

# Risk handling of Lithium-ion batteries

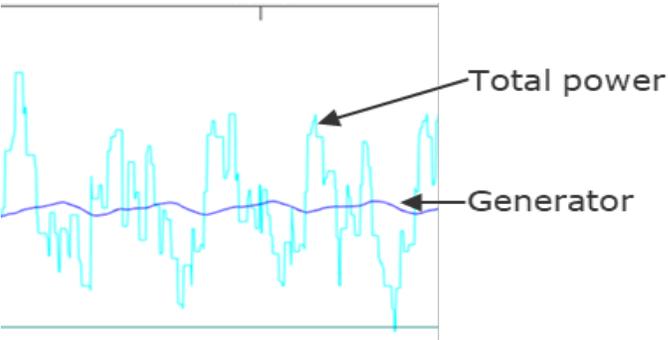
Henrik Helgesen, Maritime Advisory DNV

19 October 2021

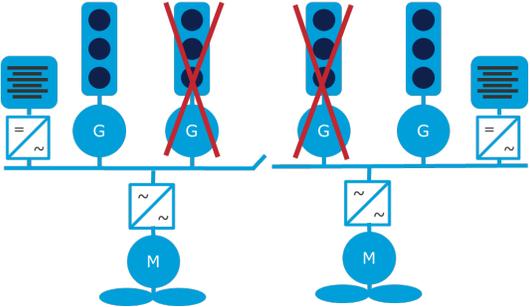
# When are batteries useful?



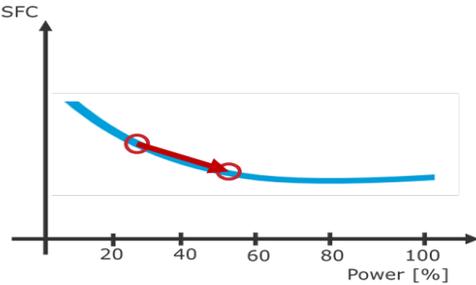
Peak shaving/load levelling



Reducing running engines



Improve machinery efficiency



Need to identify operational modes with:

- 1. Low average engine loads
- 2. High load variations



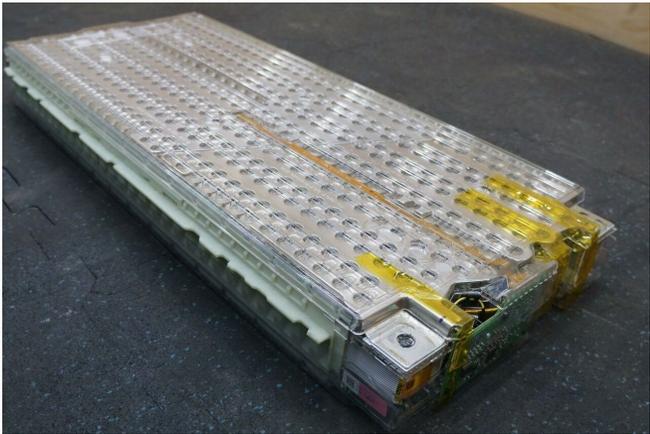
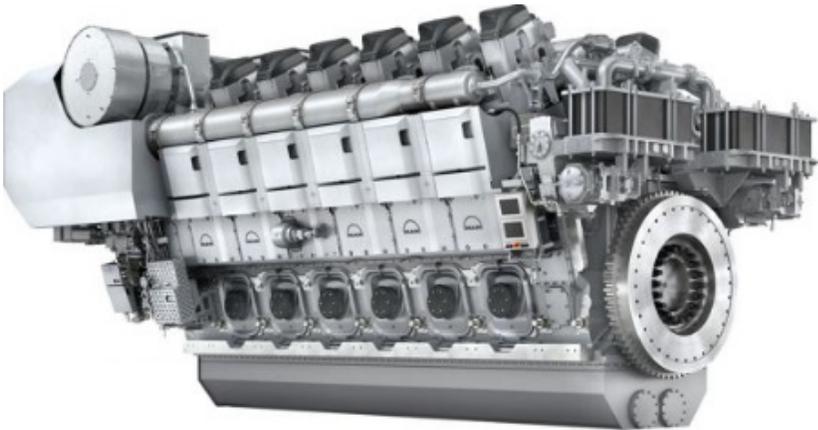
# Motivation for Battery Safety



**Known risk**



**New and unknown risks involved**



**Need to understand the risks batteries introduce to sleep well**

# Common understanding of using the available tools

- We have the sufficient tools
- Question is how to use them correctly
- How strict should the safeguards be designed
- Common understanding is the key for rapid and safe uptake



