The risk of methane or hydrogen pressure vessel explosion in the event of fire

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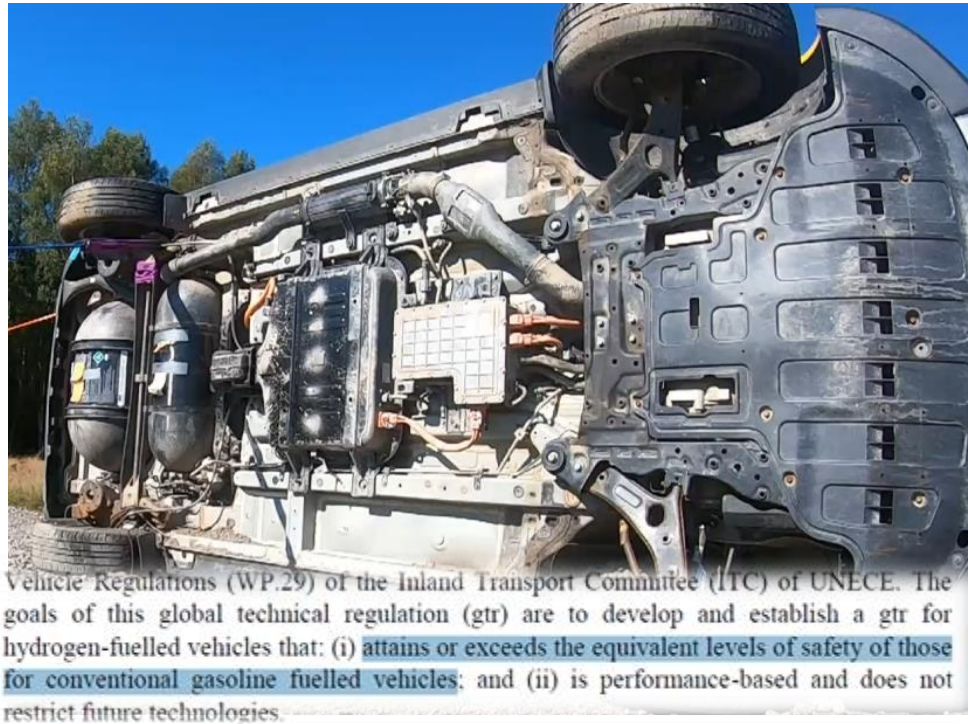
Tunnel and Underground Safety Center

All fuels pose risks

- Handling of petrol iterated to high safety standards
- Methane and hydrogen introduce a new risk picture

All fuels pose risks

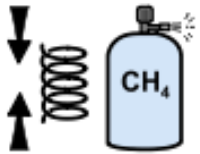
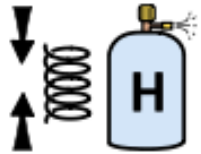
- Handling of petrol iterated to high safety standards
- Methane and hydrogen introduce a new risk picture
- Developed to achieve high international safety standards (also in tunnels and garages)
- May need some learning and iteration



Vehicle Regulations (WP.29) of the Inland Transport Committee (ITC) of UNECE. The goals of this global technical regulation (gtr) are to develop and establish a gtr for hydrogen-fuelled vehicles that: (i) attains or exceeds the equivalent levels of safety of those for conventional gasoline fuelled vehicles; and (ii) is performance-based and does not restrict future technologies.

