Virtual Conference
TUNNEL SAFETY & VENTILATION
Graz, Austria

New Developments in Tunnel Safety


# Safety aspects related to Fuel Cell Vehicles

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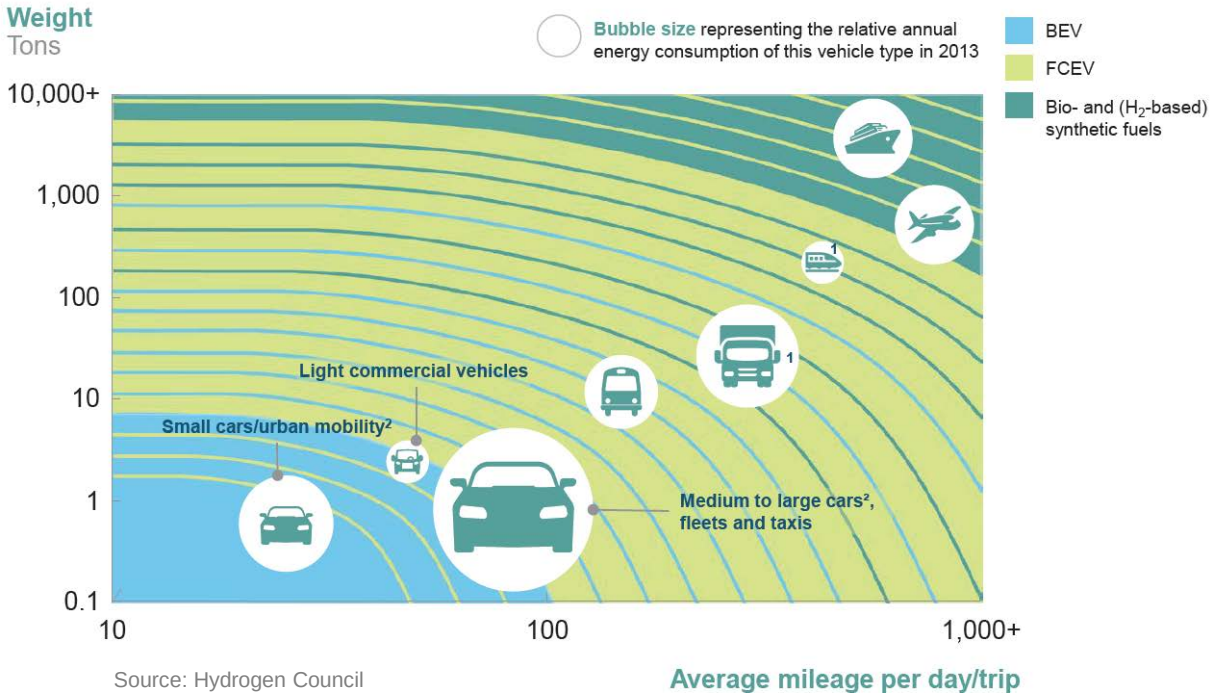
# Zero-Emission Mobility

## BEV - Battery Electric Vehicle, Accumulator

## FCEV – Fuel Cell Electric Vehicle, Hydrogen – Fuel Cell

- Highest Efficiency
- Short Driving Range
- Long Charging Time
- Low life cycle emissions – short range



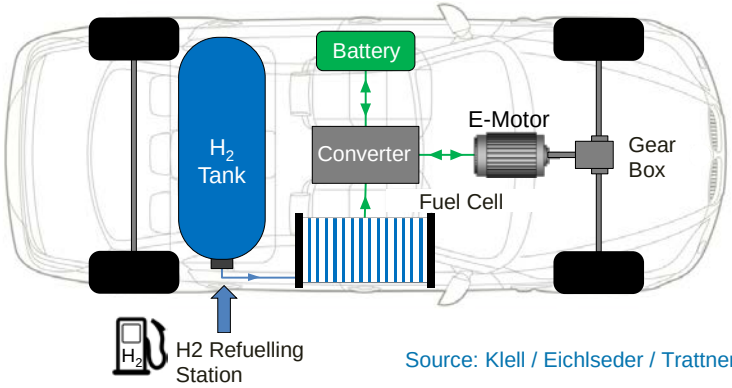

Source: Hydrogen Council

- High Efficiency
- Long Driving Range
- Short Fuelling Time
- Lowest life cycle emissions – long range

