Impact of battery electric vehicles on operation and safety of underground structures and buildings

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Impact of Battery Electric Vehicles on operation and safety of underground structurs and buildings

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

This might have an impact on the nature of safety risks (including fire) in underground facilities like tunnels and garages

New Energy Carriers (NEC)

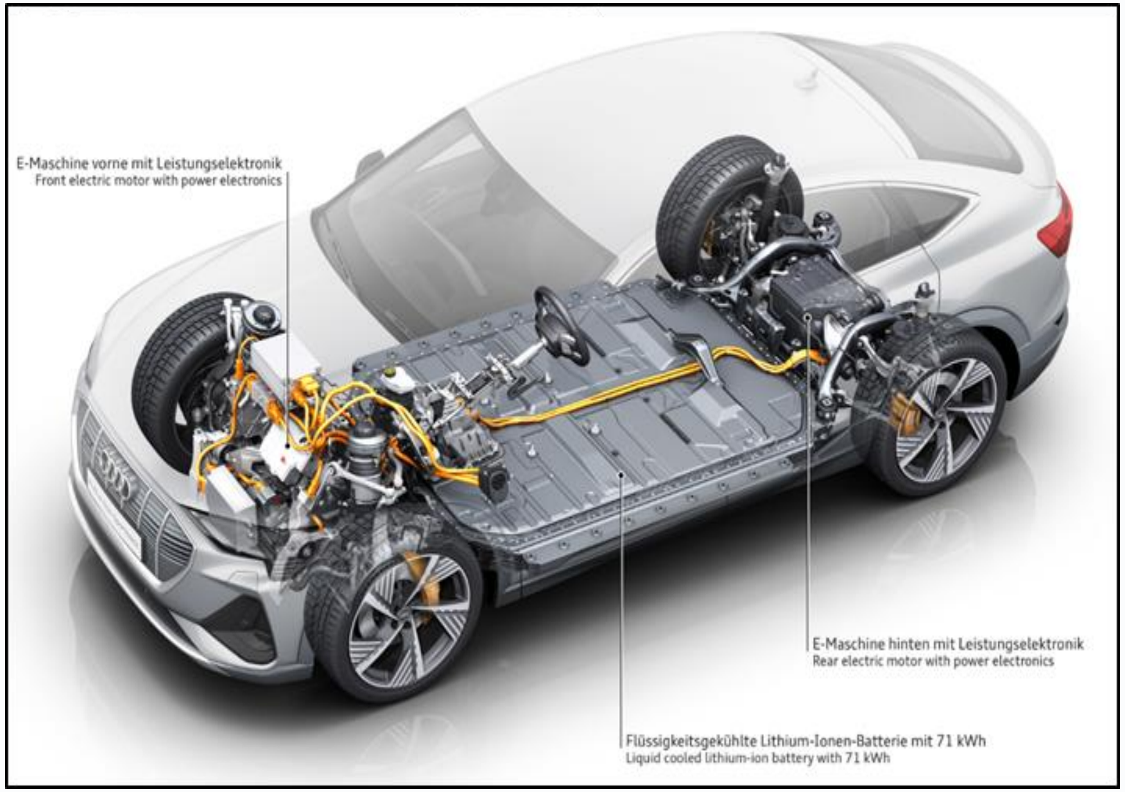
- Battery electric vehicles (BEV)
- Hydrogen powered fuel cell electric vehicles (FCEV)
- Hydrogen or syn-fuel powered internal combustion engine vehicles
- ICEV with compressed or liquified gas (CNG, biogas, LPG, LNG) → bridging technology

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[2]	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_2	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 11th Conference Tunnel Safety and Ventilation, 2022 Graz, Austria

