

# **International Seminar on "Advances in Design, Construction and Operation of Tunnels"**

19-21 April 2023 at Dehradun, India



**Indian Roads Congress**



# Impact of new energy carriers on tunnel design and safety

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Alternative propulsion technologies, including battery-electric vehicles, are becoming more prevalent

This might have an impact on the nature of tunnel safety risk (including from fire)

### New Energy Carriers (NEC)

- Battery electric vehicles (BEV)
- Hydrogen powered fuel cell electric vehicles (FCEV)
- Hydrogen powered internal combustion engine vehicles (H<sub>2</sub>-ICEV)
- ICEV with compressed or liquified gas (CNG, biogas, LPG, LNG) → bridging technology

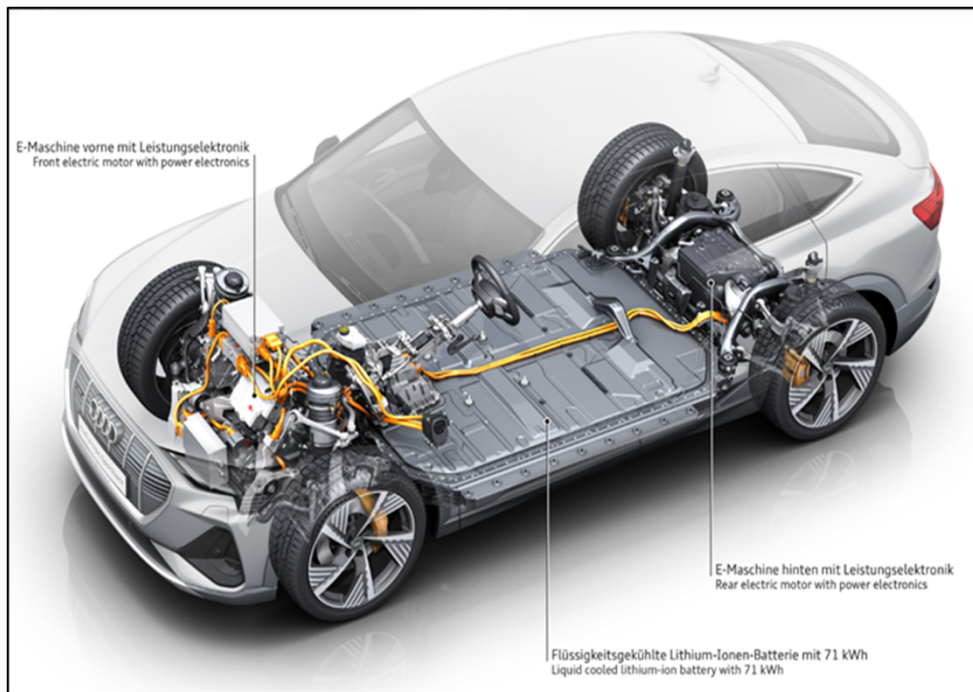
## Expected fleet penetration of NEC vehicles – example for Germany

	Cars			Light HGV			Heavy HGV			Bus		
	2020	2030	2040	2020	2030	2040	2020	2030	2040	2020	2030	2040
Conventional	high	high	medium	high	high	high	high	high	high	high	high	high
Hybrid <sup>2</sup>	high	medium	medium	low	medium	medium	low	medium	low	medium	medium	high
BEV	medium	high	high	low	medium	medium	low	low	low	medium	high	high
CNG	low	low	low	low	low	low	low	low	low	low	low	medium
LNG	low	low	low	low	low	low	low	low	medium	low	low	medium
LPG	low	low	low	low	low	low	low	low	low	low	low	low
FCEV	low	low	medium	low	low	medium	low	low	medium	low	low	medium
H <sub>2</sub>	low	low	low	low	low	low	low	low	medium	low	low	medium

Schmidt, R., Lehan, A., Fößleitner, P., Kammerer, H.; Influence of alternative energy carriers on tunnel safety – a quantitative consequence analysis, In: Proceedings of the 11<sup>th</sup> Conference Tunnel Safety and Ventilation, 2022 Graz, Austria