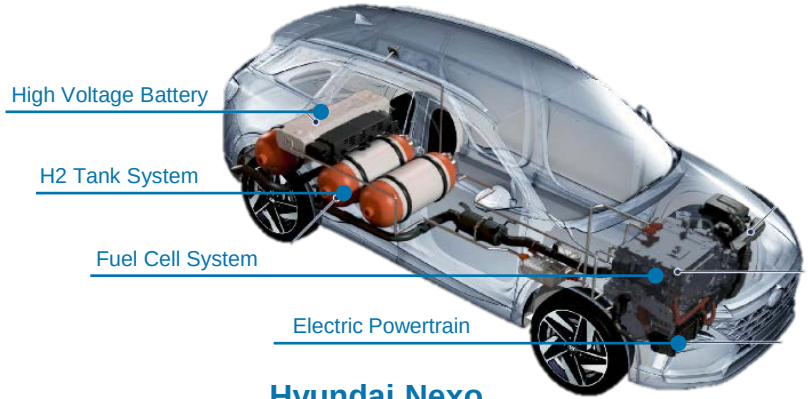
# FCEV Powertrain

## Dominant fuel cell electric powertrain

- Power demand covered by the fuel cell
- HV battery for recuperation and power support during acceleration
- Fuel Cell Power: 95 – 150 kW
- HV Battery Power: 25 – 40 kW
- HV Battery Capacity: 1 – 2 kWh
- $H_2$ Tank: 5 – 6.5 kg
  → Driving ranges up to 750 km




Source: Klell / Eichlseder / Trattner

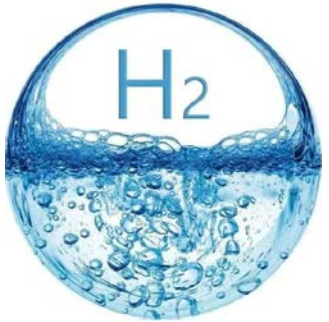



**Hyundai Nexo**

Source: Hyundai

# Hydrogen – Safety Relevant Properties

## Hydrogen at Normal Conditions (20 °C, 1.01325 bar)


- Colorless, odorless gas
- No toxic effects
- Lowest density of all gases (14 times lighter than air)
- High diffusion tendency
- Low melting and boiling temperature
- Highly flammable
- Forms ignitable mixtures with air in a wide range of mixtures with high flame velocity and high combustion temperature
- High concentrations of hydrogen have an anesthetic or suffocating effect by displacing air
- Not hazardous to water, non-corrosive

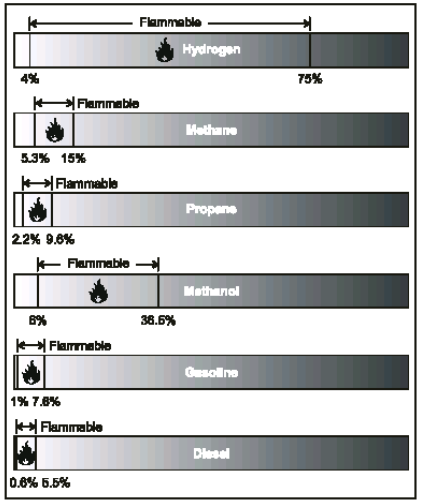



**Figure 1-7** Flammability Ranges of Comparative Fuels at Atmospheric Temperature

# Hydrogen Compared to other Gases

| Property | Unit | Hydrogen | Methan | Propan |
|---|---|---|---|---|
| Molar Mass | kg/kmol | 2.016 | 16.04 | 44.1 |
| Density @ 0 °C & 1 bar | kg/m³ | 0.09 | 0.72 | 2.01 |
| Triple-Point Temperature | °C / K | -259 / 14 | -182 / 91 | -188 / 85 |
| Ignition Range | Vol % in Air | 4 - 76 | 4.4 – 16.5 | 2.12 – 9.35 |
| Detonation Range | Vol % in Air | 18 - 59 | 8 – 14.5 | N/A |
| Minimum Ignition Energy | mJ | 0.017 | 0.28 | 0.25 |
| Auto Ignition Temperature | °C | 585 | 595 | 470 |
| Gravimetric Energy Density | kWh/kg | 33.3 | 15.4 | 13.8 |
| Volumetric Energy Density 1 bar | kWh/Nm³ | 2.98 | 11.1 | 27.7 |

# Hydrogen - Labels

## Labels/Hazard Pictograms:

- Global Harmonized System: GHS02, GHS04

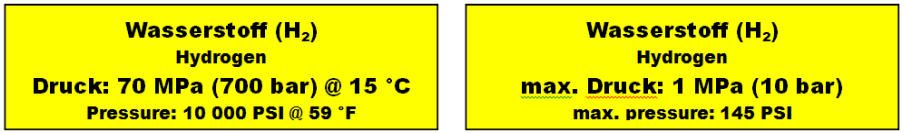
## Danger Warnings:

