



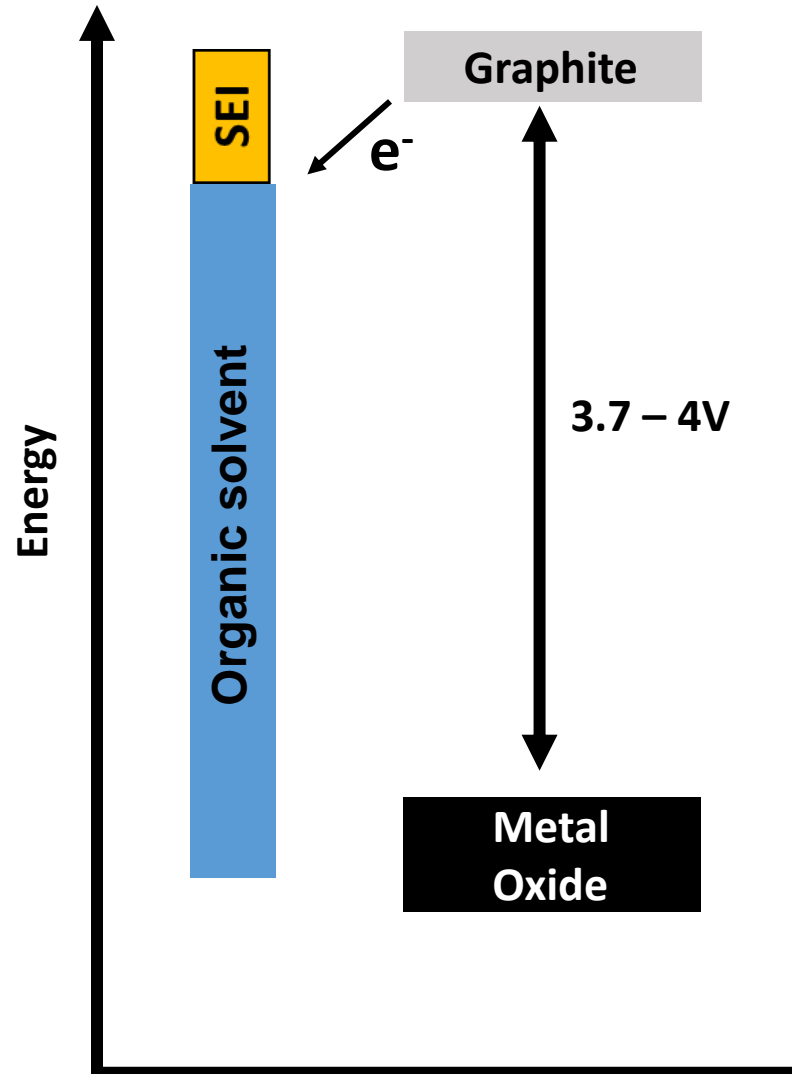
Lithium Ion Batteries, EVs and Vapour Cloud Explosions

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Newcastle University**

ReLiB and SafeBat Faraday Institution projects

Director, Lithiumionsafety Ltd.

Lithium-ion batteries are thermodynamically unstable and should not exist.

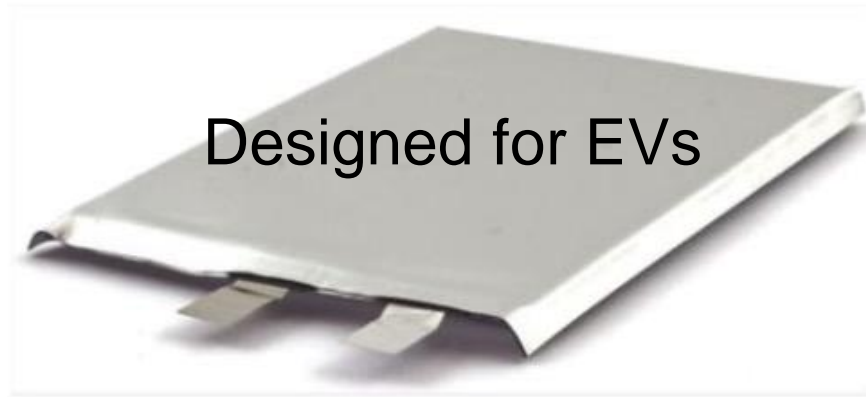


Lithium-ion cell form factors

Designed for portable electronic devices



Cylindrical



Pouch



Prismatic

Many cells make a module or string; many strings or modules make a battery pack. All form factors are employed in EVs, residential and grid-scale LiBESS.

