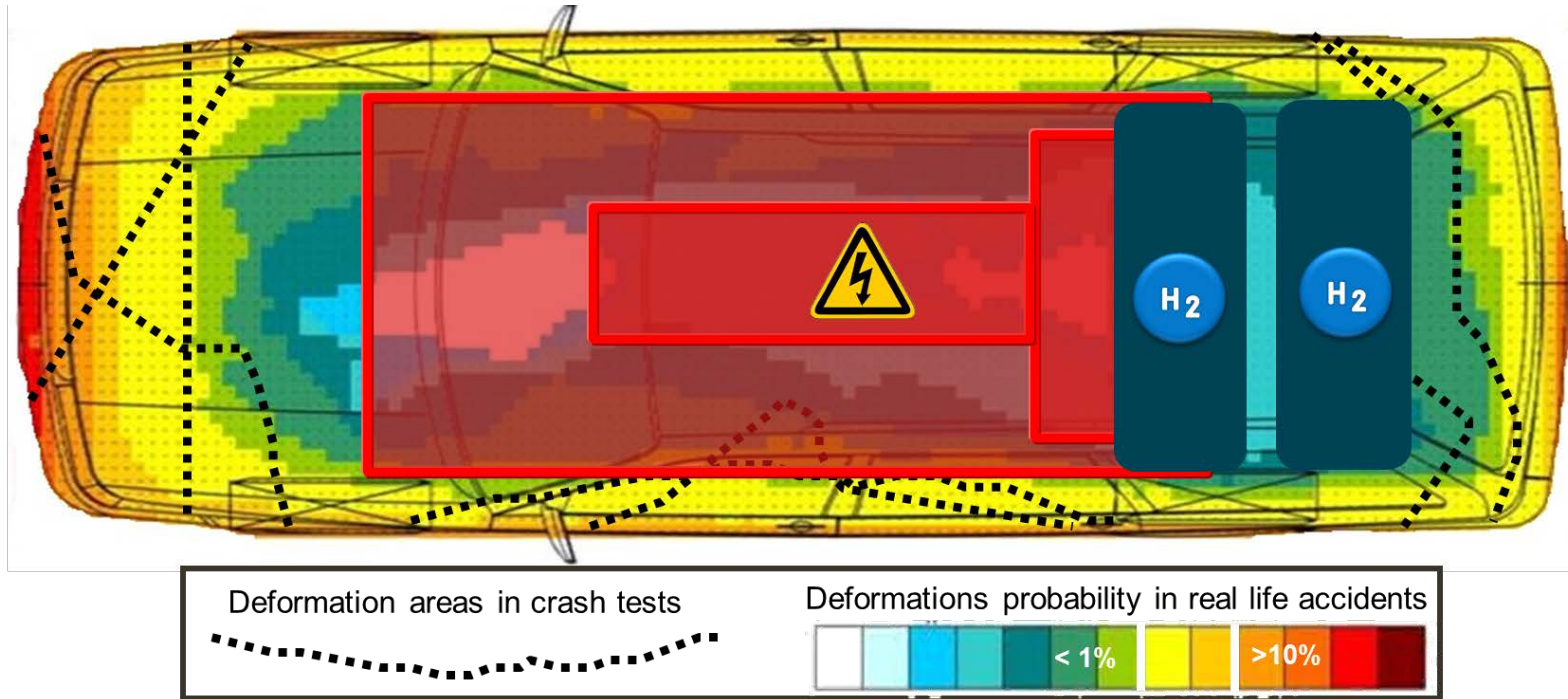




- Analysis of deformation depth of the vehicle closure
- Sample of 8612 selected vehicle accidents (Data source: GIDAS German In Depth Accident Study)
- Cumulative deformation frequency (normalized vehicle size)
- Occurrence for vehicle deformation depth in 1%/2%/10%
- Deformation risk of supposed H2 tank position < 2%

Source: SAE-Paper 11B-0132 Crashworthiness of Fuel Cell Vehicles Equipped with Compressed Hydrogen Storage Systems from a Road Accident Safety Perspective

