



The Vapour Cloud: when lithium-ion batteries are in thermal runaway

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ReLiB and SafeBat Faraday Institution projects

The history of lithium ion batteries

1991 Sony camcorders, then rapidly mobile phones and laptops.

2008 Tesla Roadster: EV production triggered very large scale production of LiBs in gigafactories. Used off-the-shelf 18650 cylindrical cells.

2008 First Lithium ion Battery Energy Storage System (LiBESS) in Guadeloupe: a group of domestic LiBESS (DLiBESS), consisting of 15 SAFT 11 kWh units each connected to a 2 kW PV system.

2010 Plug-in hybrid EVs and the Nissan Leaf BEV.

2012 The first large scale (5MW) LiBESS commissioned for Portland General Electric.

2015 Significant increase in the LiB market due to the application of LFP cells in Chinese buses.

2021 3140 MWh LiBESS planned W. Sussex.

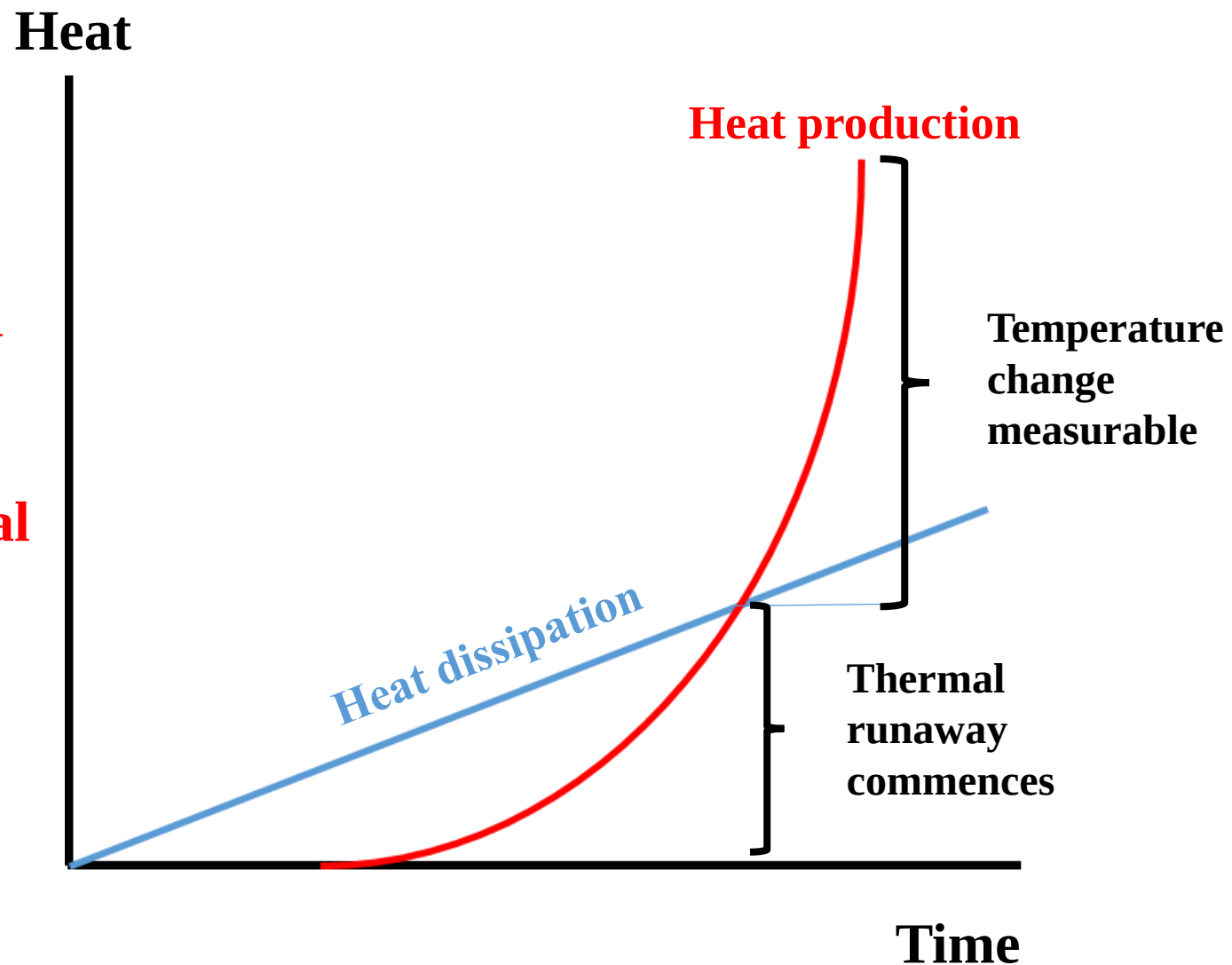
Penetration outstrips our knowledge of the risks



Thermal runaway

The ever-present fear in LIB manufacturer's minds is that of **thermal runaway**.

