Learning from 10 years of Li-Ion battery fire tests

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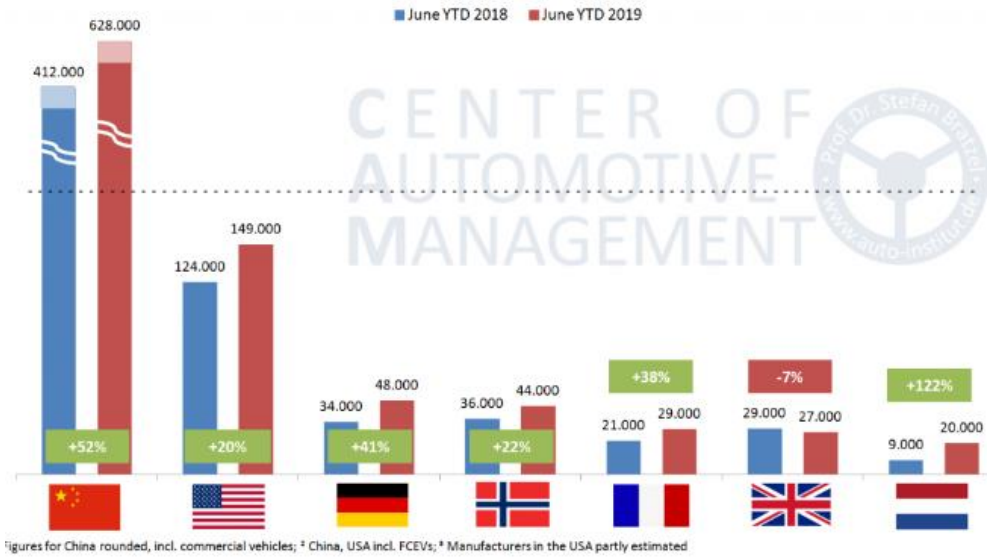
Context

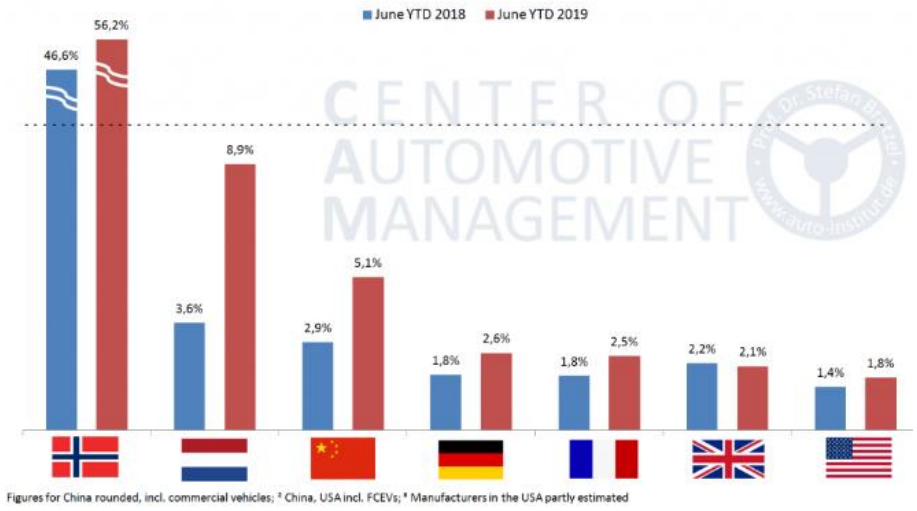
10 years ago, 2010, Electric Vehicles was quite new on the road, first questions appeared

- How such a car burn in case of fire?
- What about the global HRR, is it in accordance with design fire?
- What about smoke toxicity in case of LiB fire?

Nowadays electric vehicules (EV) go through tunnels and other underground facilities