Safe Integration of Energy Storages



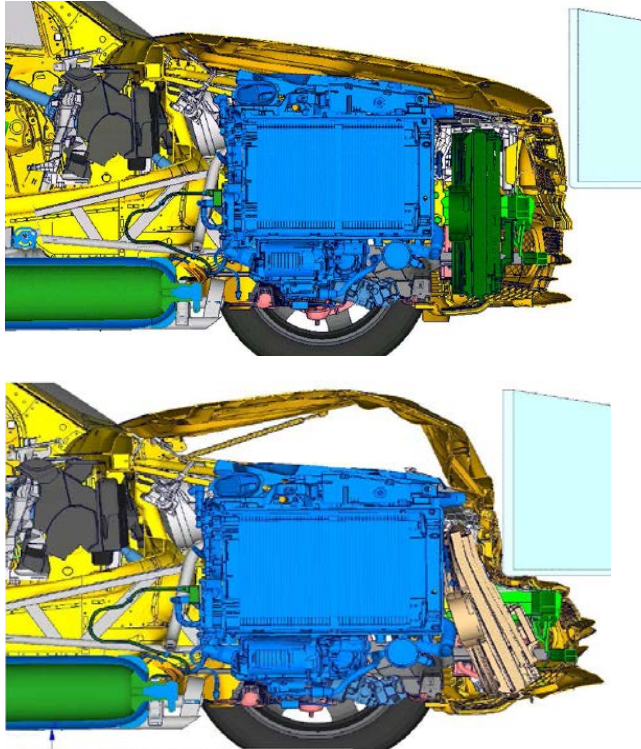
Standard crash tests will cover approx. 90% of all vehicle deformations in real life accidents