Once battery becomes unstable, chemical reactions produce heat and gases: heat speeds up these reactions, producing more heat and more gases.



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 dioxide and nitrogen oxides.

i.e. a VAPOUR CLOUD

Thermal runaway should be prevented by the safety systems....but fires and explosions are occurring on land and sea, and in the air.

Lithium ion Battery Energy Storage Systems LiBESS

Domestic LiBESS (DLiBESS)

Industrial LiBESS

Commercial

DIY

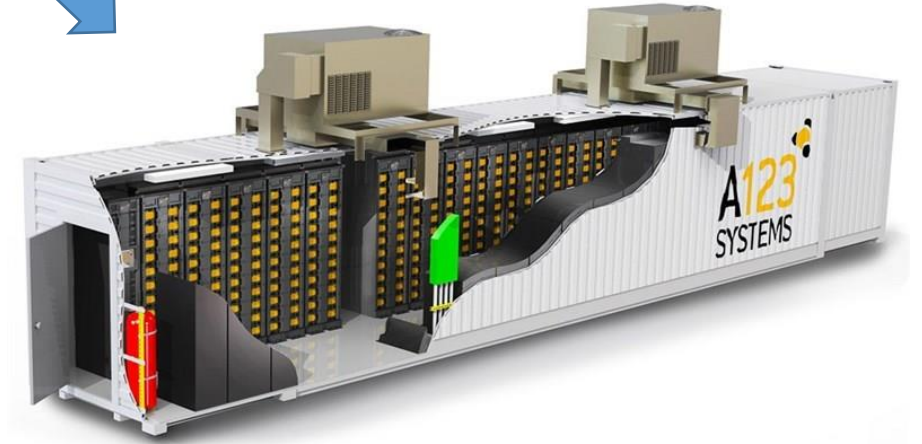


2 kWh → 130 kWh or more
(Tesla S 100 kWh)

UK absolutely NO regulations



??kWh



1MWh → 1000's MWh

Grid-scale LiBESS incidents

2012 A new 1.5MW LiBESS owned by APS exploded in Arizona. This was followed by:

- **Wisconsin (Aug 2016)**
- **Drogenbos Belgium (Nov 2017)**
- **South Korea 2018 – 2019 up to 30 LiBESS on fire or exploded.**
- **Surprise Arizona (April 2019) 3 first responders injured, 2 very badly. 9 first responders contaminated with hydrogen cyanide. VCE**
- **Nathan campus of Griffiths University, Brisbane (March 2020)**
- **Carnegie Road, Merseyside (Sep 2020) VCE**
- **Perles-et-Castelet, Ariège France (Dec 2020)**
- **SBG-2 OVHcloud data centre in Strasbourg, France (March 21)**
- **Hongseong, South Chungcheong Province (April 2021)**
- **Beijing (April 2021) 25MWh LiBESS on shopping mall: 3 killed, 1 injured. VCE**
- **Tesla Megapack LiBESS, one container ignited during testing (30 July 21) at the newly registered Victoria Big Battery at Moorabool, near Geelong.**
- **Invenergy storage facility, LaSalle County USA (July 2021).**
- **Moss Landing, California “world’s biggest battery storage facility” cells go into thermal runaway (4 Sep 2021).**

From the May 2020 Fichtner translation of the official South Korean Government report on the LiBESS fires

- **It is likely that these safety flaws are not unique to battery systems and BESS made in Korea. It is more likely that the large amount of BESS installed in Korea has made the flaws evident earlier. These flaws are also likely to exist in BESS and battery systems that were not made by Korean manufacturers.**
- **BESS safety can only be fully assessed on the **system level**. A safe battery cell is the foundation for a safe BESS, **but not a guarantee**. The historical strong focus on cell safety only has led to avoidable slips in the technical risk management of BESS projects as a whole. Therefore, **the safety assessment of the BESS should cover all hazards**, not just the electrochemical related hazards.**

LG Chem report on SK incidents blames:

- 1. Inadequate design of the electrical protection system**
- 2. Inadequate control of the operating environment within system enclosures**
- 3. Careless installation practices that degraded system integrity**
- 4. Inadequate ESS system control and protection**

Failures could only be reproduced with multiple stresses, e.g.:

High humidity + Common Mode Voltage (CMV) aka Common Mode Noise....