- And new wondering is coming with the increase of the knowledge

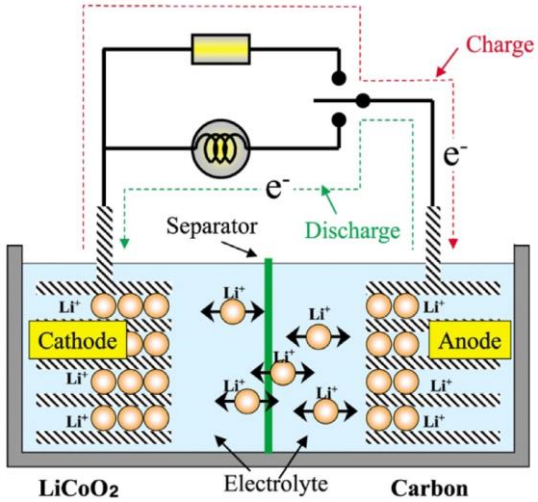




What is LIBs

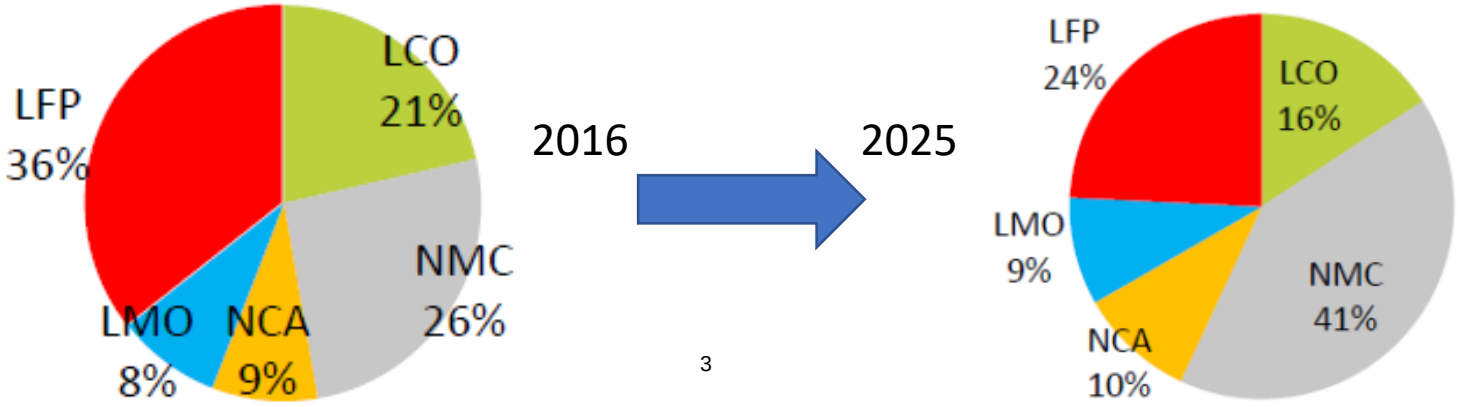
Lithium-Ion Batteries are numerous and different in terms of:

- Chemistry
- Cell characteristics
- Cell and module arrangements



Principle is the same

- Use a chemical reaction to get electricity based on Lithium, on an ionic form, exchange between anode and cathode
- Use material for the electrodes varies
  - LCO ($LiCoO_2$), NMC ($LiNi_xMn_yCo_zO_2$), LPF ($LiFePO_4$), … for the cathode
  - Graphite, titanate-based material or silicium for the anode
- And a dedicated electrolyte: mix of flammable solvents and lithium salt ($LiPF_6$)



The thermal runaway phenomena

When talking about battery, let's talk about THR (Thermal Run Away)

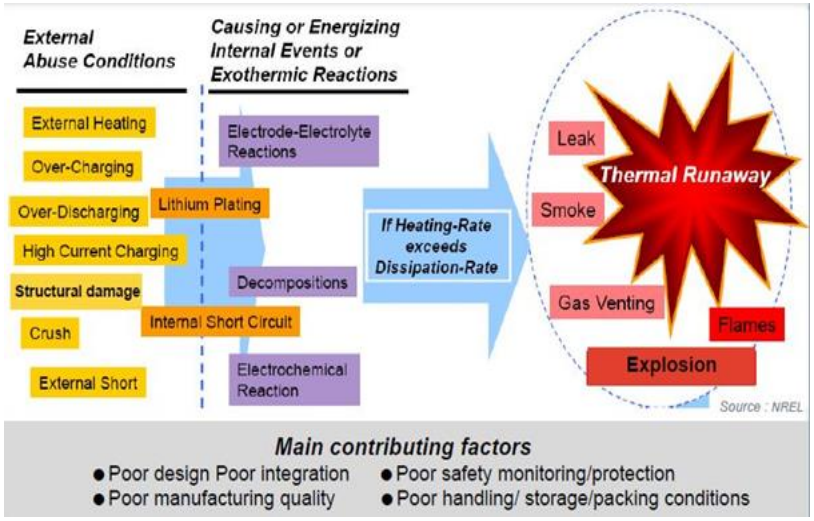
- Can be caused by overcharge, over-discharge, choc on the battery or on the vehicle