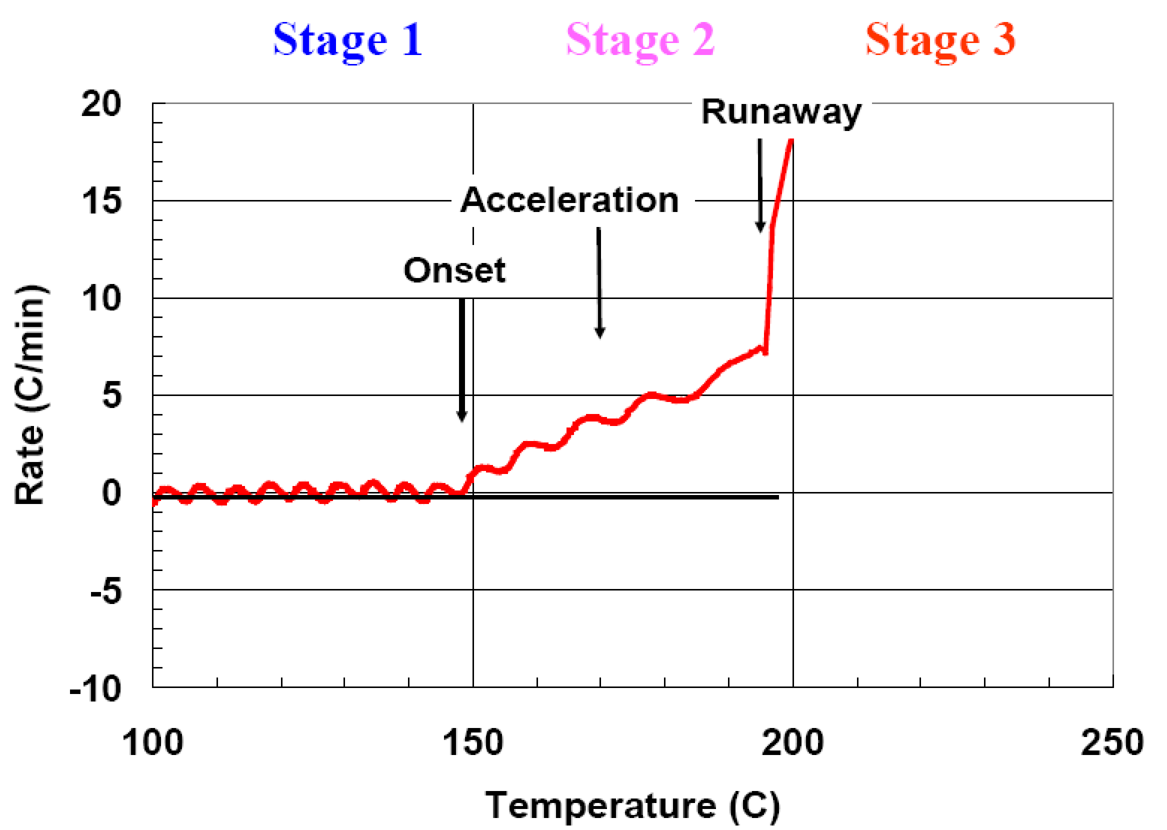
Battery electric vehicles



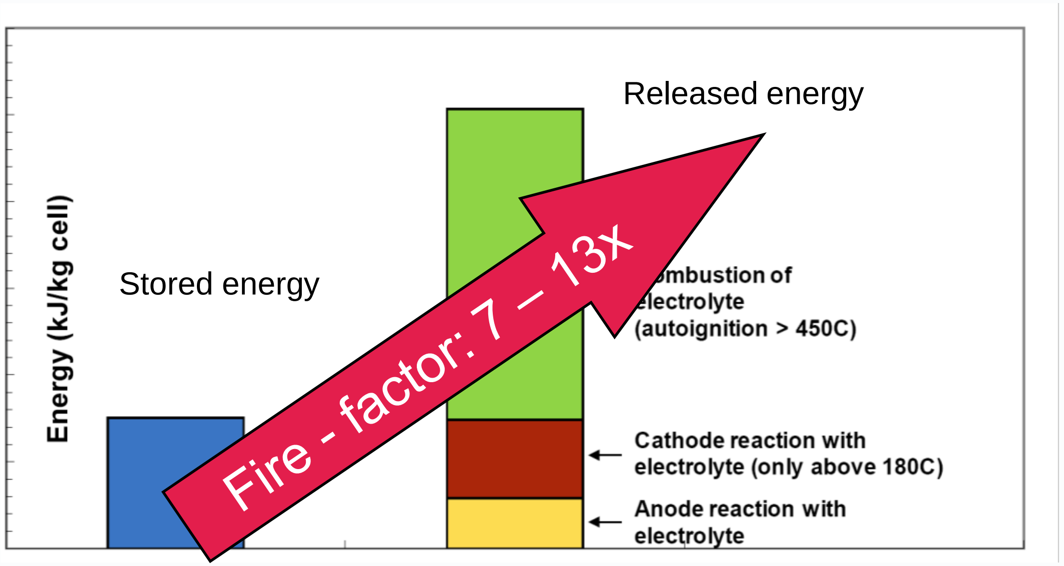
Vehicle fire:

- 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



Heat content and release of a Li-Ion Zelle



Source: D. H. Doughty, A. A. Pesaran "Vehicle Battery Safety Roadmap Guidance," National Renewable Energy Laboratory, Golden, Colorado, USA, NREL/SR-5400-54404, 2012

Battery electric vehicles

Sturm et. Al.: Fire Safety Journal 134 (2022) 103695 https://www.youtube.com/watch?v=7PDwm_-dI3I&ab_channel=FVTmbH