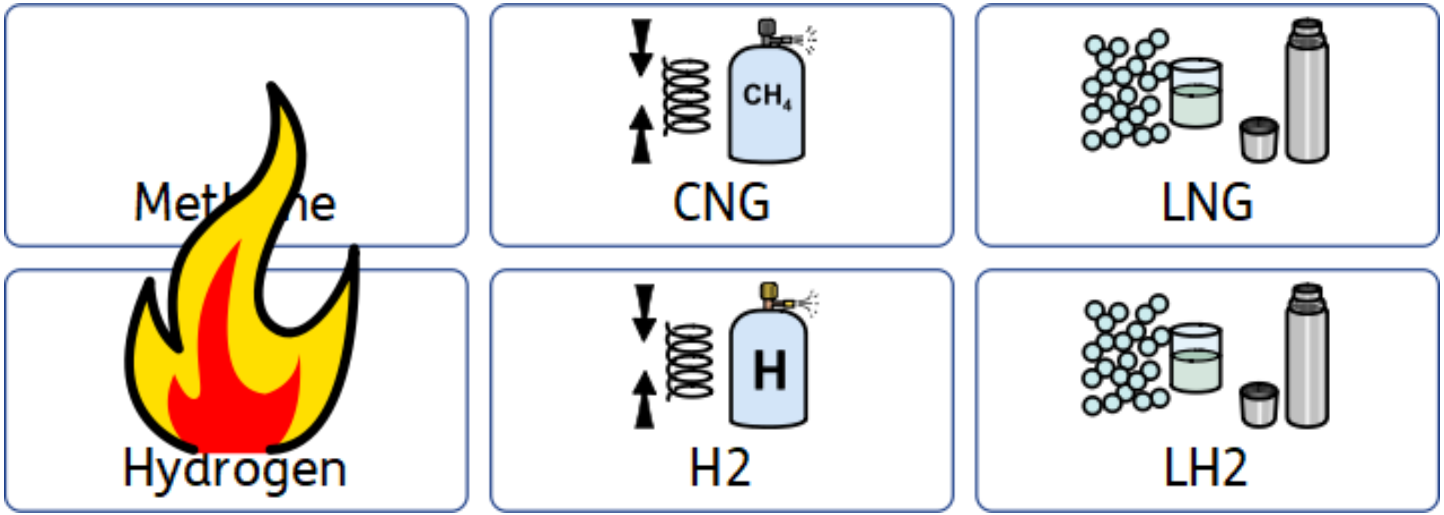
Methane and hydrogen

Storage of methane and hydrogen

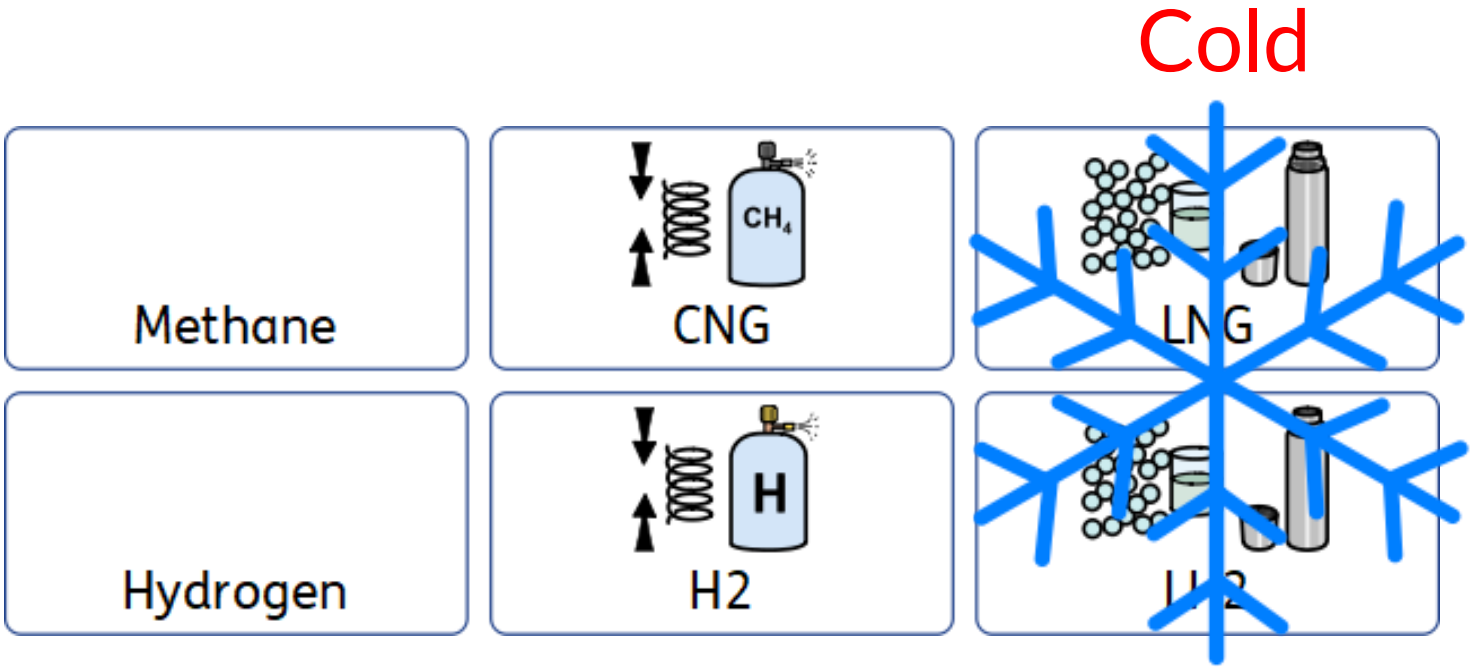
Methane	 CNG	 LNG
Hydrogen	 H2	 LH2

Associated risks

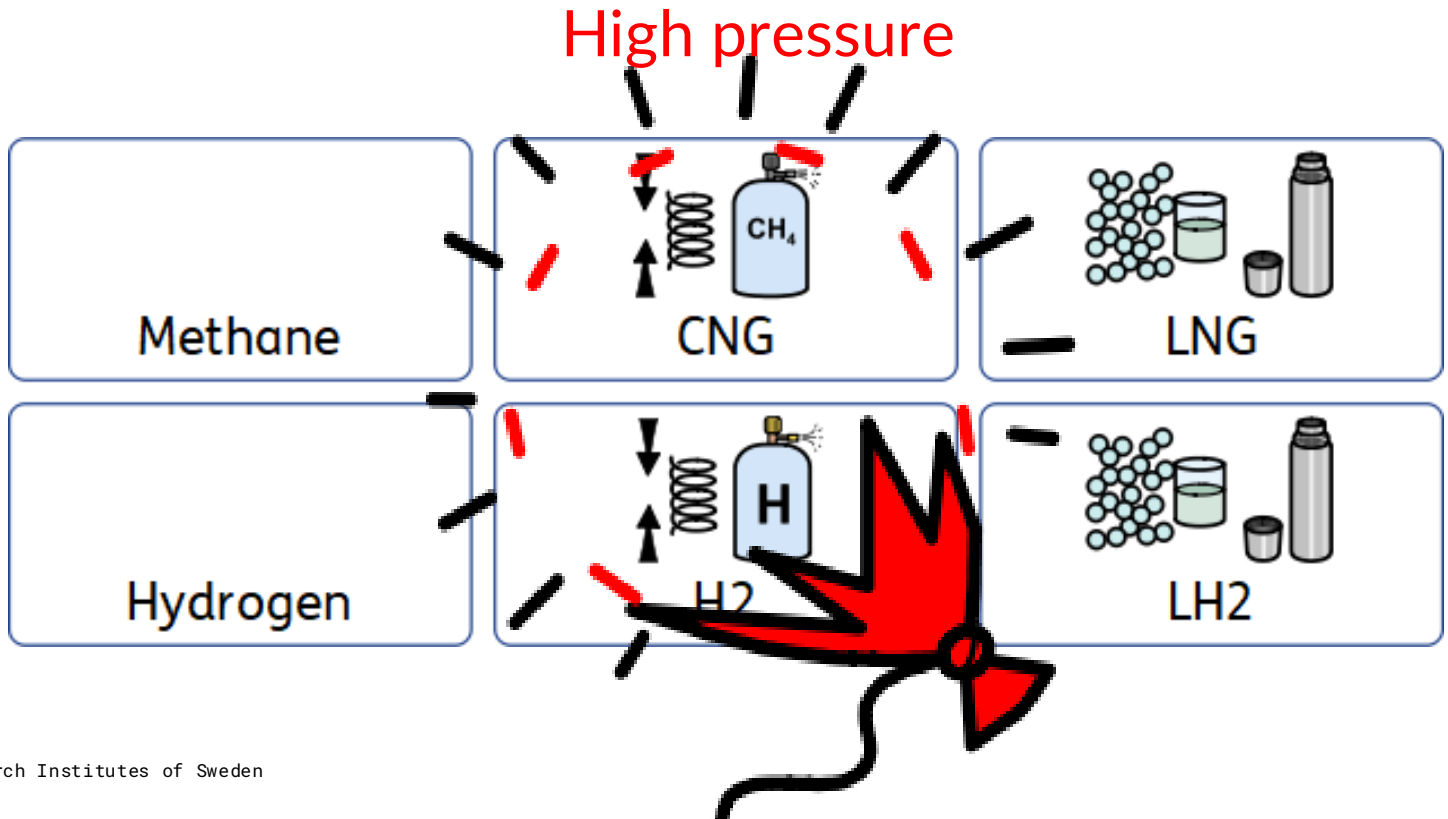