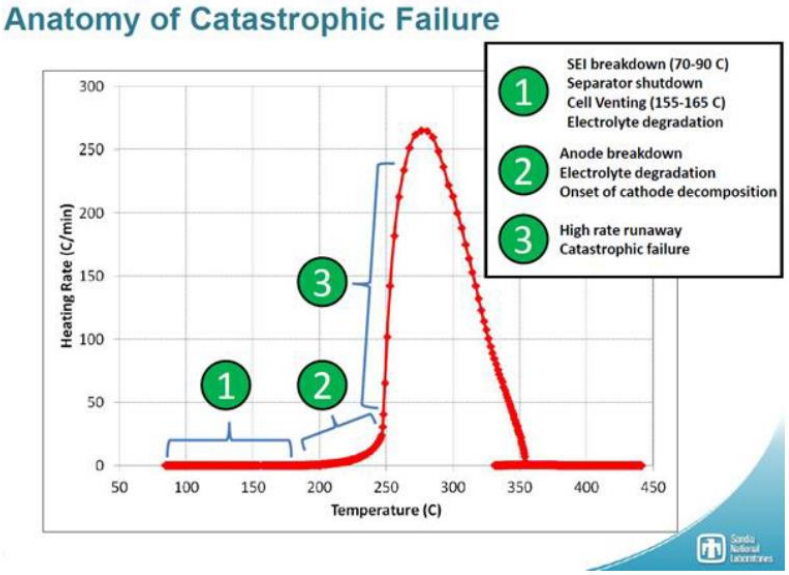
Some cannot occur in tunnels

- As charging process

Others can occur either inside or outside

- choc, on the vehicle or on the battery, external heating (distant fire, …)





Risk analysis leads to new questions

How such a car burn in case of fire?

- Flammable gas inside the LIB: possible release in accident situation
  - Is explosion can occur? What do you call explosion !
  - Jet fire in case of pressurised releases

What about the global HRR, is it in accordance with design fire?

- Flammable product: when released, the corresponding HRR will be added to the car one
- The release rate (size of the release orifice and cell to cell propagation) will govern this

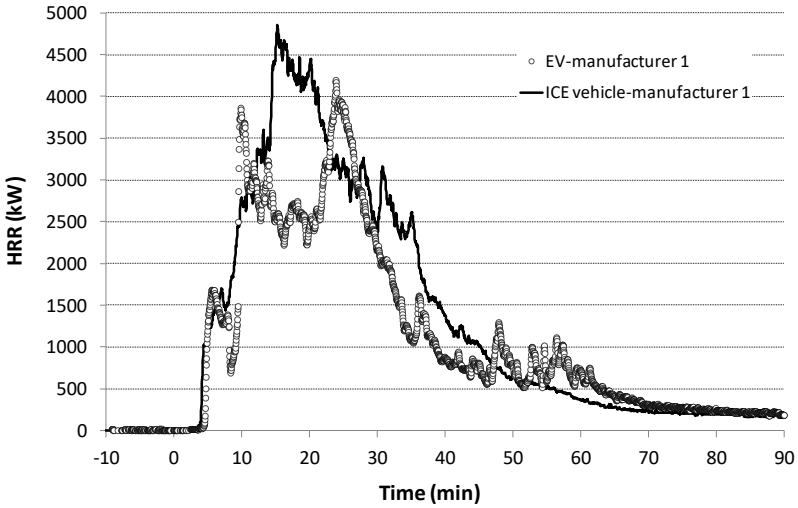
What about smoke toxicity in case of LiB fire?