BRAFA

Brandauswirkungen von Fahrzeugen mit alternativen Antriebssystemen

Fire Effects of New Energy Carriers

BV05: Thermal Runaway eines Elektrofahrzeuges

BV05: Thermal Runaway of BEV

Graz University of Technology

Institut für Verbrennungskraftmaschinen und Thermodynamik

Vehicle Safety Institute

CONSULTING ENGINEERS

ÖBFV

MONTAN UNIVERSITÄT

ZaB ZENTRUM am BERG

ASFINAG

Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie

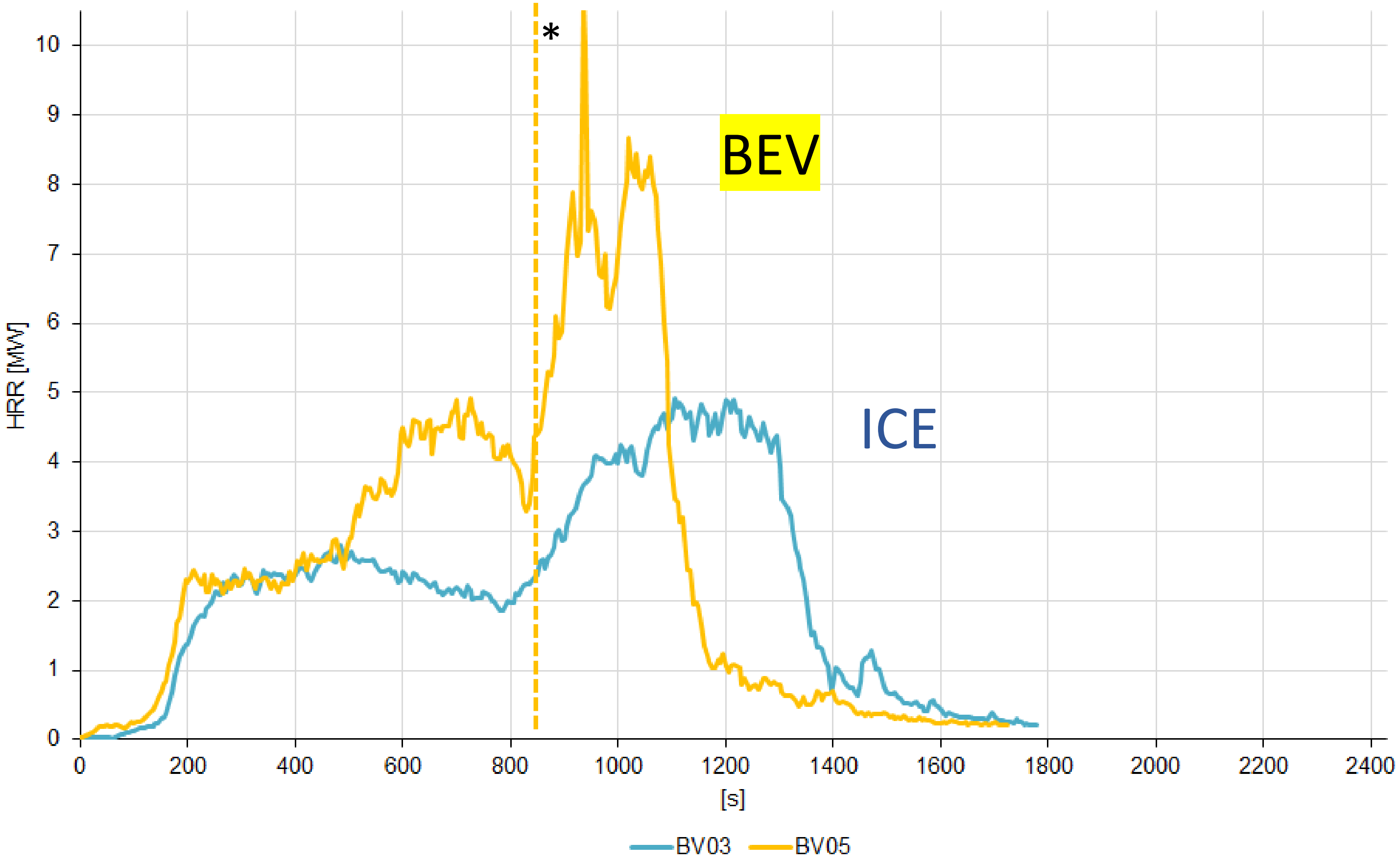
FFG Forschung wirkt.

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

Comparison of fire tests of 2 identical vehicles

BEV – 80 kWh NMC Battery 100% SOC (BV 05)