Thermal runaway

Thermal runaway

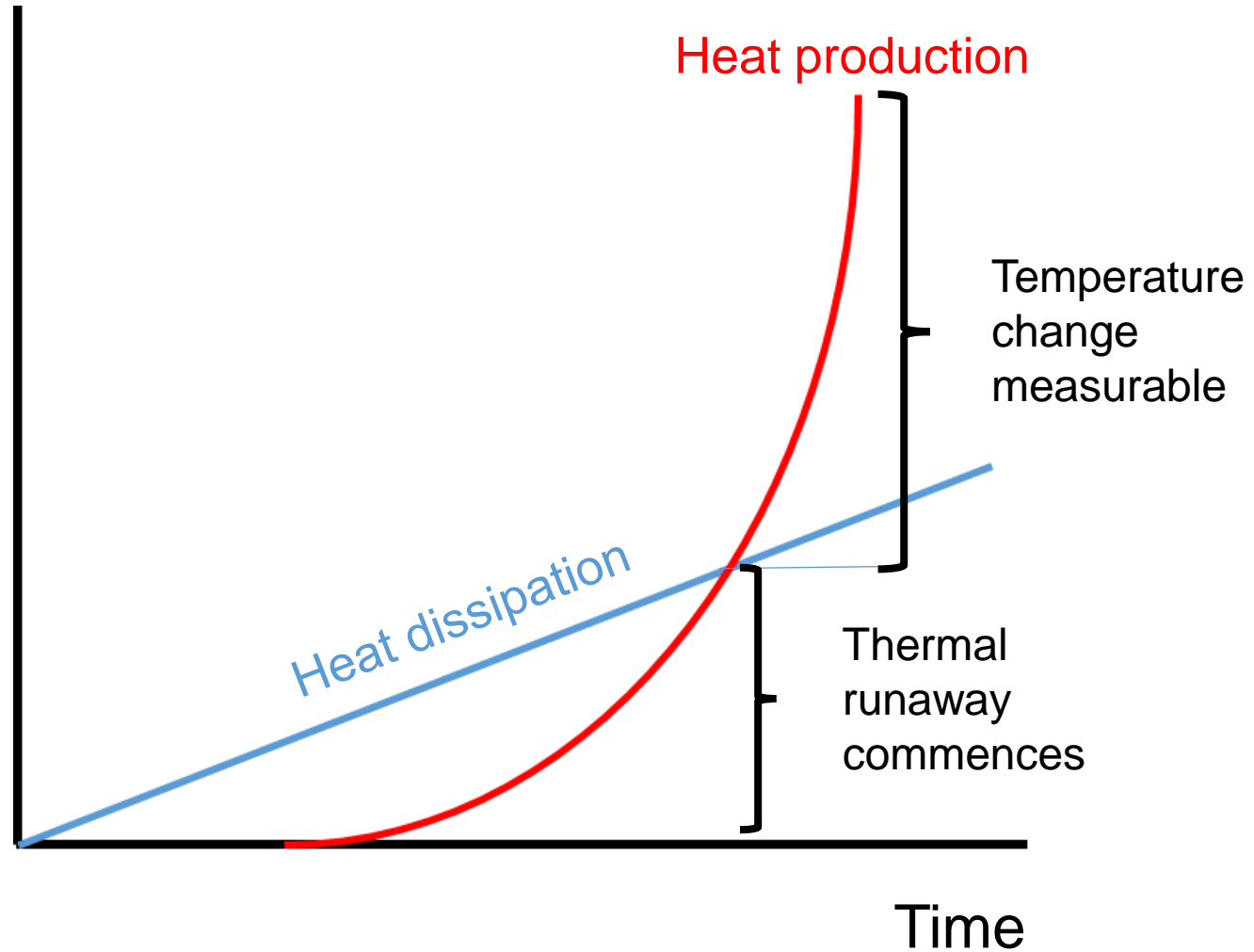
Abuse – heat, crush, penetration,
overcharge – or defect/contamination....

Chemical reactions supersede the normal
electrochemical processes (ion and electron
flow).

These chemical reactions produce heat and
gases: heat speeds up these reactions,
producing more heat and more gases =
“uncontrolled positive feedback” = thermal
runaway.