- In most of fire safety studies in tunnel, only CO is considered for car fire
- In LIB, there is at leaf Fluor … this means HF, COF_2 and others to be considered

Since 2K, many fire tests were managed

In 2010: Large scale fire test

- Full scale EV burnt by various laboratories
  - HRR is quite similar to the one measured for ICE cars
  - Even with EV, toxicity is not strongly modified
  - The environmental impact was not considered (PAH, metals, …)



- From 2010 to now
  - The battery capacity strongly increased
  - This tendency should continue

- Fire Safety Engineers required tools and knowledge to deal with such a technology

- It is important to identify main parameter that govern the THR

But the LIB technology is moving

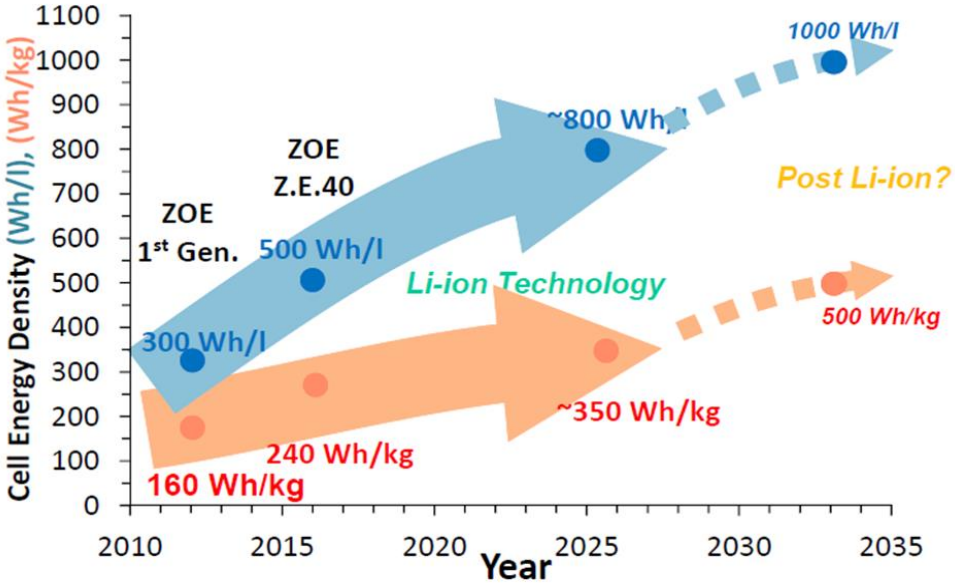
The need of increase the vehicle autonomy

- Increase of the cell energy density
- 10 years ago: a large battery for car was about 30 kWh
- Nowadays: batteries for car reach 100 kWh

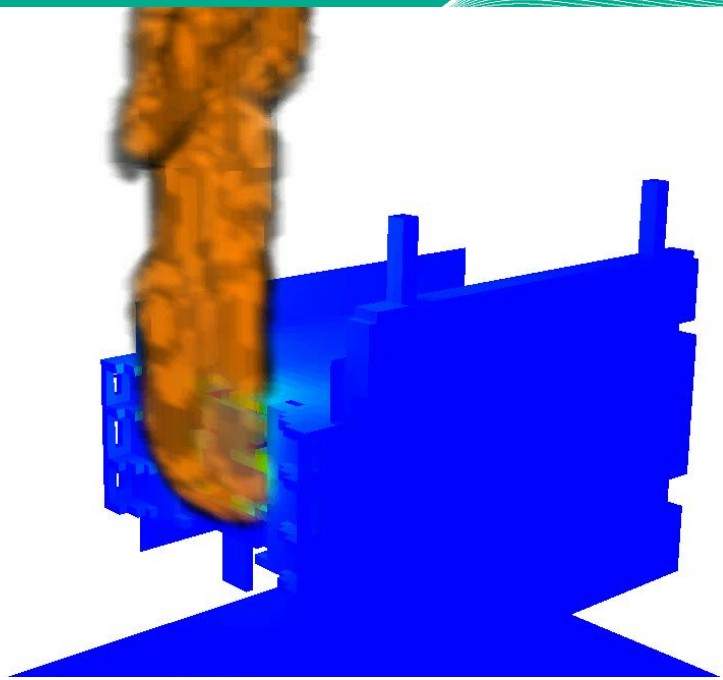
Increasing the energy density may increase the consequences in case of fire

- More electrolyte?
- More electric energy?
- More cells?
- ???

How can the test be extrapolate between LIBs?