Flammable



Associated risks

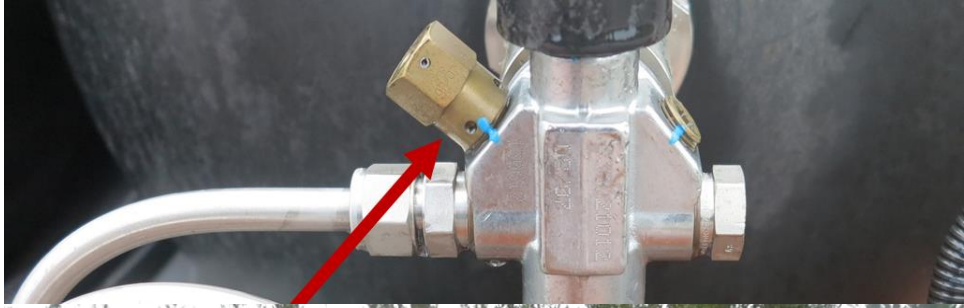


Associated risks



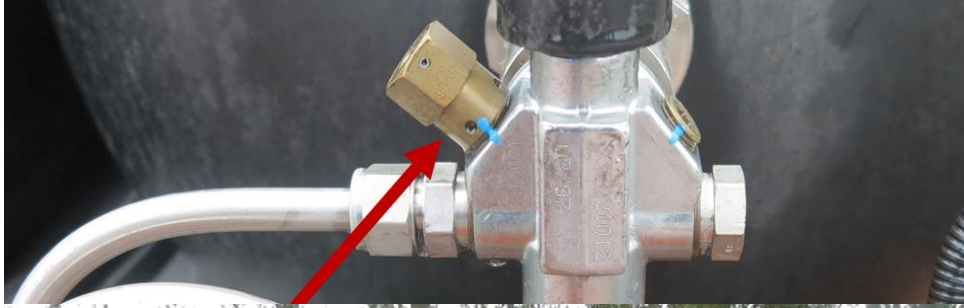
Compressed gas storage fire safety

- Fire resistance/strength of tank material
- The TPRD (melt fuse) should release



Compressed gas storage fire safety

- Fire resistance/strength of tank material
- The TPRD (melt fuse) should release
- Pressure vessel explosions have occured
  - Local fire?
  - Extinguishing activites that cool the TPRD?