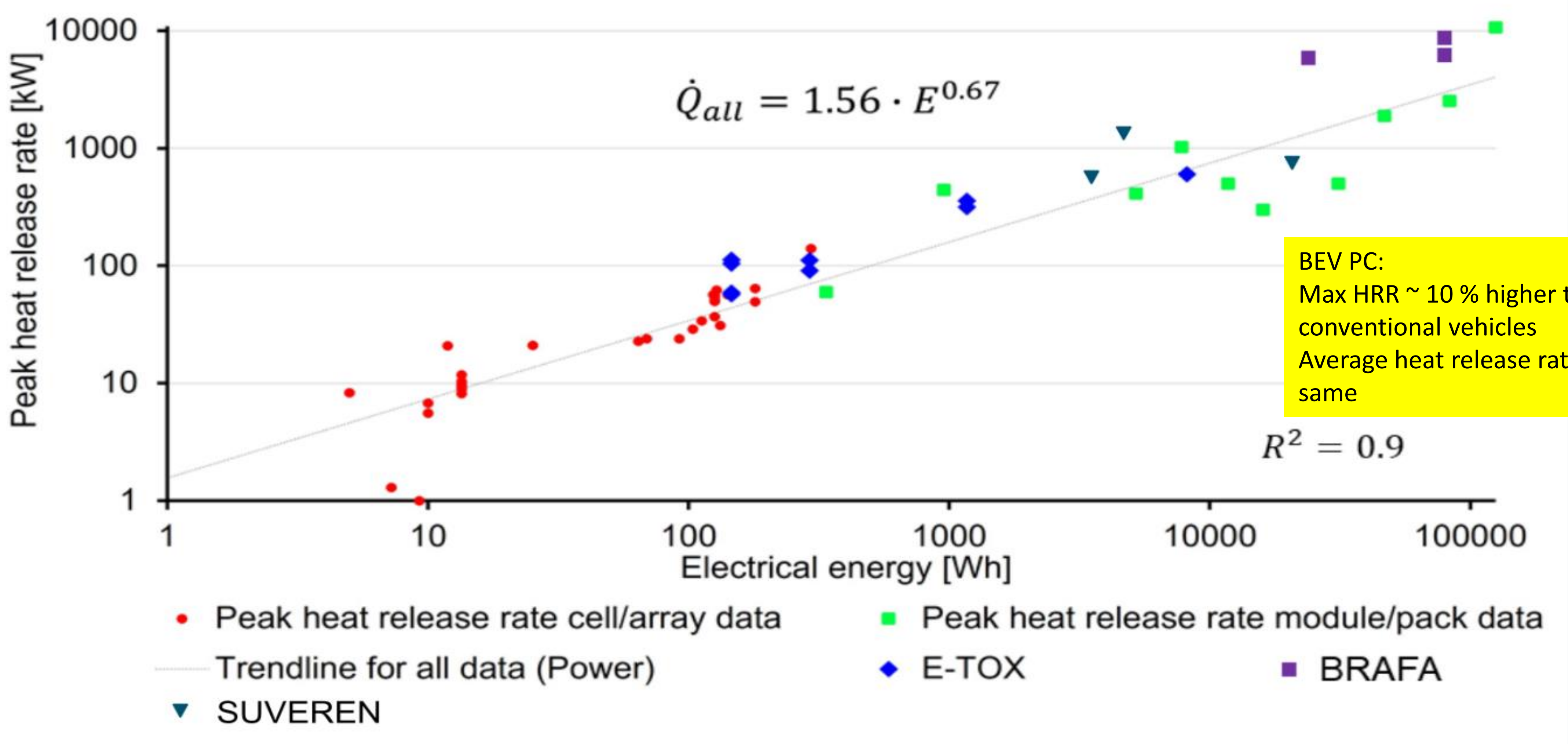
ICE – SUV 50 l Diesel (BV 03)



* Triggered ignition of almost all battery cells within very short time

Source: P. Sturm, P. Fößleitner, D. Fruhwirt, S. Heindl, O. Heger, R. Galler, R. Wenighofer und S. Krausbar, „BRAFA-Brandauswirkungen von Fahrzeugen mit alternativen Antriebssystemen," Graz University of Technology, Graz, 2021.

Battery electric vehicles –peak heat release rate (HRR)



BEV PC:
Max HRR ~ 10 % higher than with conventional vehicles
Average heat release rate almost the same

Source: PIARC TC4.4 WG 4 report 2023

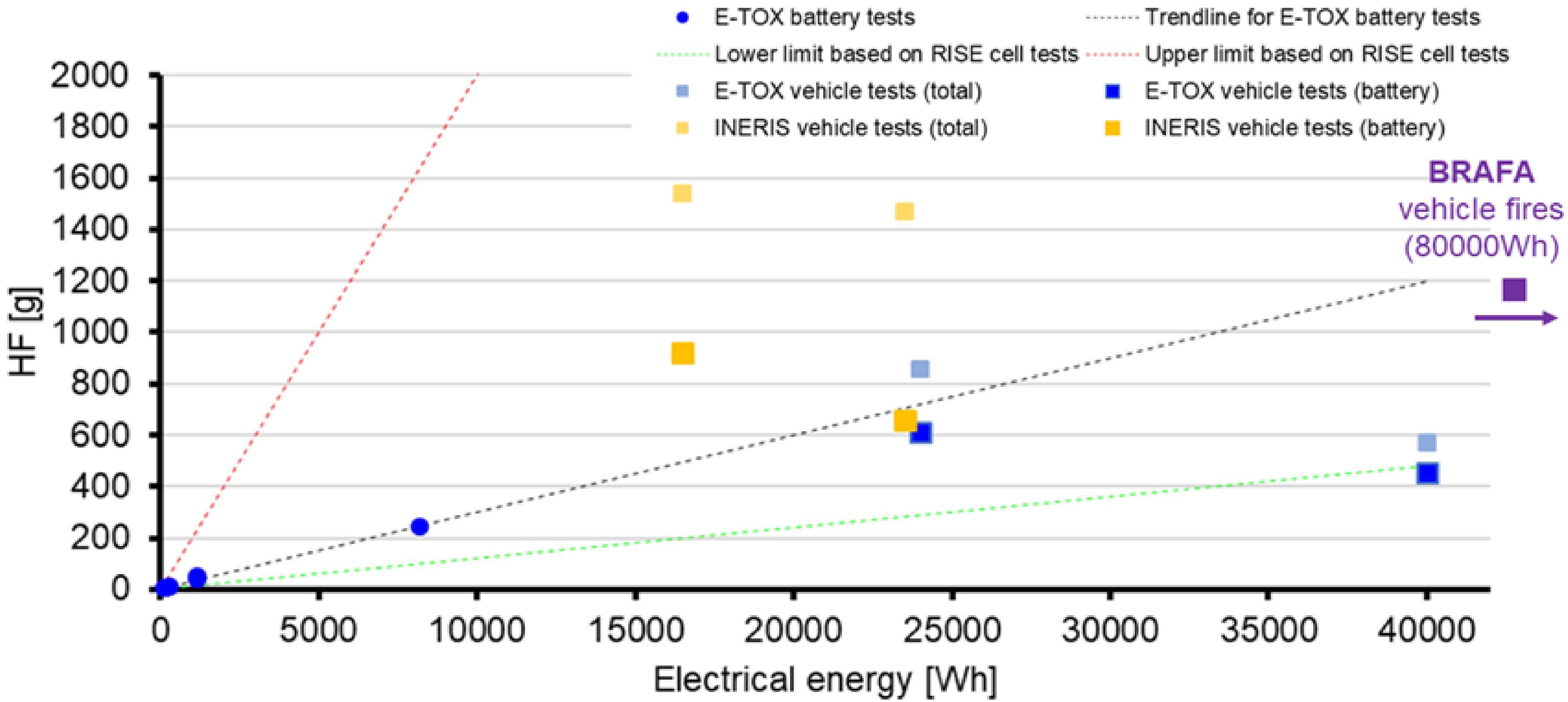
Status of charge (SOC) in most cases 100%