Mercedes-Benz Crash Test Portfolio

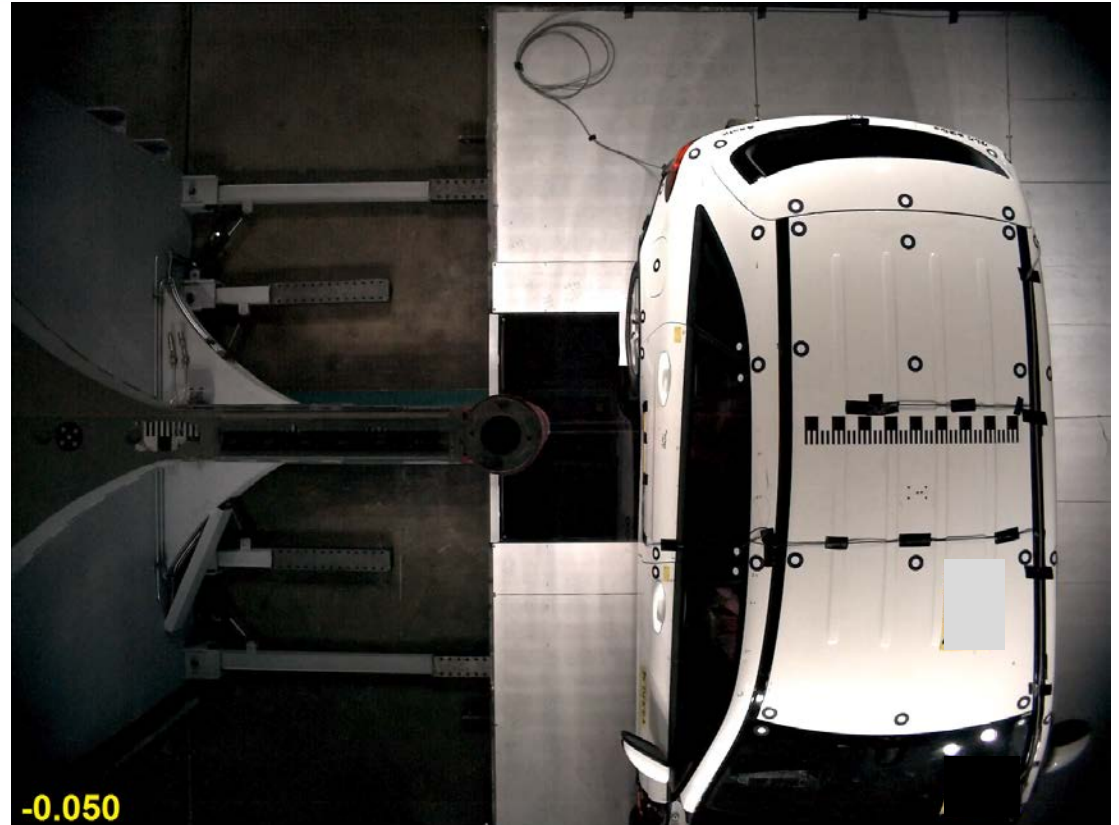
Side Impact <ul style="list-style-type: none"> •Crabbed B., 62 km/h •Defo. Barrier •1368 kg •ES2 re •SID IIs 	Side Impact <ul style="list-style-type: none"> •90°, 55 / 60 km/h •Defo. Barriere •1300 kg / 1400kg •ES2 / WS •Q-Fond (Korea, Euro) 	Roof <ul style="list-style-type: none"> •Roof strength test •Quasi-static •two sided •One sided (China) 	Roof 1 	Frontal Impact <ul style="list-style-type: none"> •40% Overlap •64 km/h •Defo. Barrier IIHS •50% (Dr) 	Frontal Impact <ul style="list-style-type: none"> •15°, 35% Overlap •90 km/h •MDB USNCAP •50% THOR (Dr, P) •left (right) 	Frontal Impact 1 	Frontal Impact 2 	
Side Impact <ul style="list-style-type: none"> •Crabbed B., 54 km/h •Defo. Barrier •1368 kg •ES2 re, SID IIs 	Side Impact <ul style="list-style-type: none"> •90°, 50 km/h •Defo. Barrier •950 kg •ES2 •SID IIs (China) 	Roof <ul style="list-style-type: none"> •Roof strength test •Quasi-static •One sided 	Roof 2 	Frontal Impact <ul style="list-style-type: none"> •100% Overlap •56 km/h •Rigid Barrier US-NCAP •50% THOR (Dr) •5% (Pass/Rear) 	Frontal Impact <ul style="list-style-type: none"> •25% Overlap •64 km/h •Rigid Barrier IIHS •50% (Dr) •left 	Frontal Impact <ul style="list-style-type: none"> •25% Overlap •64 km/h •Rigid Barrier IIHS •50% (Dr) •50% (Pass.) •right 	Frontal Impact <ul style="list-style-type: none"> •100% Überdeckung •50 km/h •starre Barriere •50% (Dr.) •5% (Pass.) 	
Side Impact <ul style="list-style-type: none"> •90°, 50 km/h •Defo. Barriere •950 kg •ES2 	Side Impact <ul style="list-style-type: none"> •90°, 50 km/h •Defo. Barriere •AEMDB1400 kg •WS 50% 	<div style="text-align: center;"> <p>Roof</p> <p>Side</p> <p>Frontal</p> <p>Rear</p> </div>		Frontal Impact <ul style="list-style-type: none"> •+...- 30° •32 - 40 km/h •Rigid Barrier •50% (Dr, Pass) •unbelted 	Frontal Impact <ul style="list-style-type: none"> •100% Overlap •32 - 40 km/h •Rigid Barrier •5% (Dr, Pass) •unbelted 	Frontal Impact <ul style="list-style-type: none"> •40% Overlap •40 km/h •Defo. Barrier •5% (Dr, Pass) 	Frontal Impact <ul style="list-style-type: none"> •100% Overlap •50 km/h •Rigid Barrier •no Dummy •ECE-12 	
•Side Impact / MoU Comp. <ul style="list-style-type: none"> •90°, 50 km/h •Defo. Barrier, IIHS •1500 kg •SID IIs •MoU 	Side Impact <ul style="list-style-type: none"> •Pole •75°, 32 km/h •E2 re, 			Frontal Impact <ul style="list-style-type: none"> •100% Overlap •56 km/h •Rigid Barrier •50% (Dr, Pass) 	Frontal Impact <ul style="list-style-type: none"> •100% Overlap •56 km/h •Rigid Barrier •5% (Dr, Pass) 	Frontal Impact <ul style="list-style-type: none"> •40% Overlap •56 km/h •Defo. Barrier •50% (Dr, Pass) 	Frontal Impact 3 	
Side Impact <ul style="list-style-type: none"> •Pole •75°, 32 km/h •WS 	Side Impact <ul style="list-style-type: none"> •Pole •75°, 32 km/h •SID IIs 			Frontal Impact <ul style="list-style-type: none"> •100% Overlap •26 km/h •Rigid Barrier 	Frontal Impact <ul style="list-style-type: none"> •+ ...- 30° •(FMVSS 301, 305) •50 km/h •Rigid Barrier 	Frontal Impact <ul style="list-style-type: none"> •100% Overlap •50 km/h •Rigid Barrier •50% (Dr, Pass) 		
Side Impact <ul style="list-style-type: none"> •Pole •90°, 29 km/h •ES2 	Side Impact 2 			Rear Impact 1 	Rear Impact <ul style="list-style-type: none"> •100% Overlap •35...50 km/h •1100 ... 1805 kg •Rigid Barrier 	Frontal Impact <ul style="list-style-type: none"> •100% Overlap •56 km/h •Rigid Barrier •J: 50% (Dr.), 5% (Pass.) •K: 5% (Dr., Pass.) 	Frontal Impact <ul style="list-style-type: none"> •100% Overlap •50 km/h •Rigid Barrier •50% (Dr, Pass) •5% Rear •P-Fond Rear 	Frontal Impact <ul style="list-style-type: none"> •40% Overlap •64 km/h •Defo. Barrier •50% •Q- / P-Fond
Side Impact 1 	Side Impact 2 	Rear Impact 2 	Rear Impact <ul style="list-style-type: none"> •70% Overlap •80 km/h •Defo. Barrier 	Frontal Impact <ul style="list-style-type: none"> •100% Overlap •50 km/h •Rigid Barrier •5% (Dr, Pass, Rearright) 	Frontal Impact <ul style="list-style-type: none"> •50% Overlap •100 km/h •Moving def. Barrier •THOR (Dr.) •50% (Pass.) •Q6, Q16 Rear 	Frontal Impact <ul style="list-style-type: none"> •40% Overlap •64 km/h •Defo. Barrier •C+; 50% (Dr) •C; 50% (Pass.) •C+; 5% (Rear) 		