FIRE RESEARCH AND DEVELOPMENT TECHNICAL REPORT

UL 9540A Installation Level Tests with
Outdoor Lithium-ion Energy Storage
System Mockups

April 12, 2021

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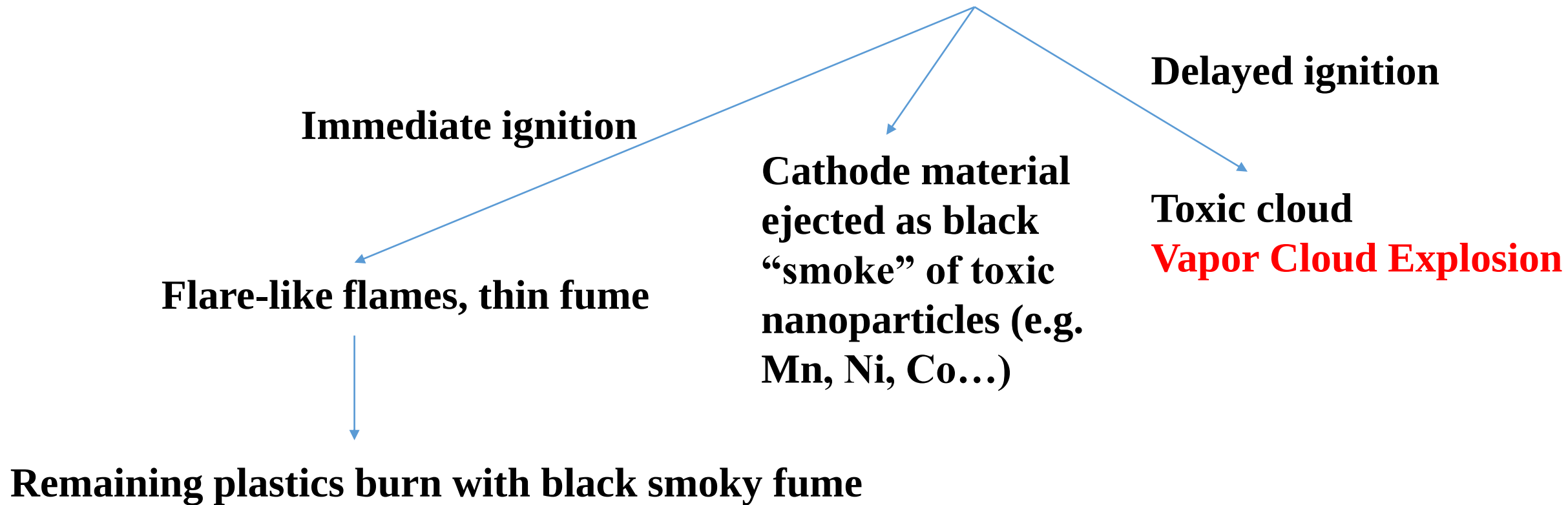
“Neither the Novec 1230 system or water suppression system prevented the accumulation of flammable gases or subsequent deflagration. Potential ignition sources in these tests included hot surfaces or sparks ejected from thermal runaway, or DC powered wall-mounted gas detectors not intended for explosive atmospheres. An actual ESS installation will likely present considerably more ignition sources...”



“Full structural PPE (Level D ensemble) with full SCBA should be donned before performing size-up or operating within the hot zone. The results of these tests showed that hazardous concentrations of carbon monoxide (CO) and hydrogen cyanide (HCN) were measured by exterior portable gas meters.”