Toxic gases – BEV fires

Flue gases and particles:

- Main combustion gases like CO, CO2, HCl are similar to conventional car fires
- HF and some metals like Li, Mn, Co are much higher in BEV fires
- HF has two sources: battery (major part) and coolant (present in both vehicles, but in smaller quantities)
- HF content strongly dependent on battery chemistry and status of charge of battery (lower SOC → higher HF content)

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



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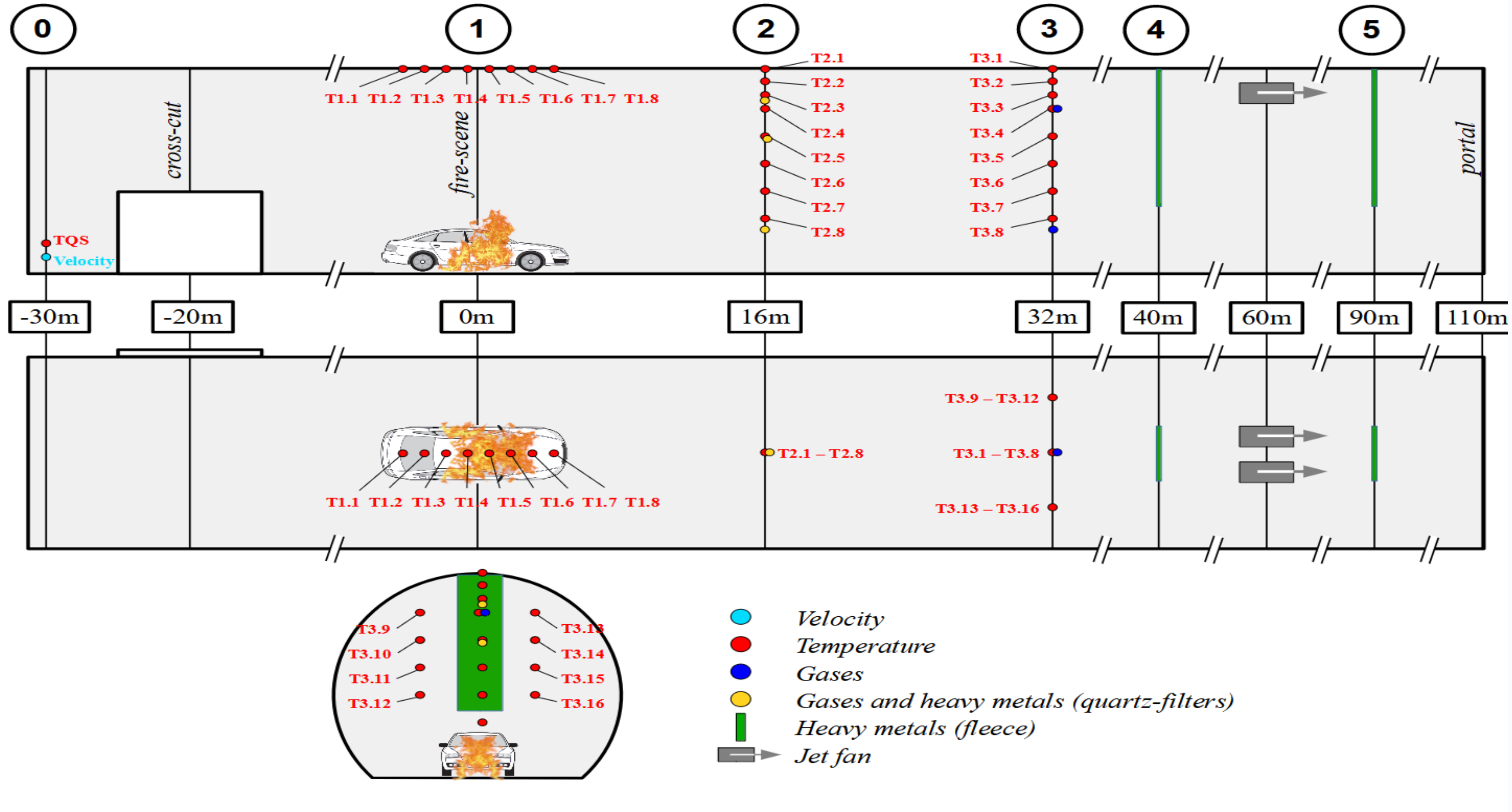
Battery electric vehicles – test set-up – road tunnel