Risks with local fire: Experiments

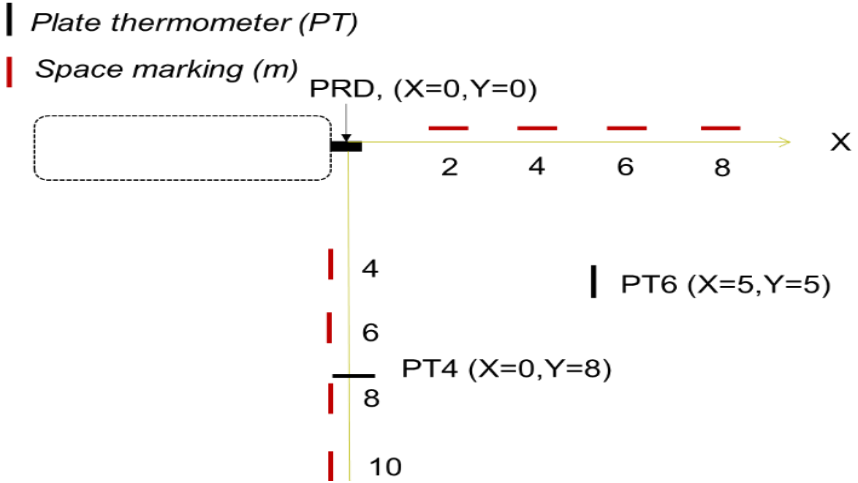
Local fire tests (2019)

- 8 tests in total
  - 6 with local fire
  - 4 bus composite tanks (190 L)
  - 4 car steel tanks (35 L)
- Measurements
  - Jet flame length & heat radiation
  - TPRD temperature
  - Internal tank pressure
  - Pressure wave
- Report/movies: ”CNG vehicle containers exposed to local fires”




Result – jet flame

- Different release directions
- Length: 1 – 3 – 10 m
- Heat flux at 5 m: 2 – 4 – 5 kW/m2



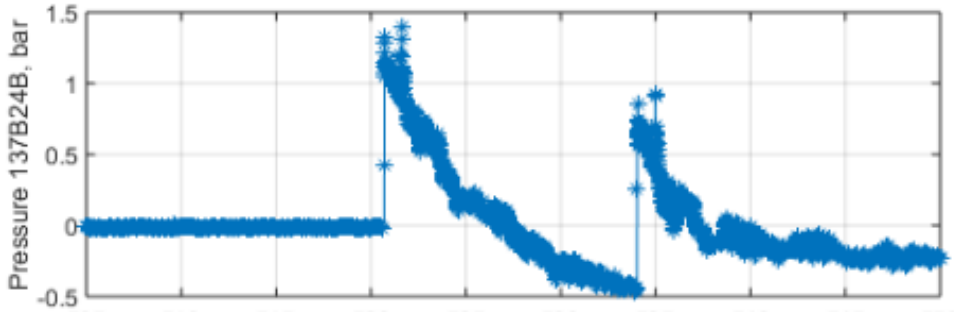
Test #8 on CNG composite container

- 2*Local fire
- Ambient temperature: 13 °C
- 150 bar starting pressure
- After 19:20 [min:s] fire exposure
  - Internal pressure was 217 bar
  - TCs on TPRDs measured 33 & 37 °C

Movie 1

Result – pressure vessel explosion

- 5 m: pressure 1.1 bar, impulse 3.0 bar×ms
- 10 m: pressure 0.21 bar, impulse 0.59 bar×ms



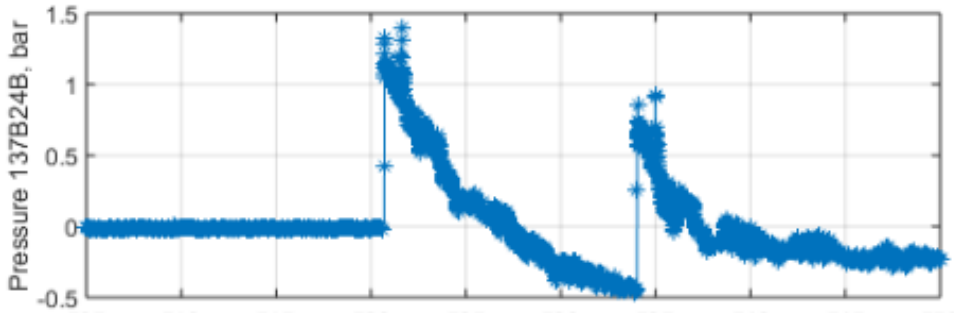
Result – pressure vessel explosion

- 5 m: pressure 1.1 bar, impulse 3.0 bar×ms
- 10 m: pressure 0.21 bar, impulse 0.59 bar×ms
- (+ risk for projectiles; ruptured tank flew 32 m)

↔

1% risk for fatality at 1 bar

Limit for serious injury at 0.2 bar



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Pressure vessel explosion – inside tunnel

Table: Prohibited tunnel distance from explosion [m], on the upstream and downstream side of the gas-powered vehicle.