A new approach is needed

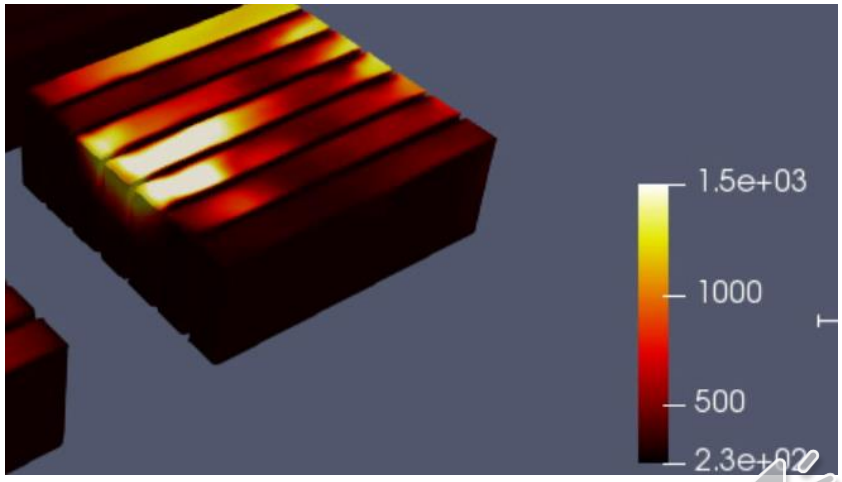


Model can be used but

- Inside cell modelling is highly complex
- Thermal propagation between cell includes
  - Radiation
  - Conduction
  - Convection
- The part of electric energy convert to heat cannot be neglected

Then we should learn about existing fire tests

- To determine the most important parameters
- To provide input data for modelling
- To adopt a realistic but safe approach for tunnel safety



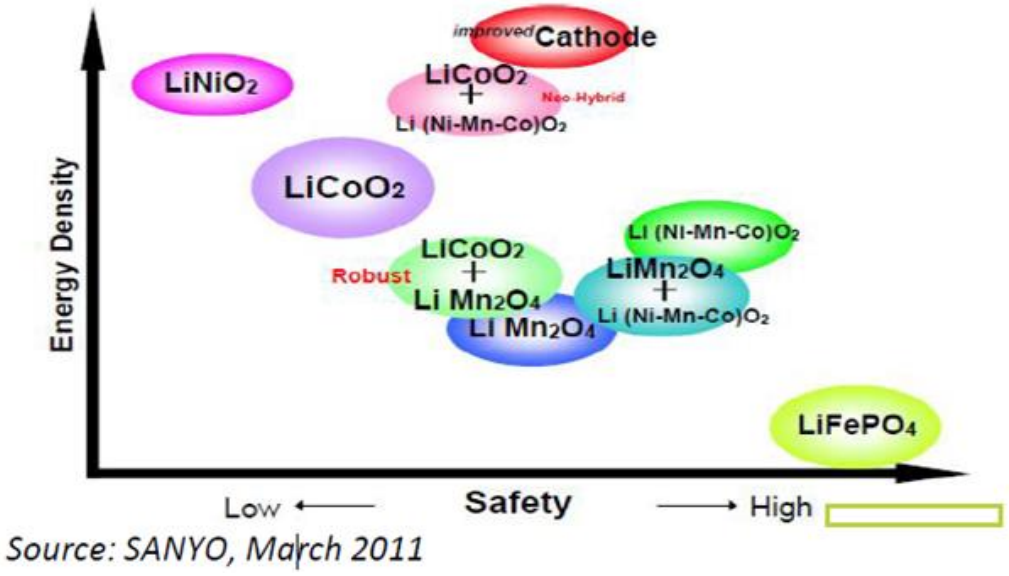
A strong influence of the chemistry

A global knowledge about the consequences as a function of the chemistry

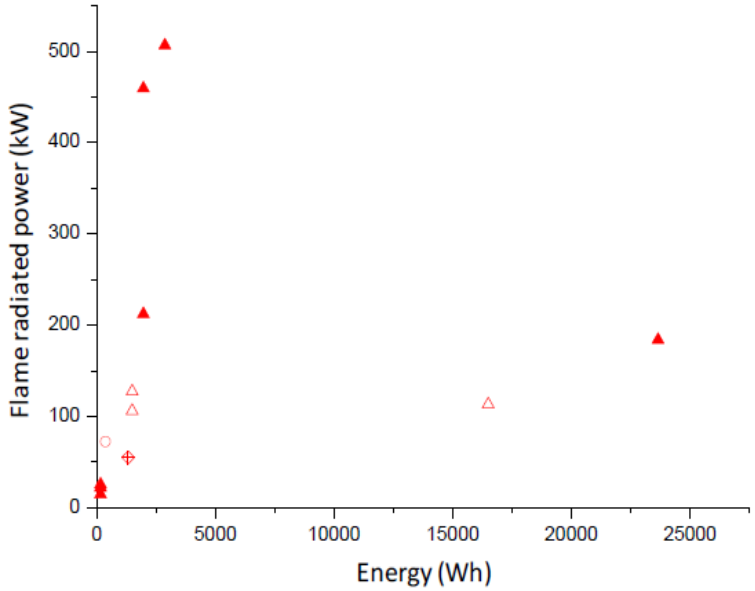
But it is difficult to establish a link with the energy contained in the cell