Thermal run away and the vapour cloud

Thermal runaway → gases → gases vent → white vapour cloud

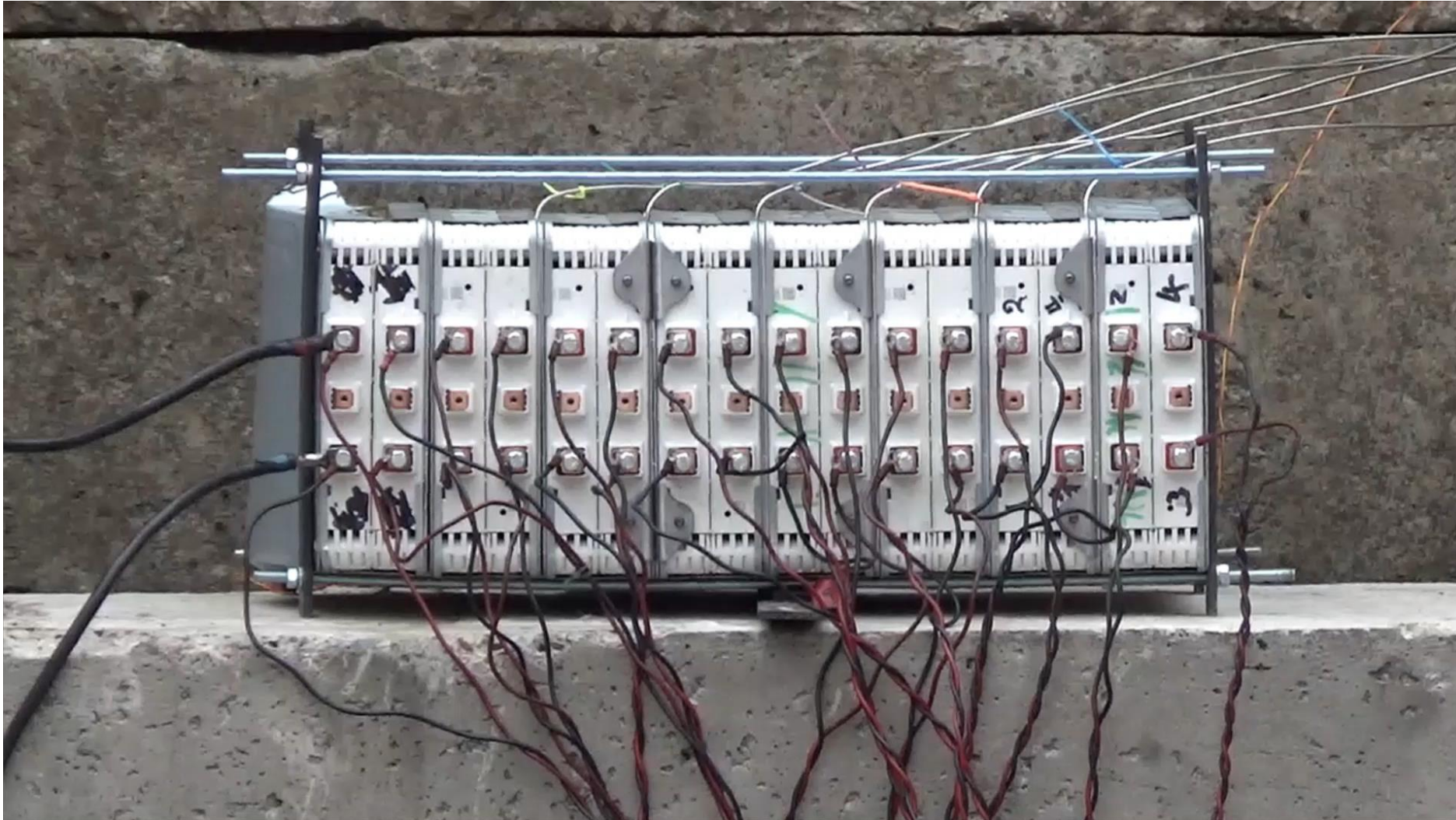


If the gasses ignite immediately, long flare-like flames can result.



**Hammer +
nail weighs
~ 23kg!!!**

Single EV module 1.7 kWh at 100% SOC, nail penetration.



**Just 1
module
ignited by
end of clip**

Imagine this in your loft, or the cupboard under the stairs....overcharge of 2 cells out of the 8 in the end module. NOTE crackling sound.....

Crackling sound....

**..fragmentation of the
surface of the concrete
blocks sending fragments
vertically and
horizontally 20 – 30m**



If the vapour cloud does not ignite.....



**Nail penetration
of a 1.67 kWh
module, 40%
SoC.**

Again, imagine this in the loft, the bedroom cupboard, under the stairs....CO, HF, explosive...

If the vapour cloud does not ignite immediately.... **different chemistry and form factor**



Container fills from floor upwards.....

Vapour cloud explosions are not confined to large LiBESS

Explosion on board the Carila Sis, 4 May 2019 in Sneek Harbour, the Netherlands due to portable LiBESS

Small VCE during test of fire blanket on EV fire at Horiba Mira site in UK.

CSIRO experiment.....

If the vapour cloud does not ignite immediately....



The CSIRO tests: towbar travelling at 10 km/hr.

Thankyou for your kind attention