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## Vehicle fire:

- Due to a technical defect
  - Starting from the vehicle
  - Starting from the battery
- Due to a collision
  - Fire spread from another vehicle
  - Fire starting from the battery due to a damage

## Battery electric vehicles





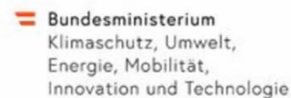
# BRAFA

Brandauswirkungen von Fahrzeugen mit alternativen Antriebssystemen

*Fire Effects of New Energy Carriers*

**BV05: Thermal Runaway eines Elektrofahrzeuges**

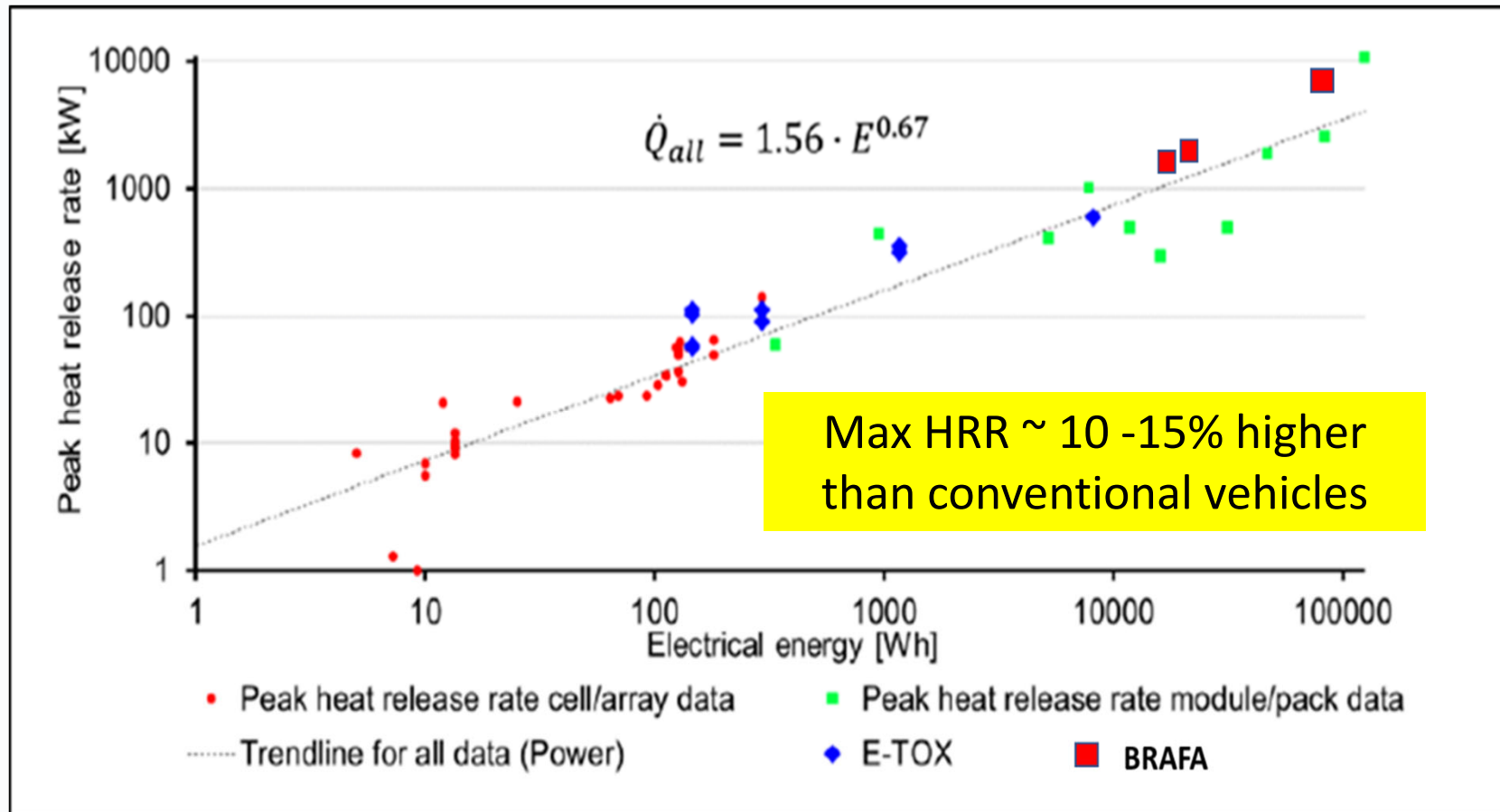
*BV05: Thermal Runaway of BEV*