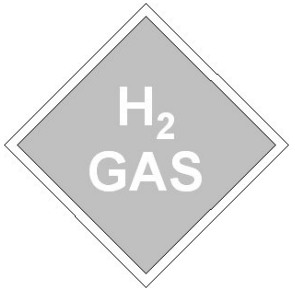
- **H220:** Extremely flammable gas
- **H280:** Contains gas under pressure; may explode when heated

## Safety Instructions:

- **P210:** Keep away from heat/sparks/open flames/hot surfaces. Do not smoke.
- **P377:** Fire from escaping gas: Do not extinguish until leak can be safely removed.
- **P381:** Remove all ignition sources if safe to do so.
- **P403:** Store in a well ventilated place

## Labels on Vehicles:

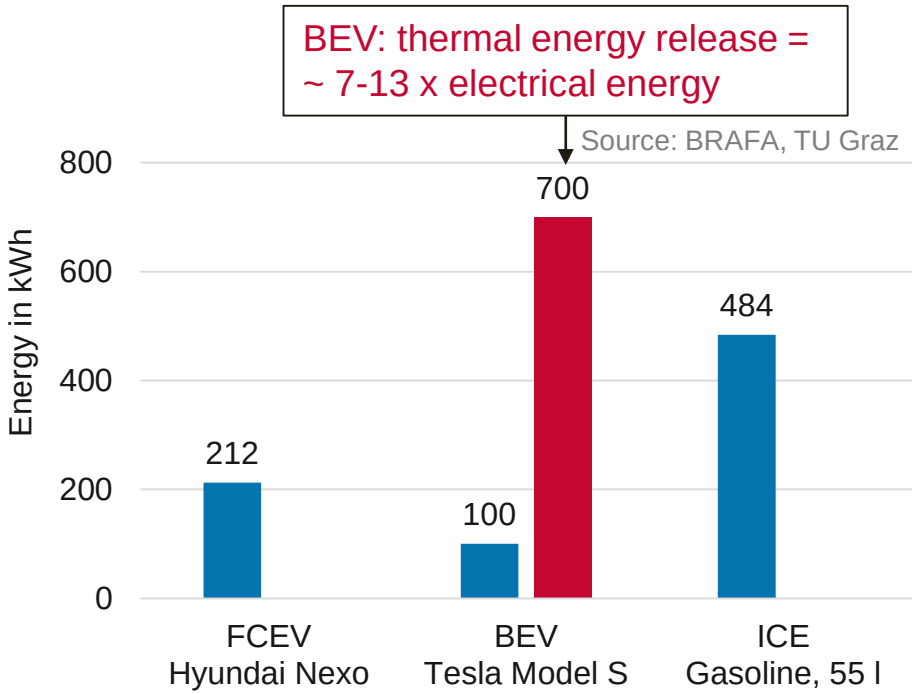


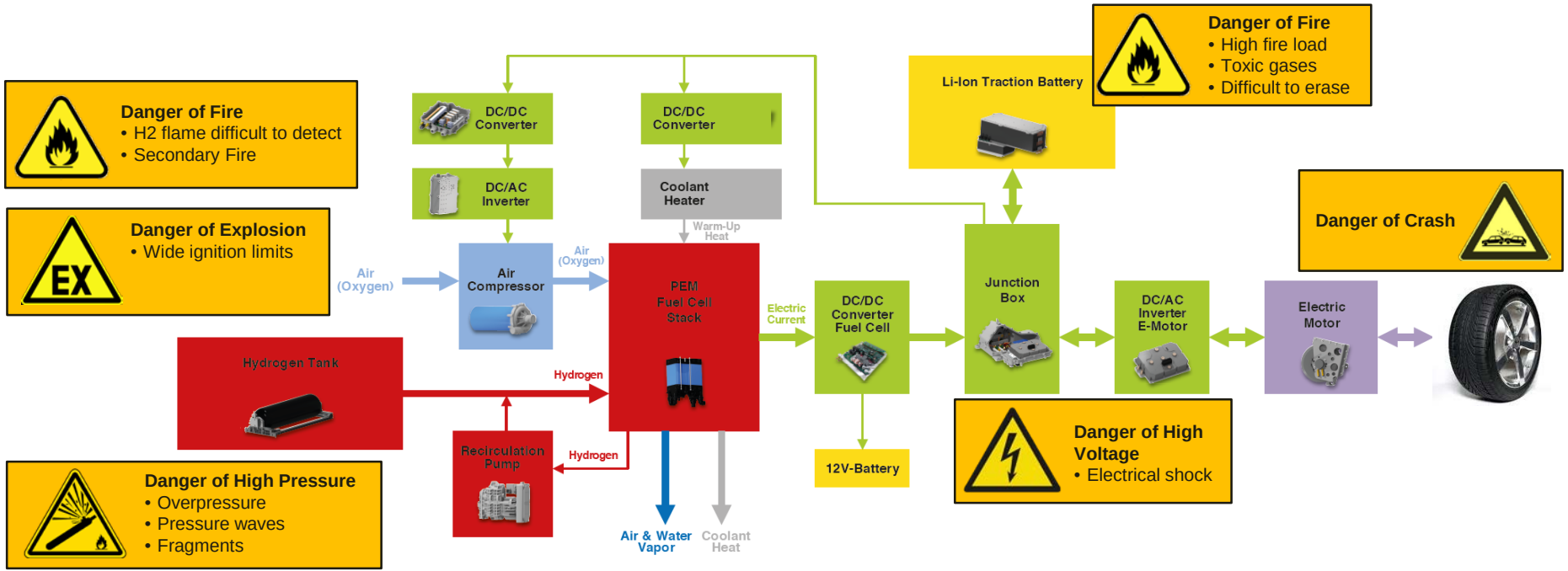
# On-Board Energy

Thermal energy release in case of fire of different propulsion systems: FCEV, BEV, ICE

- Modern vehicles contain a large quantity of flammable materials