Thermal runaway should be prevented by
safety systems....but these activate too
late....

Heat



In thermal runaway and prior to ignition, LiBs produce a white vapour which consists of:

- Hydrogen (ca. 30 – 50%)
- Carbon monoxide
- Carbon dioxide
- Hydrogen fluoride
- Hydrogen chloride
- Hydrogen cyanide
- Small droplets of the organic solvents
- Ethane, methane and other hydrocarbons★
- Sulphur and nitrogen oxides.

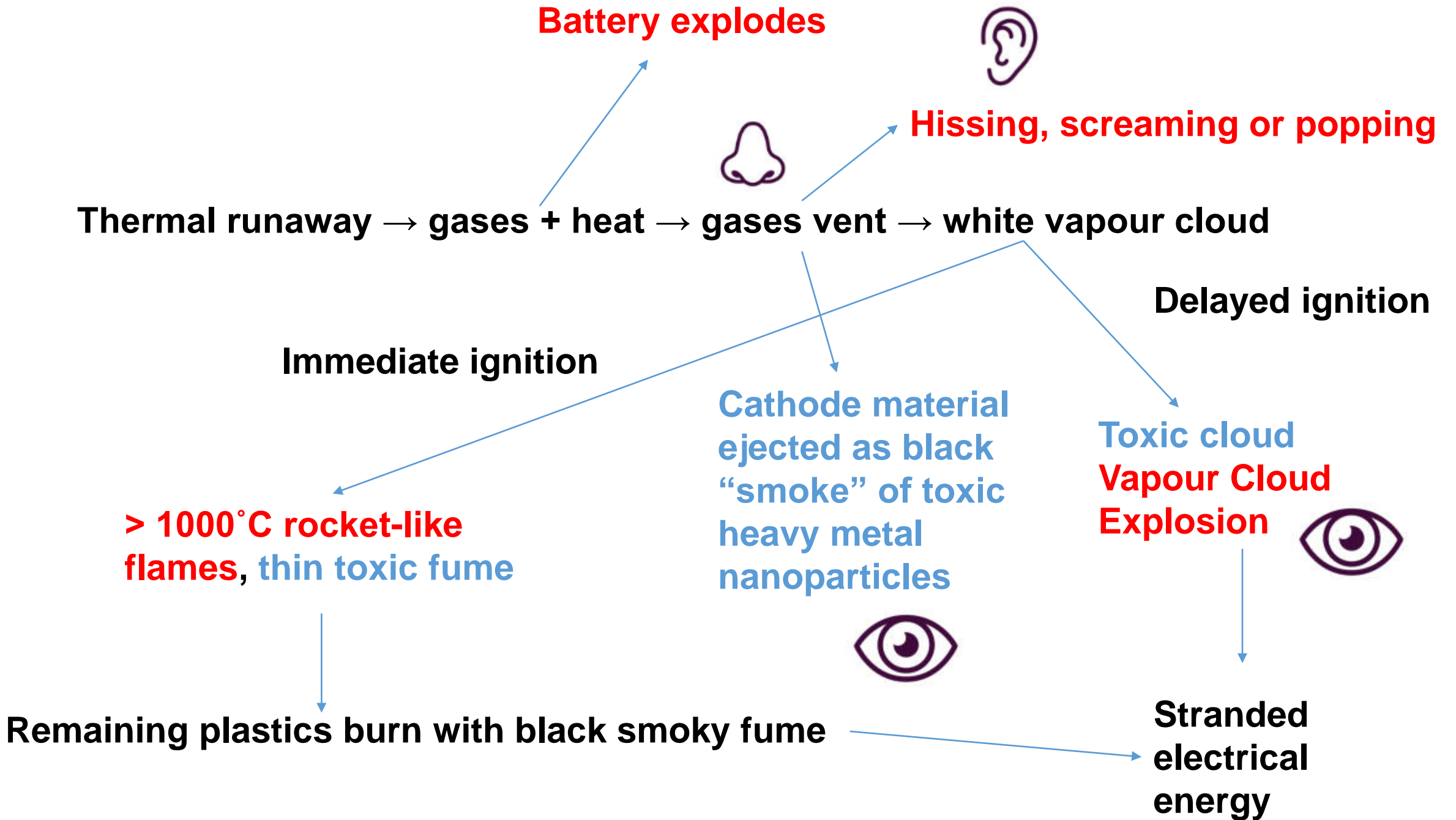


Vapour cloud from 1.7 kWh
LiB module at 50% SoC
i.e. a VAPOUR CLOUD

Fires and explosions are occurring on land and sea, and in the air.