<https://projekte.ffg.at/projekt/3290205>

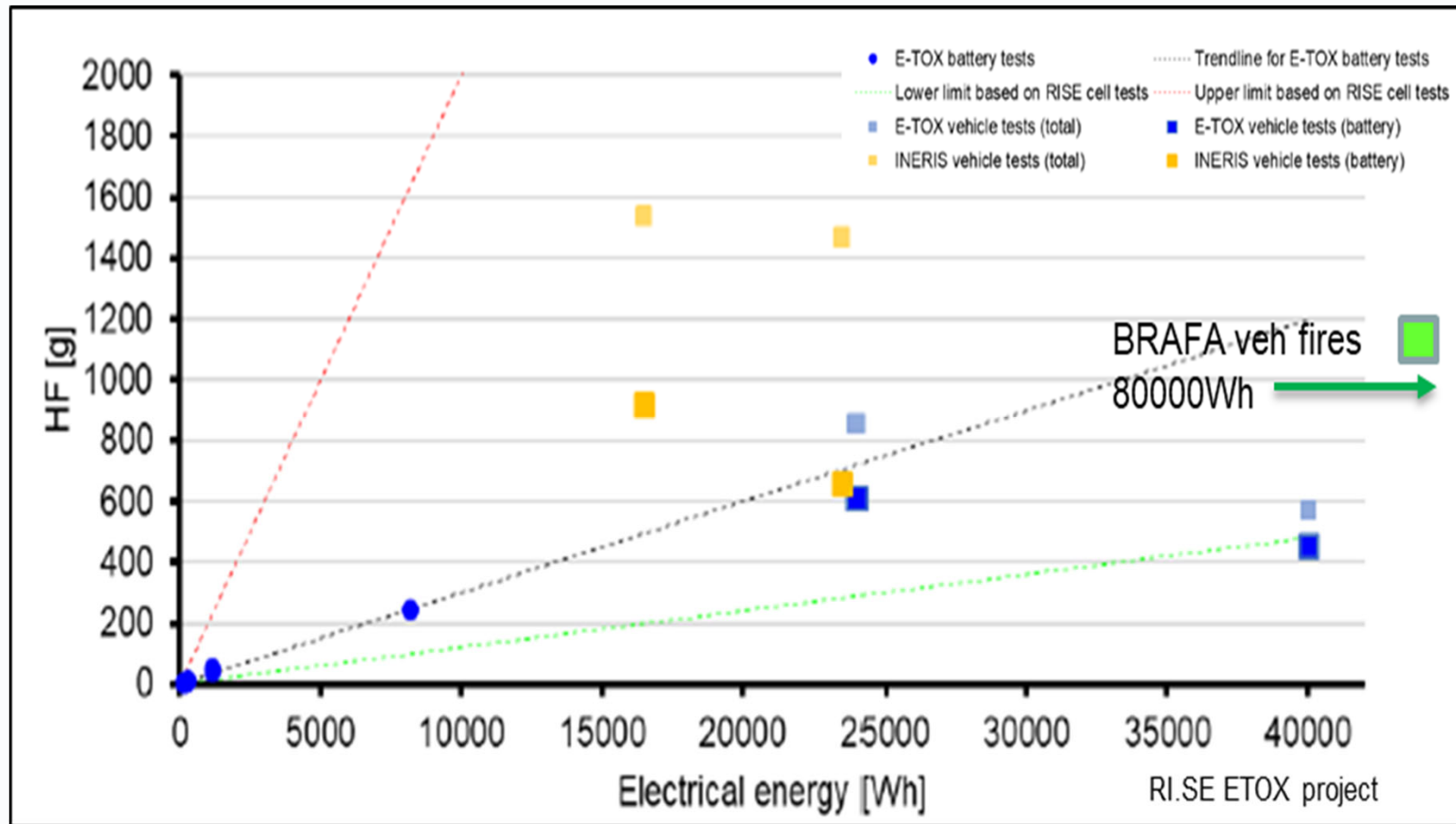


## Battery electric vehicles –peak heat release rate (HRR)





# Battery electric vehicles – toxic gases - hydrogen flouride (HF)



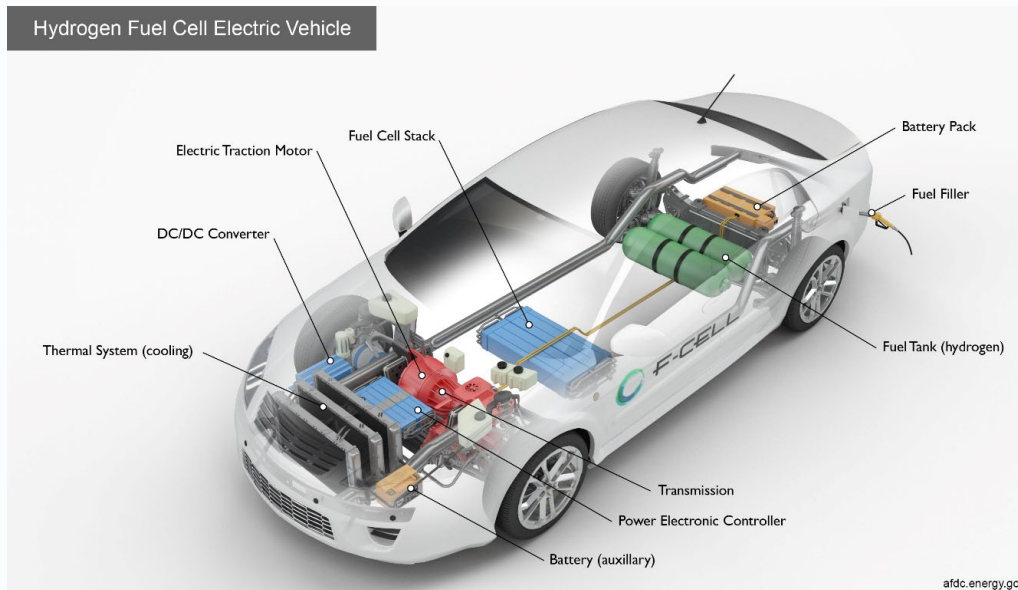
Fire fighting/extinguishing difficult as battery (electrolyte) is an oxygen carrier

Lot of water needed

Direct injection of water into battery casing proved to be very effective



## H<sub>2</sub> powered Fuel cell electric vehicles (FCEV)



### Risks during fire:

- High pressure storage (gas phase)
  - 700 bar (PC)
  - 350 bar (HGV/busses)
- Like BEV but smaller battery
- Risks for tank like for other gas vehicles

## Compressed gas vehicles (ICE with CNG, LNG, LPG or H<sub>2g</sub>)

CNG and LPG vehicles are in the fleet already for a long time  
LNG as well as H<sub>2</sub> are of interest for long distance transport

Gases: stored in tanks at pressures up to 700 bar (H<sub>2g</sub>) or 200 bar (CNG)

Risks:

- Jet flames
- Tank rupture
- Vapor cloud explosion (VCE)

Liquids: stored in tanks under low temperature (LNG -130°C, H<sub>2aq</sub> - 250 °C)  
at moderate pressure levels (10 bar)