Statutory
Rating
Mercedes-Benz

Real Life Safety Case 1: Truck Underride

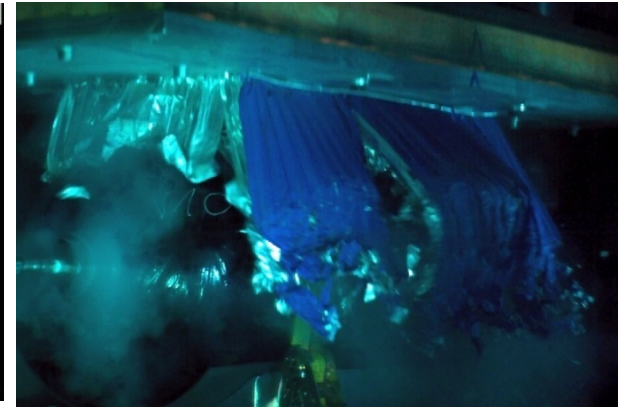
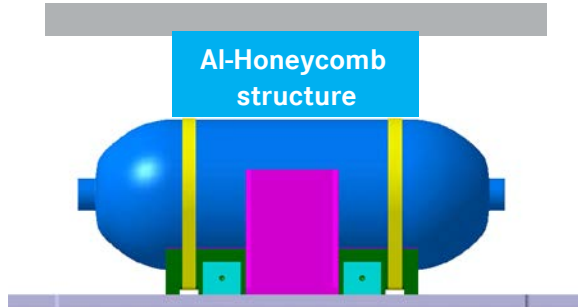