- Main differences are only propulsion systems and energy storage
- Comparison of the stored on-board energy:
  - BEV has lowest stored on-board energy but highest potential for the release of thermal energy
  - Low energy density leads to high battery mass



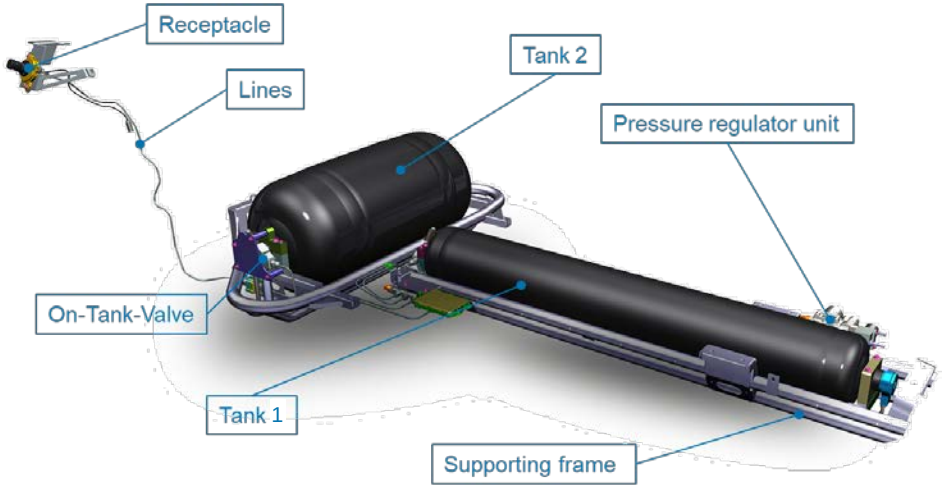
# FCEV Powertrain & Hazards



# Hydrogen Storage System (HSS)

## Main Tasks

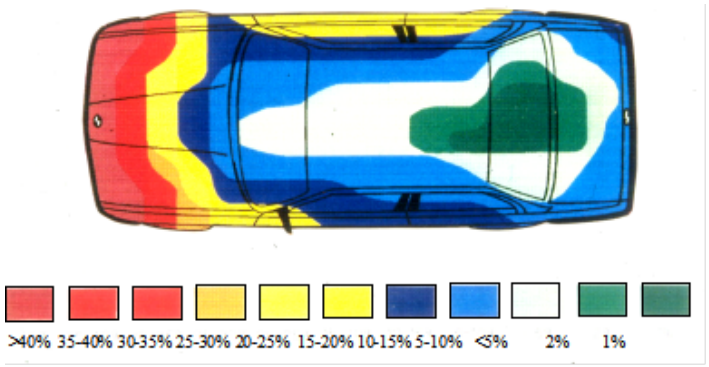
- Delivers hydrogen to the fuel cell
- Pressure reduction
- Refuelling interface via a filling receptacle
- Control of the electro-mechanic tank valve
- Temperature, pressure and hydrogen concentration monitoring
- Gas tightness
- Material compatibility
- Crash safe