Consequences of thermal runaway

Use your common sense(s) !



Battery explodes

Tesla crash on Moscow freeway....

10 Aug 2019 Tesla hit a parked tow truck at 100km/h.



No petrol or diesel.
A new kind of fire
challenge.

Battery explodes



Toxic fumes



1 November 2021, Parsons Green
Tube Station, London

If the gasses ignite immediately, long flare-like flames can result.



Hammer + nail
weighs
~ 23kg!!!

Single 1.7 kWh
module (24 in
40 kWh EV)

Newcastle University experiment at DNV site in RAF Spadeadam April/May 2021

Immediate ignition of vapour cloud and flare-like flames



Santa Monica Blvd
16 June 2018.

Immediate ignition: risk of structural damage: 13 kWh pack.



12 Feb 2022 Brussels



Fire in sub-basement car park.

Kulmbach and Leonberg in Germany banned EVs from Parking houses in 2021. Belgian pompiers calling for similar ban.

Can't put EV fires out, highly directional flames, damage to structure

The Singelgarage fire 1 July 202, Alkmaar, the Netherlands

Built 1998.

2 levels below canal, EV 50 m from ICEV. Arson. Both vehicles on fire.

Took 3 hours to locate fire (thick smoke) – almost out when located. No heat source located on TIC.

The ceiling above the EV suffered more structural damage than above ICEV.

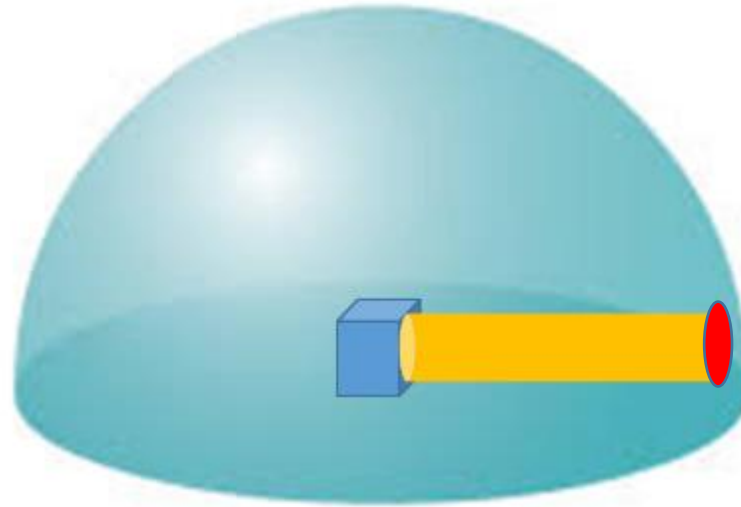
Tom Hessels et al NIPV, due to specific hazards of EVs (jet fire, UVCE) attack on EV in enclosed car park should only be attempted if:

- Fire can be seen
- Is close to entrance
- Only one vehicle involved
- Otherwise-leave to burn

Highly directional flames



ICEV



EV

Heat impinging on
this area of wall ca.
315x greater



If the vapour cloud does not ignite....single 1.7 kWh module, nail penetration **40% SoC**.



LEL said to be ca.
6 – 11%: LEL of
mixture less than
that of any
component of
mixture.

IDLH < LEL

Abuse method irrelevant to consequences. **Vapour cloud 500 – 6000 L/kWh.**

Newcastle University experiment at DNV site in RAF Spadeadam April/May 2021

500 – 6000 L/kWh: so even small LiBs can produce VCEs



< 0.5 kWh battery

New York: VCE from ebike blows owner out of window, fall is fatal. Brisbane Oct 22 – scooter VCE blows out windows and move wall between flats.

Delayed ignition and VCE



Ca. 15 verified VCEs involving EVs since 2010

Ca. 320 verified incidents

(EV Firesafe)

15 fire engines, 1 hour to extinguish fire.

Queanbeyan City Brigade, Burra NSW (near Canberra)

Jan 2023

Garage fire involving Tesla S, Tesla 3 and a Toyota Prius.