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Battery electric vehicles – toxic gases – road tunnel

Ventilation rate ~ 120 m³/s

Test-Nr.	HCl [mg/m³]			SO_2 [mg/m³]			H_3PO_4 [mg/m³]			HF [mg/m³]		
Location	16 m downstream fire location											
Height	6.4 m	4.8 m	1.6 m	6.4 m	4.8 m	1.6 m	6.4 m	4.8 m	1.6 m	6.4 m	4.8 m	1.6 m
BV01 (BEV), 80 kWh	61.8	31.0	4.4	2.8	14.3	1.5	2.5	1.3	0.3	38.4	10.3	13.5
BV02 (BEV), 24 kWh	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
BV03 (ICE), diesel	61.2	32.1	0.9	0.9	3.0	0.5	0.1	0.1	0.1	8.3	3.2	0.7
BV04 (ICE), diesel	n/a	6.3	n/a	n/a	3.7	n/a	n/a	n/a	n/a	n/a	*	n/a
BV05 (BEV), 80 kWh	18.8	35.0	2.6	0.5	9.3	0.7	n/a	n/a	n/a	17.3	20.1	5.3
IDLH-30	81			286			1092			27		
n/a = not analysed * = below detection limit												

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Battery electric vehicles – toxic gases – road tunnel

Ventilation rate ~ 120 m³/s

Element [mg/m³]	BV01 (BEV)			BV02 (BEV)			BV03			BV04			BV05 (BEV)		
Height above road level	*6.4m*	*4.8m*	*1.6m*	*6.4m*	*4,8m*	*1,6m*	*6,4m*	*4,8m*	*1,6m*	*6,4m*	*4,8m*	*1,6m*	*6,4 m*	*4,8m*	*1,6m*
Al	5.988	4.318	0.899	n/a	n/a	n/a	0.157	0.415	0.354	n/a	0.238	n/a	5.381	3.197	0.697
Sb	0.998	0.565	0.376	n/a	n/a	n/a	0.428	0.237	*	n/a	*	n/a	0.356	0.273	*
Pb	*	*	*	n/a	n/a	n/a	*	*	*	n/a	0.119	n/a	0.047	*	*
Cd	0.002	*	*	n/a	n/a	n/a	0.001	*	*	n/a	*	n/a	0.001	*	*
Co	9.139	4.215	0.730	n/a	n/a	n/a	*	*	*	n/a	*	n/a	6.292	*	0.558
Cu	0.746	0.668	0.281	n/a	n/a	n/a	0.233	0.222	*	n/a	*	n/a	0.993	0.780	0.172
Li	5.778	4.524	0.899	n/a	n/a	n/a	0.038	*	*	n/a	*	n/a	4.222	4.679	0.837
Mn	11.555	5.963	0.899	n/a	n/a	n/a	0.045	0.142	*	n/a	*	n/a	8.692	5.458	0.744
Ni	26.262	20.048	3.371	n/a	n/a	n/a	0.151	0.503	0.188	n/a	*	n/a	29.140	18.325	2.603
Se	0.032	*	*	n/a	n/a	n/a	*	*	*	n/a	*	n/a	*	*	*
Tl	*	*	*	n/a	n/a	n/a	*	*	*	n/a	*	n/a	*	*	*

Ni IDLH 11 mg/m³ (Standard conditions); work place regulation (TRK) 2 mg/m³ (15 min)/BGBl. II Nr. 253/2001

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Limitations and implications of BEV fire tests