- Strong influence of the cell characteristics (pouch; prismatic; …)
- Strong influence on the cell arrangement inside modules
- Strong influence on the module arrangement inside the LIB

And how estimate the gas concentration as a function of the technology?



Source: SANYO, March 2011



The SOC: a first order parameter

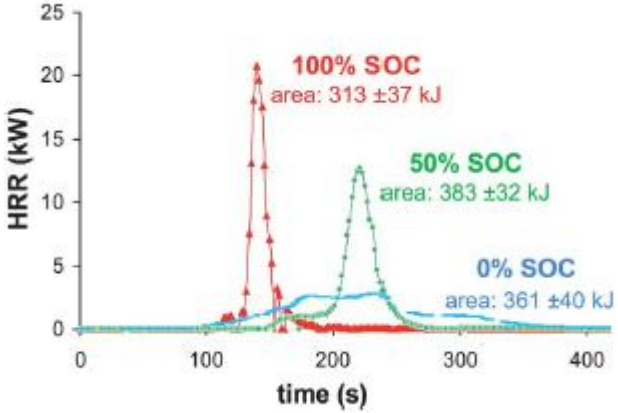
The SOC (State Of Charge), a key factor

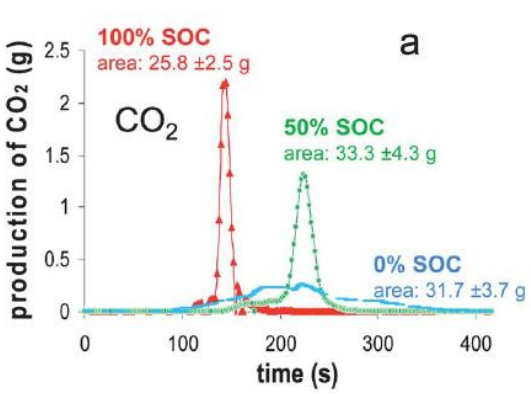
- More important is the SOC, more reactive the LIB is

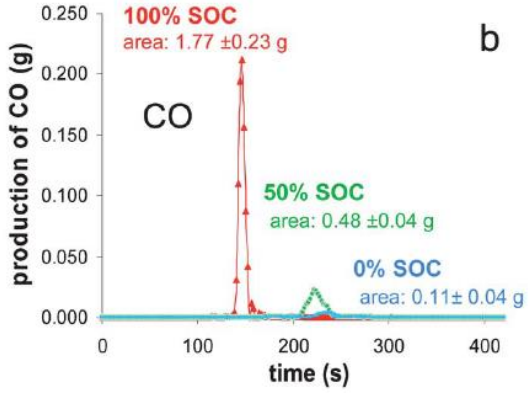
Several aspect were highlight through LIB abusive test

- More important is the SOC, faster is the THR apparition :
  - typically 120 s after heating start for a 100% SOC to 250 s for a 50% SOC
- More important is the SOC, higher the HRR peak value is
  - Under 30% SOC, risk is strongly reduced – At 50% SOC, peak HRR is divided by 2
- More important is the SOC, larger the amount of toxic gases is

Most of LIB fire test are done with 100% SOC ! To be kept in mind







Synthesis for fire in tunnels

When dealing with Fire in Tunnels, we should consider

- The probability of fire
  - The available feedback tends to show that this would not be modified for EV
- The nature of the phenomena
  - Gas toxicity: Very few effect of LIB on this aspect according to the numerous plastic in cars
  - If we are looking for HF, let's remind that AC system uses a fluorine compound …
- Occurrence of explosion
  - Some local UVCE can occur with a small amount of gas
  - Very few explosion reported due to LIB in the international feedback

Keep in mind: All abusive tests are managed in the worst case we can imagine