Note quantity of vapour cloud prior to ignition (it then is consumed) – and I wouldn't stand that close!

The fire occurred at around 0130hrs and was extinguished by around 0700hrs. VC produced several times then ignition.

c.a. **500 – 6000 L vapour per kWh**

LiBESS in sub-basements, EV charging points in underground car parks

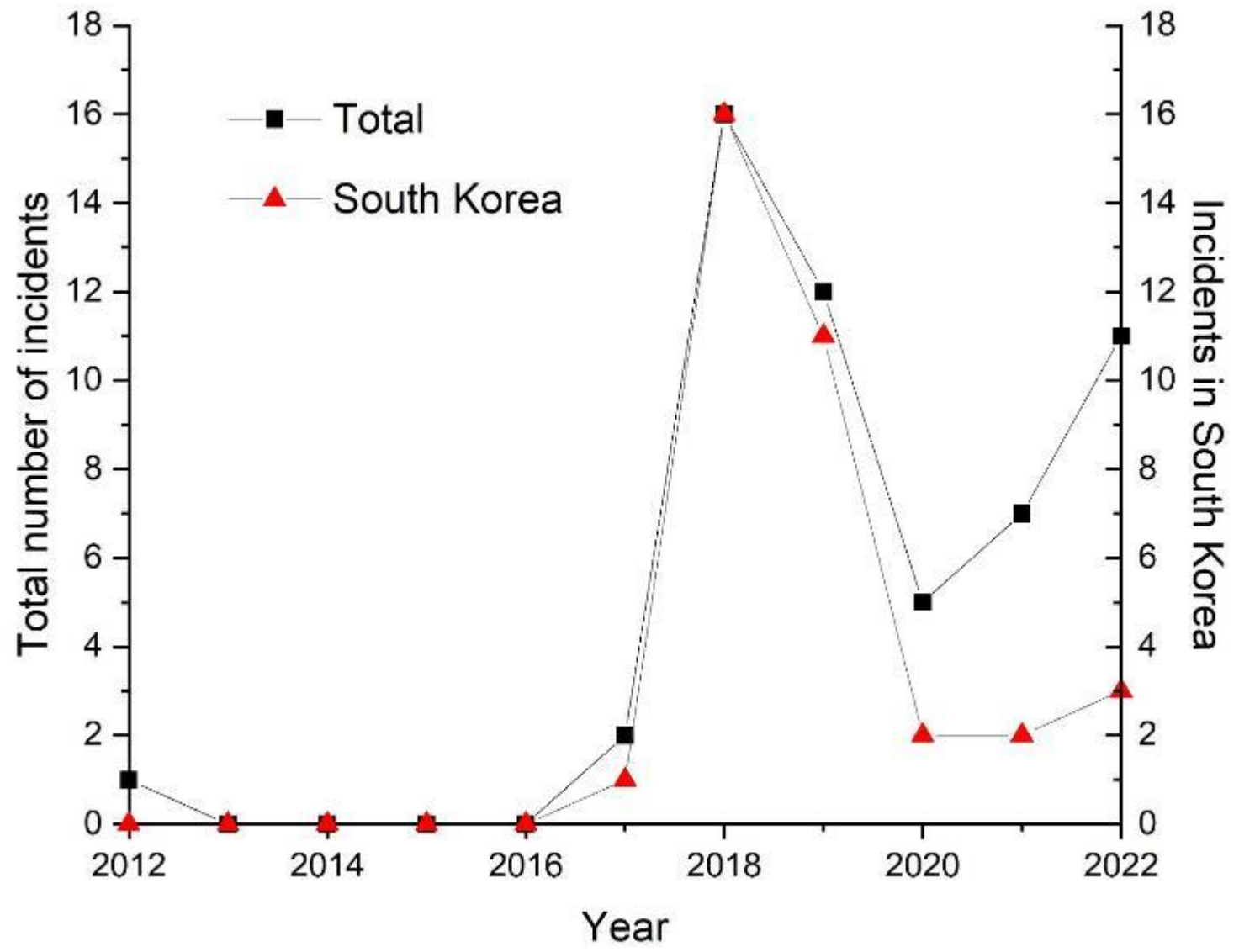


Toxic and explosive

Lithium ion Battery Energy Storage Systems LiBESS:

- **Rooftops**
- **Basements**
- **Sub-basements**
- **Floor 13**
- **UPS in office blocks**

Grid-scale LiBESS incidents ca 60 since 2012



The McMicken LiBESS explosion in Surprise, Arizona

Highway

Game changer



Door

Chain metal fence.