Source: Mercedes Benz AG

# Passive Safety

- **Identification of safe areas: in the longitudinal center plane and around the rear axle**
  - Position of tanks in this area
  - Supporting beams (longitudinal and cross) around the tanks
  - Protection plates around critical components

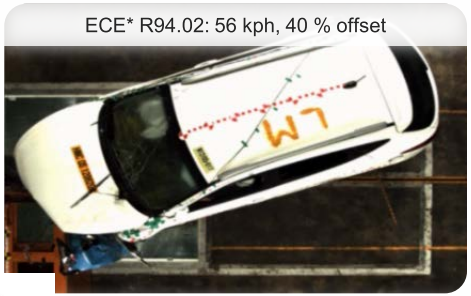


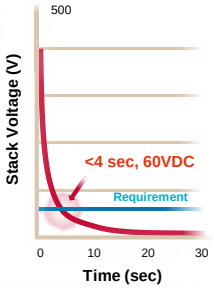

Source: EU-project StorHy

Source: Hyundai

# Passive Safety – Crash Test

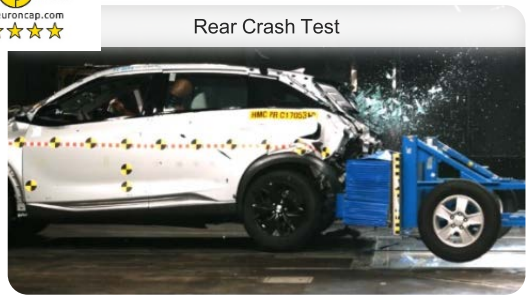
For the **national type approval** of vehicles, crash tests by the manufacturer are mandatory: **Euro NCAP** (European New Car Assessment Programme) e.g. Hyundai Nexo






## Targets:

- **No external leakage** (test afterwards with helium)
- **No severe damage** of any component of the HSS
- **No contact** between the chassis and the HSS

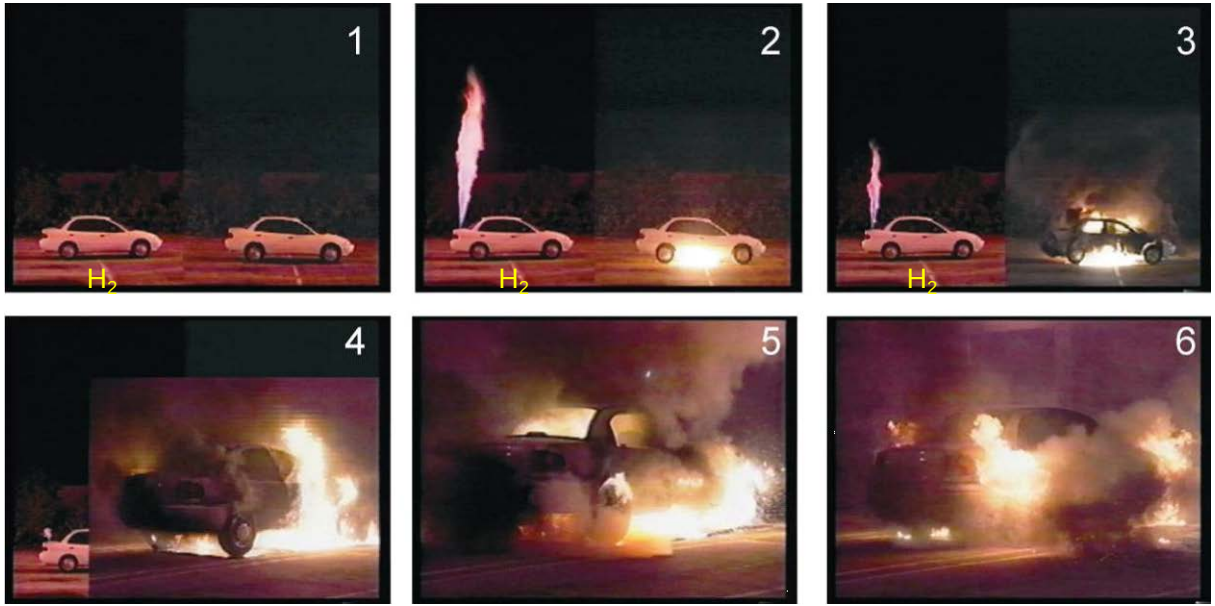
## Crash Test Nexo:

- No H2 leakage
- Voltage level after collision: < 60 V within 4 sec. (standard = 60 sec.)