- Additional risk: Boiling liquid vapor explosion (BLEVE)

Safety measure for avoiding overpressure (tank rupture):

- Temperature activated pressure relief valve (TPRD) –opens at 110°C
- Pressure triggered valves in LNG cars at 16 and 24 bar
- Tanks are either made from composite material or steel





## Fire tests performed by RISE (RISE Rapport 2019:120\_rev1)

- 8 tests
- pressures between 50 and 170 bar
- Jet flames up to 10 m
- In one of the 8 tests a pressure vessel explosion occurred: at 5 m max pressure rise above 1 bar (direct lethal effects for 1%, eardrum rupture at 0.2 bar) – open air



Ref: ISBN 978-91-89049-73-4





Courtesy of Johan Gerhandler, RISE

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## CNG in tunnels (CETU Study)

- Jet flames (9 kg vessel): release from a CNG bus with TPRD oriented horizontally can cause severe problems in the vicinity of the fire
- VCE: fatal health effect distance for test case (flammable mass 50 g) around 12,5 m on either side of the explosion in the tunnel
- Tank rupture (9 kg vessel): the associated health effects up to 25 meters either side of the tank, i.e. 50 meters of tunnel

Ref: C. Willmann, B. Truchot, New energy carriers and additional risks for user's safety in tunnels. International symposium on tunnel safety and security - , 5-7 May 2021

## Compressed gas vehicles (ICE with CNG, LNG, LPG or H<sub>2</sub>)

### LNG in tunnels (CETU Study)

- Jet flame: release can cause severe problems in the vicinity of the fire
- VCE: the flammable mass will remain low, significant lethal effect distance is around 2 m.
- Tank rupture HGV size (182 kg of LNG ): the lethal health effects, would occur up to around 375 meters either side of the tank, i.e. 750 meters of tunnel. Due to the thermal effects induced by the BLEVE triggered by the tank ..... after 20 minutes .... sufficient time to escape (dependent on tank type)

Ref: C. Willmann, B. Truchot, New energy carriers and additional risks for user's safety in tunnels. International symposium on tunnel safety and security - , 5-7 May 2021

# H<sub>2</sub> - Fuel cell electric vehicles (FCEV) Blast wave hazard for tank rupture (HyTunnel Project)

Harm to people	Tank 99% SoC (70 MPa) 62.4 l = 2.5 kg H <sub>2</sub>	Tank 59% SoC (35.5 MPa)
Fatality	0 – 90 m	0 – 70 m
Serious injuries	90 – 1150 m	70 – 900 m
Slight injuries	1150 – 4600 m (end of tunnel)	900 – 4600 m (end of tunnel)
No harm	Does not exist	Does not exist

**Conclusion: tank rupture in a tunnel MUST NOT occur**

## Conclusions

NEC vehicles are steadily penetrating the vehicle fleet

BEV vehicles:

- Information for PC size vehicle show a slightly higher heat release rate (at 100% SoC), compared to conventional vehicles.
- HF is identified as an additional critical pollutant related to battery fires.
- But, as long as sufficient ventilation is provided, a harm to tunnel users is not to be expected → valid for passenger cars.
- Solid results for bigger size vehicles (busses or HGV) are currently not available



## Conclusions

Gas vehicles (information restricted to parameters of cases studies):

- Jet flames: CNG buses might be a problem (dependent on the TPRD release)
- Vapour cloud explosion:
  - CNG: regions for lethal health concerns ~25 m in tunnel
  - LNG: very small region concerned
- BLEVE LNG (182 kg tank): 750 meters of tunnel
- Tank rupture:
  - CNG 9 kg tank - lethal health concern region ~ 50 m
  - H<sub>2g</sub>: tank rupture must not happen
- Data basis for heavy goods vehicles/buses with LNG and H<sub>2</sub> needs to be improved

Technical measures to avoid  
tank ruptures are set



Thank you very much for your attention

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