Four firefighters thrown by explosion 2 severely injured, 2 badly. Hazmat Team leader blown > 20m to here: he and surrounding bushes set on fire. Safety masks ripped off and destroyed. PPE contaminated with HCN. Chemical burns and crush injuries. All lost consciousness.

9 first responders in total sent to hospital with chemical burns & HCN contamination.

VCE

There was no fire at any time before or after the VCE.

500 – 6000 L vapour per kWh: 1 rack in McMicken LiBESS = ca. 90kWh

= 27 – 540 m³ vapour in 220 m³ volume (less racks & modules)

DNV at RAF Spadeadam, Mr. Rob Crewe. Tests on generic lithium-ion vent gas mixture (UL 9540A) in 26 m³ chamber – 80% of volume of 20' shipping container. 11 m³ partitioned off with plastic sheet. 28.7% mix with air. 50% H₂, 30% CO₂, 10% CO, 10% CH₄. **EQUIVALENT TO 0.6 - 6.3 kWh battery. Saturday 25 Feb 2023. 0.3 atm overpressure.**

Explosion of Lithium Ion Battery Offgases



A near miss: last week of February 2023. FRS called to research lab, pod off main warehouse space containing EV pack in thermal runaway.....



Suppressants

Thermal runaway need not result in fire

If no ignition – toxic and flammable vapour cloud continually produced

If immediate ignition – fire.

If fire suppressed BUT thermal propagation is NOT – vapour cloud vented AGAIN – with risk of VCE.

Fire extinguishing tests

Complete extraction
and treatment system

Tests at Durham and Darlington FRS 21 -25 March 2022



Fire extinguishing tests

Five Envision-AESC NMC (532) modules, each with 8 x 54 Ah pouch cells: c.a. 10 kWh. Mounted in open-fronted steel case.

2 cells in module 2nd from bottom overcharged.

i.e. small domestic LiBESS

Overcharge and leave 1 minute



Fire extinguishing tests

- Please note:
 - Only enough resources for one 5-module test for each extinguisher.
 - X only recommended for LiBs < 0.75 kWh by manufacturer
 - X system had fault & operated under pressure

Fire extinguishing tests

Five module stack unless specified.

- Coldcut cobra
- Liquid N₂ single module
- F500
- X

USELESS!

Lance+

Fire allowed to burn for 1 minute before deployment.



Other suppression systems

Fireblanket...but understand the hazards



Profuse thanks to David Smyth of Fireblanket.com



Heavy – keeps heat in
Permeable VCE hazard
moves outside of blanket
Re-ignition fire/VCE when
removed

Fire tests with lithium-ion battery electric vehicles in road tunnels

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Simon Franz Heindl^d, Stefan Krausbar^e, Oliver Heger^f



**THE ELBAS PROJECT – ELECTRIC VEHICLE FIRES
AT SEA: NEW TECHNOLOGIES AND METHODS FOR
SUPPRESSION, CONTAINMENT, AND EXTINGUISHING
OF BATTERY CAR FIRES ONBOARD SHIPS**