Real Life Safety Case 2: Side Pole Impact

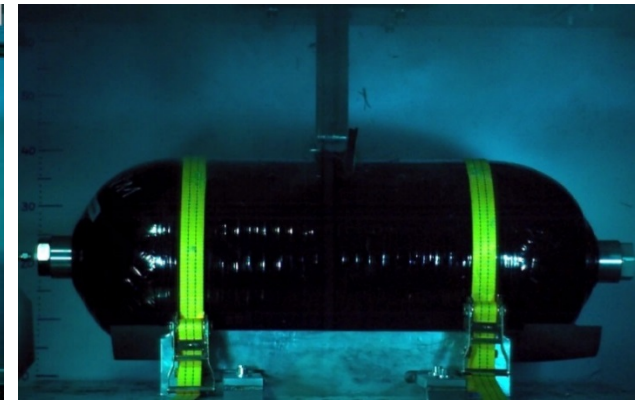
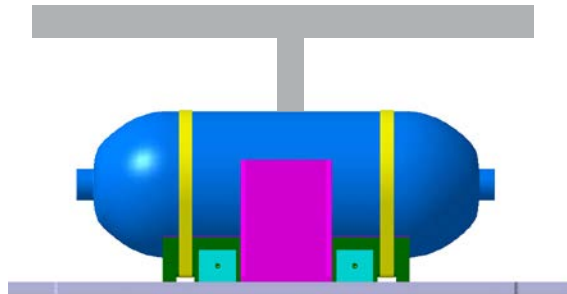


Crash Robustness of Gas Tanks

Test Set-up Stiffness



Test Set-up Penetration



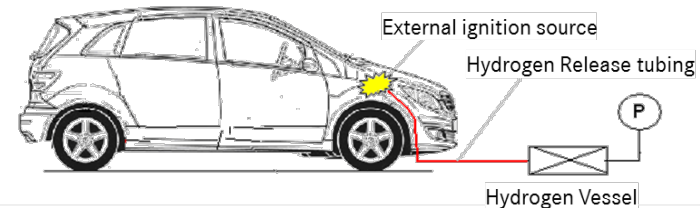
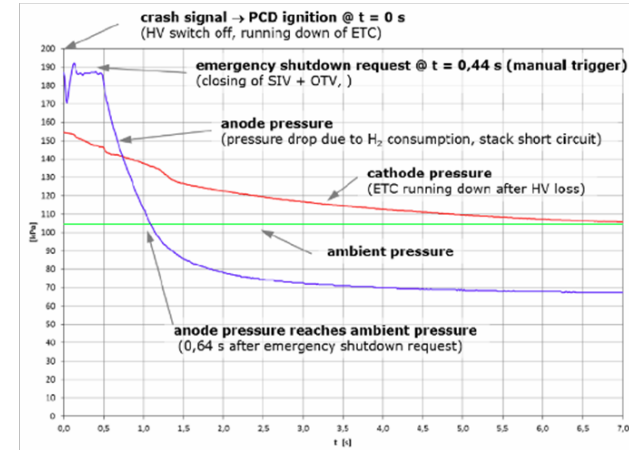
Crash related Hydrogen Safety Tests

1) Short-cut of Fuel Cell:

- Voltage < 60 V within few ms
- Hydrogen Pressure below ambient pressure in less than 1 s after closure of valves

2) Ignition Tests to address multiple failure situation (accidentally released hydrogen in conjunction with an external ignition source in the engine compartment):

- Short thermal reaction, no fire of vehicle parts
- Measured noise level inside the vehicle max. 110 dB(A)
- Measured noise level 2m in front of the vehicle max. 126 dB(A)



Summary

- Safety challenges for FCEV are high voltage safety, fire of energy storages (electric and gas) and bursting gas tanks
- Globally > 15 million gas vehicles on the road without noticeable accident problems
- Existing regulatory requirements and standards addressing post crash leaking limits, safety equipment and performance requirements of the fuel systems and components
- High intrinsic safety of Type IV hydrogen gas tanks (rigidity of carbon composite)
- Supplementation of standardized test procedures by additional real life safety cases
 - Crash scenarios (e.g. Truck underride)
 - Abuse tests (e.g. Ignition of possible hydrogen leakage)

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Thank You for Your Attention!



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