Scenario	MSB		
CNG bus	300		

↔ ~ Limit for serious injury at 0.2 bar

Pressure vessel explosion – inside tunnel

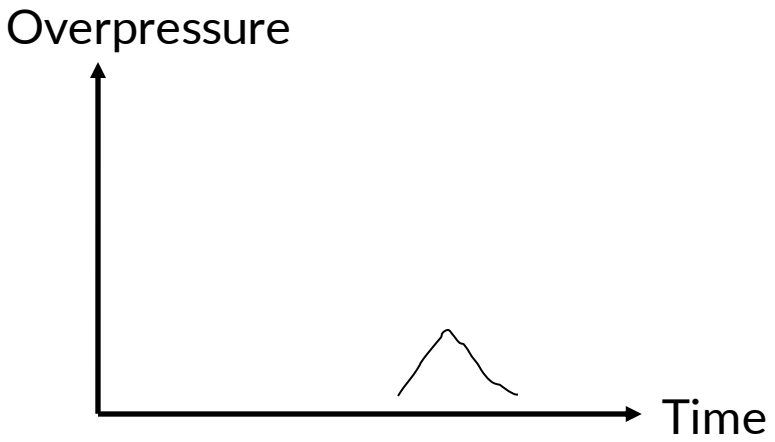
Table: Prohibited tunnel distance from explosion [m], on the upstream and downstream side of the gas-powered vehicle.

Scenario	MSB	Molkov and Dery	Experimental
CNG light vehicle	40		
CNG bus	300		
CNG HGV	55		
H2 light vehicle	160	190	170+
H2 bus	The whole tunnel		

↔ ~ Limit for serious injury at 0.2 bar

Hydrogen pressure vessel explosion inside tunnel

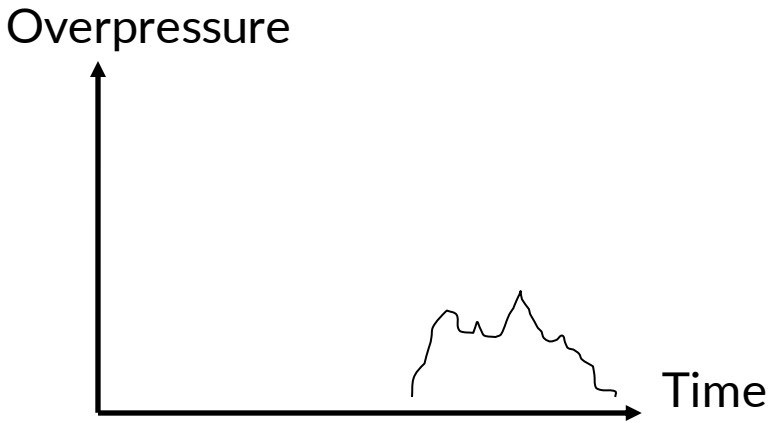
- Mechanical energy from high pressure



[Kudriakov, S., et al., *Full-scale tunnel experiments: Blast wave and fireball evolution following hydrogen tank rupture.* International Journal of Hydrogen Energy, 2022. **47**(43): p. 18911-18933.]