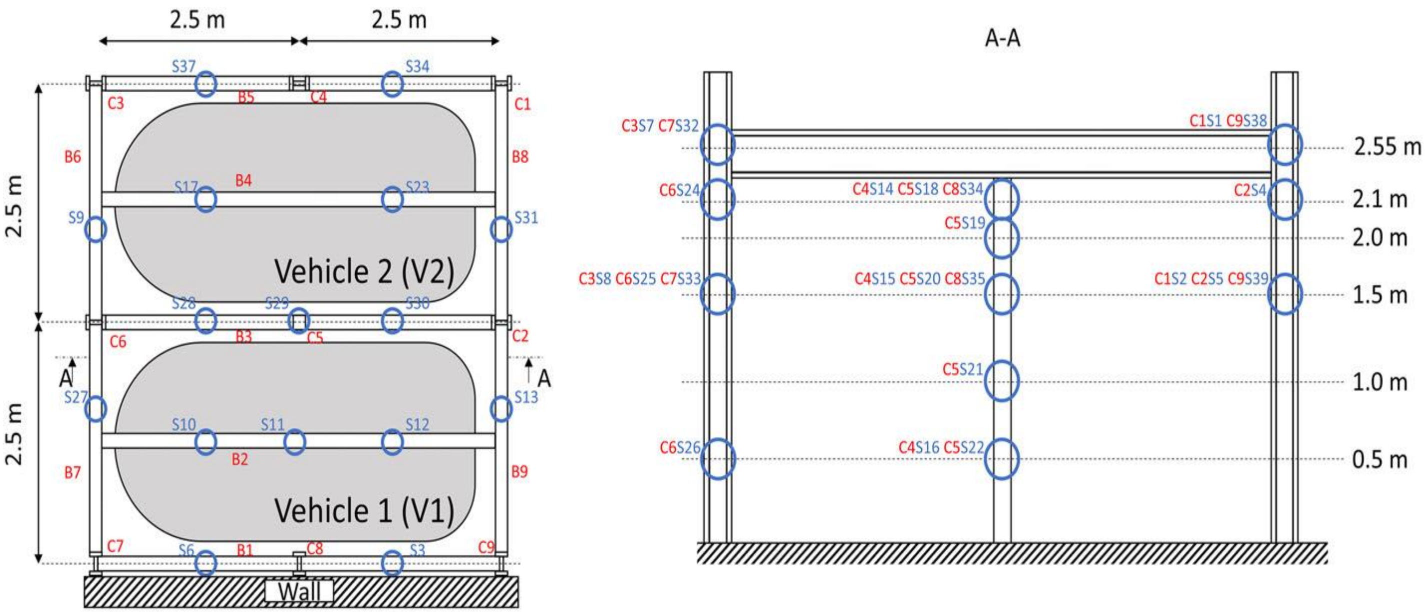
Full scale vehicle fire tests:

- The number of full scale vehicle fire tests is still small
  - Most of them have been performed in fire houses (labs), few in road tunnels
  - Sufficient air supply was provided by ventilation (ventilation rates between 50 m^3/s in fire houses and ~ 120 m^3/s in road tunnel)
- No full-scale fire tests of bigger vehicles in enclosed facilities yet published
- For lower ventilation rates (e.g. parking garages) totally different situations are to be expected (higher concentrations, higher peak temperatures on ceiling, etc.)

Fire of NEC vehicles in an underground structure

Full scale vehicle fire tests:

- Five fuel types have been tested: ICE (diesel as reference case), BEV (LMP battery), fuel-cell electrical vehicle (H_2-FCEV), CNG, LPG
- Always two cars per test, one on fire, second one (diesel) to monitor fire spread



Top view   Sectional view

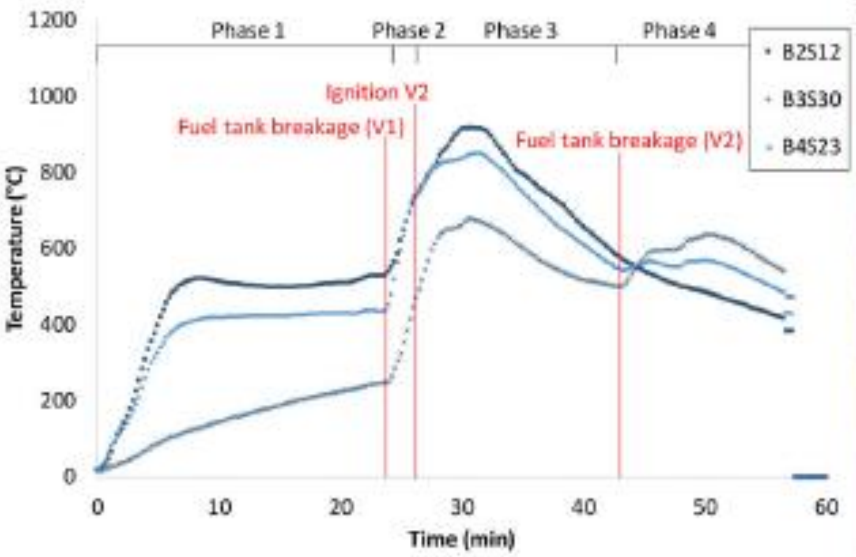
Ref: Tramoni et al. DOI: 10.1002/fam.2830

Fire of NEC vehicles in an underground structure

Results:

- Maximum temperatures at the steel beams above the cars were not much different (~900°C), only the location of the max. temperature different. Fire durations between 20/25 min (one vehicle) and 40/50 min (both vehicles).
- Activation of the safety devices led to a significant increase of released heat, but only for a short duration → no significant impact on structure observed

Reference case: two ICD-diesel



Ref: Tramoni et al. DOI: 10.1002/fam.2830

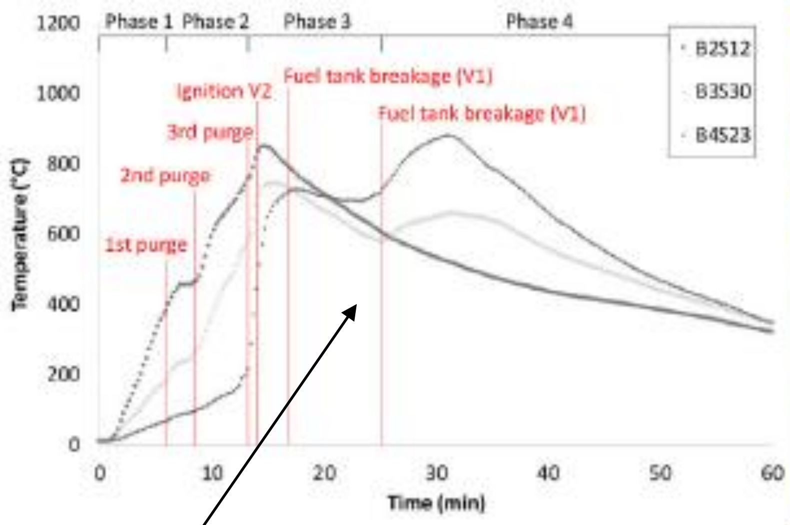
Fire of NEC vehicles in an underground structure