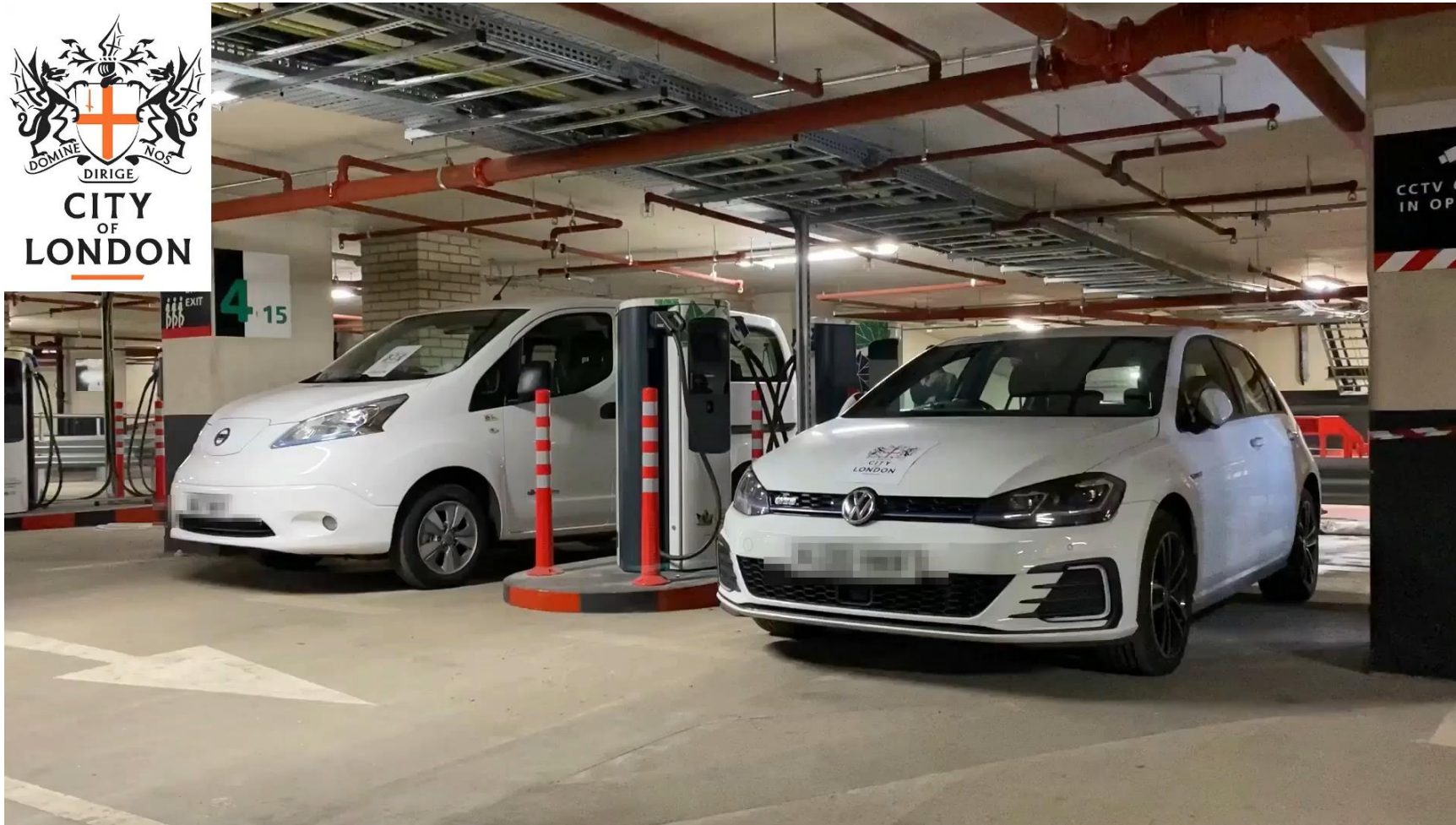
2021

Tested Rosenbauer system on Renault
Fluence ZE

Tyres had to be deflated for system to
deploy –insufficient reach.

Failed. Hole allowed water to escape.

Water mist or etc between EVs is “likely to prevent fire spread”



Re-ignition hours, days weeks later and many times.....legal liability? Let it burn!

September 2022: BMW i3 caught fire whilst on charge and was placed in a water-filled skip with the battery pack submerged.

Pack re-ignited under water.

Electrolysis?



Thermal runaway is uncontrolled positive feedback at cell level – abuse generates heat and the production & venting of a vapour cloud

Thermal propagation is heat transfer cell-to-cell, module-to-module etc

Thermal runaway need not result in fire

If no ignition – toxic and flammable vapour cloud continually produced

If immediate ignition – fire. If fire suppressed but thermal propagation is **NOT** – vapour cloud vented **AGAIN**

If ignition delayed (low SoC, lack of air etc) – vapour cloud explosion

No “lithium-ion battery fire extinguishers” have been validated by independent authorities to my knowledge.

Water remains the best of the bad options: high pressure water mist gaining supporters particularly for EVs and LiBESS

BUT

The MAJOR challenge is still – getting water in sufficient quantities to the cells in thermal runaway/on fire to PREVENT PROPAGATION: knocking down the fire without preventing propagation – hazard shifts from fire to toxic cloud or even explosion....hence aerosols and gaseous suppressants are ineffective for LiB fires and latter can facilitate explosion...

**Thankyou for your
kind attention**