Hydrogen pressure vessel explosion inside tunnel

- Mechanical energy from high pressure
- Secondary explosions from ignited hydrogen-air mixtures



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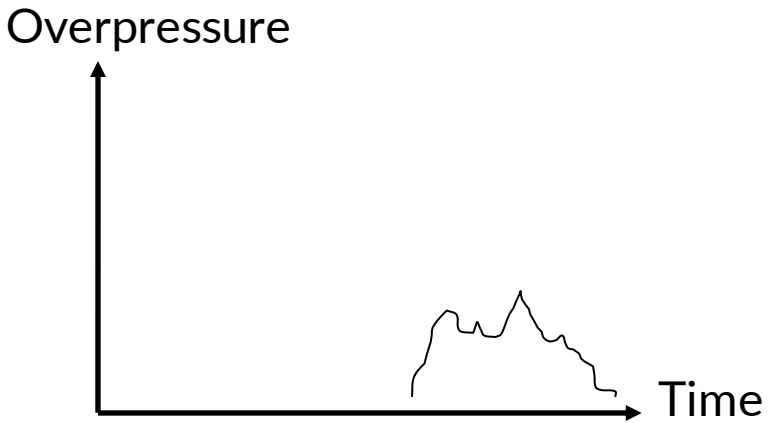
Hydrogen pressure vessel explosion inside tunnel

- Impulse above 10 bar*ms for 78 l, 530 bar
- NFPA 2: 50% fatality probability at 9 bar*ms



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Risks with extinguishing that cool the TPRD: Experiments

Tests 2021:
Fire extinguishing

- Tests within BREND 2.0 project
- Context: CNG / H2 vehicle fire in ro-ro space / tunnel
  - Sprinkler / deluge system
  - Manual intervention

Tests 2021:
Fire extinguishing

- 7 tests in total
  - 2 hydrogen composite tanks (52 L)
  - 3 CNG composite tanks (50 L)
  - 2 CNG steel tanks (48 L)
- Water flow rate 5 L/min (approx 15 mm/min).
- Water turned off after 20 min
- Not yet fully published, will be presented at ISTSS 2023 in Stavanger

Preliminary results, H2

- Hydrogen tank starting pressure 400 bar
- One tank without water and one with water
- Water was turned off after 20 min

No water

With water discharge

Movie 2

Preliminary results

- Water was able to cool the TPRD efficiently
- Out of the 7 tests – no pressure vessel explosion

Preliminary results

- Water was able to cool the TPRD efficiently
- Out of the 7 tests – no pressure vessel explosion
  - Example; CNG composite tank, after 8 min fire, internal pressure at 203 bar.

Movie 3 [01:07 – 01:15]

Conclusions

- New energy carriers pose new risks
- Pressure vessel explosions has occured and can be recreated in an experimental setting with local fire that does not reach the TPRD for composite tanks
  - Even more problematic event inside tunnel
  - Must be prevented
- R&D need a few iterations to exceed the levels of safety for conventional vehicles,
  - e.g. through an increased tank fire resistance, or leak-before-burst design for composite tanks.

Thank you!

Questions?

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Useful literature

Regulation No. 134 - Hydrogen and fuel cell vehicles, The United Nations Economic Commission for Europe. 2019.

Global Technical Regulation No.13 - Hydrogen and fuel cell vehicles, The United Nations Economic Commission for Europe. 2013.

Regulation No. 110 – CNG/LNG vehicles The United Nations Economic Commission for Europe. 2011.

MSB, Vägledning: Räddningsinsatser vid händelser med gasdrivna fordon. 2022, Myndigheten för samhällsskydd och beredskap.

Kudriakov, S., et al., Full-scale tunnel experiments: Blast wave and fireball evolution following hydrogen tank rupture. International Journal of Hydrogen Energy, 2022. 47(43): p. 18911-18933.

Molkov, V. and W. Dery, The blast wave decay correlation for hydrogen tank rupture in a tunnel fire. International Journal of Hydrogen Energy, 2020. 45(55): p. 31289-31302

Gehandler, J. and A. Lönnermark, *CNG vehicle containers exposed to local fires*. 2019.

Gehandler, J., A. Olofsson, J. Hynynen, A. Temple, A. Lönnermark, J. Andersson, J. Burgén, and C. Huang, *BREND 2.0 - Fighting fires in new energy carriers on deck 2.0*. 2022.