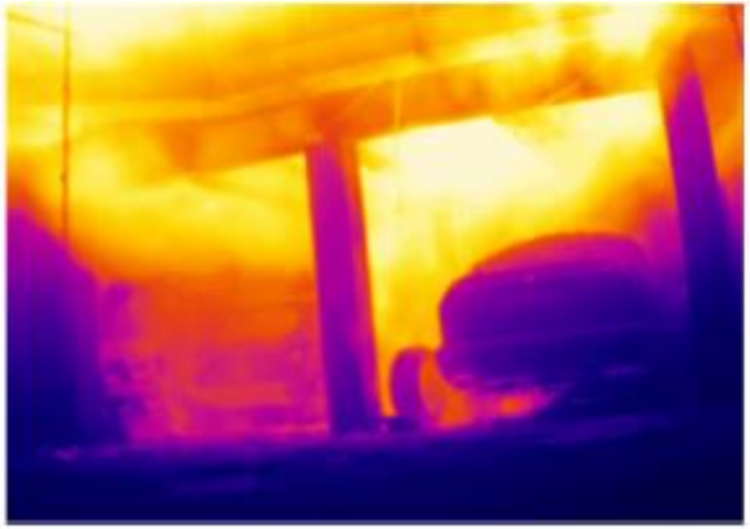
Results:

- Maximum temperatures at the steel beams above the cars were not much different (~900°C), only the location of the max. temperature different. Fire durations between 20/25 min (one vehicle) and 40/50 min (both vehicles).
- Activation of the safety devices of gas fuelled vehicles (H_2, CNG, LPG) led to a significant increase of released heat, but only for a short duration → no significant impact on structure observed

LPG vehicle test

PRD activation
1st – 3rd purge





TPRD activation

Ref: Tramoni et al. DOI: 10.1002/fam.2830

BEV vehicles in parking houses/garages (Austria)

Authority having jurisdiction is with:

- Federal Ministry in case of commercial use or companies
- Federal States (*Bundesländer*) in case of private use (9 partly different regulations)

Technical requirements only:

- for electrical part of installation
- for charging stations according to EN 61851

No safety concerns according to an official statement from Ministry (BMVIT 2016)

- Restrictions concern obvious issues like e.g. physical blockage of escape routes, traffic, explosion proof areas …

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- Restrictions concern obvious issues like e.g. physical blockage of escape routes, traffic, explosion proof areas …

This is questionable as it ignores that

- in the unlikely case of a BEV fire during parking, the probability that a fire happens during charging is higher than due to a malfunction of the parked (and not charged) BEV
- BEV-fires are associated with high HF and CO concentrations as well as a high fire dynamics near the floor

Charging stations in subsurface structures

- should be allocated close to smoke extraction location
- the smoke shall definitely not restrict egress possibilities, i.e. location in reasonable distance to egress ways

US-NFPA 88A (2023) requires sprinkler systems in garages with BEV

Battery electric vehicles – fire fighting

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

Lots of water needed

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

Conclusions

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, no harm to tunnel users is to be expected → valid for passenger cars.
- Solid results for bigger size vehicles (busses or HGV) are currently not available.
- During fires in parking garages higher HF and CO concentrations are to be expected due to low ventilation rate
- Full-scale tests with NEC vehicles on fire show no big change in maximum surface temperatures at ceiling
- Concerning charging infrastructure in subsurface and enclosed structures in Austria currently no safety related regulation exists
- Active fighting of BEV-fires is limited to cooling

Thank you very much for your attention

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https://ivt.tugraz.at/vuu

Further information available:

BRAFA project: https://projekte.ffg.at/projekte/3290205
Full report: "BRAFA" - Brandauswirkungen von Fahrzeugen mit alternativen Fahrzeugantrieben, DOI 10.3217/8vj91-gc832
Jornal article: Sturm et al.: Fire Safety Journal 134 (2022), 103695
Videos:
https://www.youtube.com/watch?v=7PDwm_-dI3I&ab_channel=FVTmbH
https://www.youtube.com/watch?v=v83C4o2IKZE&ab_channel=FVTmbH
https://www.youtube.com/watch?v=uHlVGFsdsqA&ab_channel=FVTmbH

DOI 10.3217/8vj91-gc832

PIARC Impact of new propulsion technologies on road tunnel operations and safety [Bericht] / WG 4 ; Technical Committee 4.4 Tunnels. - Paris, F : PIARC- World Road Organisation, 2023 (in print). - S. 130

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