*ECE: Economic Commission for Europe Regulations

Source: Hyundai AUT

# Passive Safety - Fire Test




**Fire test DoE 2001 with hydrogen (left) und gasoline (right):**

1: Ignition at a 1,6 mm orifice,
2: after 3 s,
3: after 60 s,
4: after 90 s,
5: after 140 s,
6: after 160 s

Source: M. Swain, Fuel Leak Simulation, Miami: Proceedings of the 2001 DOE Hydrogen Program Review NREL/CP-570-30535, 2001

# Passive Safety

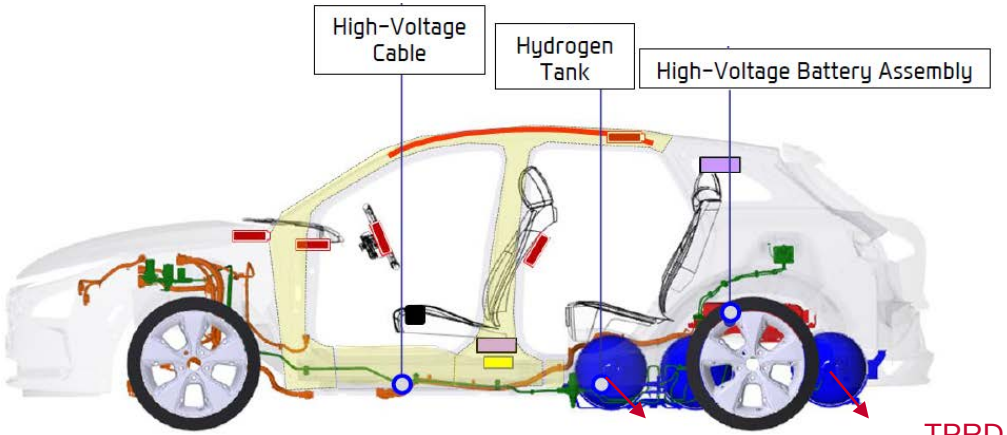
## TPRD – Thermal Pressure Relief Device

- **Over-pressure:**

  An overpressure valve protects the low pressure side against a regulator failure.

- **Over-temperature:**

  – A thermally activated fuse (TPRD) at every on-tank-valve prevents a rupture of a cylinder by over-pressure caused by rising temperatures due to e.g. fire.





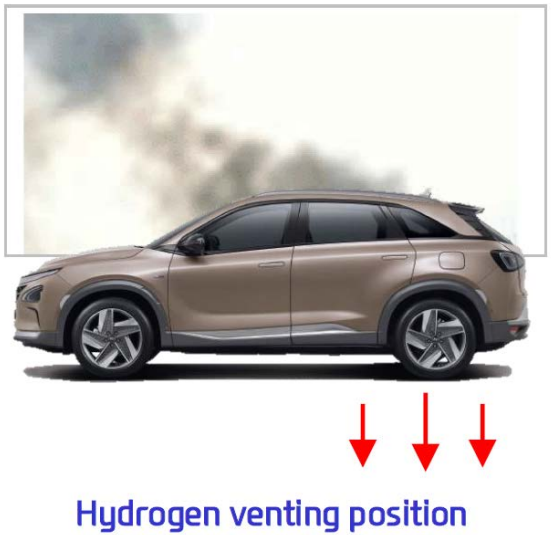
TPRD outlet directed to the ground

Source: Hyundai

# Vehicle Accident - Fire

## Emergency Measures for Fire Departments:

- **Keep away from the rear until fire is extinguished**
- If the temperature in/on the $H_2$-tank > 110 °C
  - Automatic activation of thermal fuse (TPRD)
  - Blowing off hydrogen to the environment (loud outflow noise)
- **Do not extinguish the hydrogen flame (after approx. 5 min all hydrogen is burned)**
- Hydrogen flames are almost invisible → Consider secondary fires
- **Battery:**
  - Li-Io; electrolyte leakage from 150 °C
    - Ignition, sparks
- **Release of HF, CO, CO2**
  - Face protection
  - Self-contained breathing apparatus
  - Protective suit




Source: Hyundai Nexo Emergency Response Guide

# Hydrogen Safety

## „Same compared to other fuels, but different.“

# Contact

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