Innovation

Vs

Rule  
development

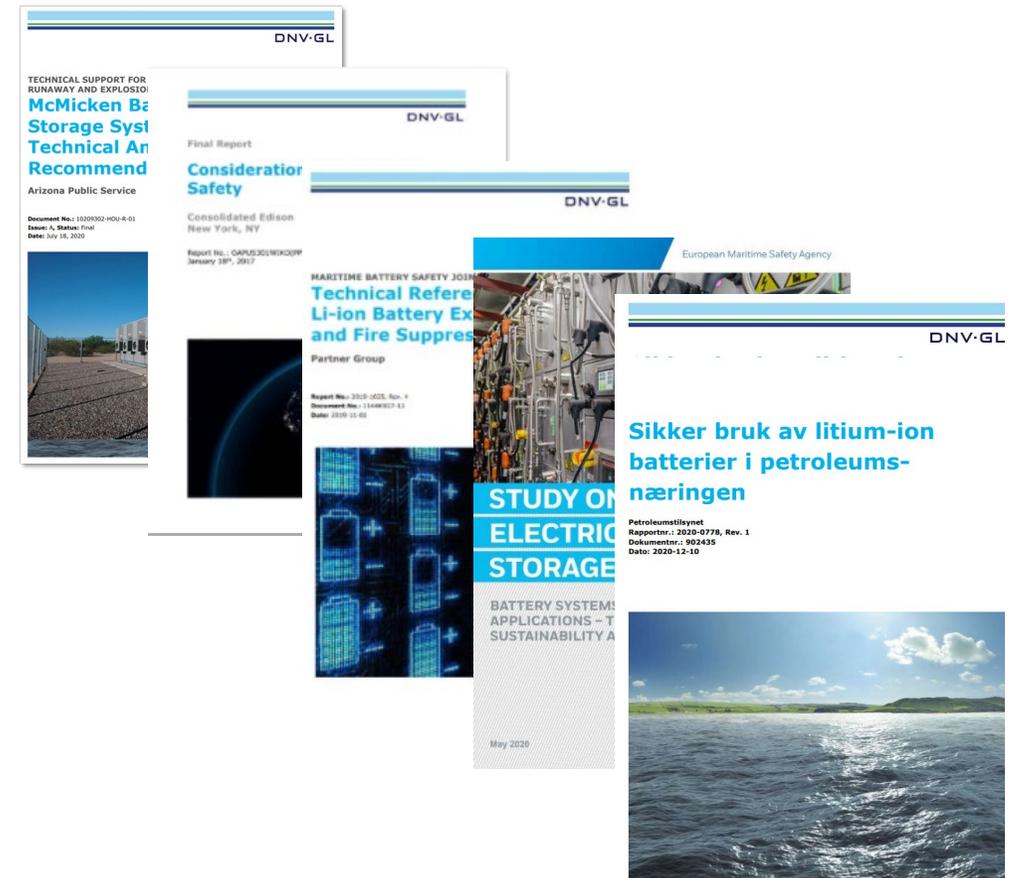


Common understanding of the risks is the key to rapid and safe uptake

# DNV reports on Lithium-ion battery fire safety

## Publicly available reports Lithium-Ion battery safety

- Considerations for Energy Storage Systems Fire Safety
  - <https://www.dnv.com/Publications/considerations-for-energy-storage-systems-fire-safety-89415>
- Technical reference for li-ion battery explosion risk and fire suppression
  - <https://www.dnv.com/maritime/publications/Technical-Reference-for-Li-ion-Battery-Explosion-Risk-and-Fire-Suppression-report-download.html>
- Study on Electrical Energy Storage for Ships - EMSA
  - <http://www.emsa.europa.eu/publications/reports/item/3895-study-on-electrical-energy-storage-for-ships.html>
- Sikker bruk av litium-ion batterier I petroleumsnæringen – Ptil
  - <https://www.ptil.no/fagstoff/utforsk-fagstoff/prosjektrapporter/2021/sikker-bruk-av-litium-ion-batterier-i-petroleumsnaringen/>
- DNV GL Handbook for Maritime and Offshore Battery Systems
  - <https://www.dnv.com/maritime/publications/maritime-and-offshore-battery-systems-download.html>



# Arizona battery fire events

Time	Event
16:54:30	Battery voltage drop of 0.24 V in rack 15, module 2, battery 7 (4.06 to 3.82 V)
16:54:38	Total voltage drop of 3.8 V in rack 15 (799.9 to 796.1 V); BMS loses module level data
16:54:40	Temperature readings begin to increase in the rear of rack 15
16:55:20	BESS smoke alarms 1 and 2 activate and the fire protection system triggers several circuit breakers to open (BMS DC breakers, inverter AC contactors, main AC breaker)
16:55:50	Fire suppression system discharges Novec 1230 suppression agent (30 second delay from alarm time, as per its design)
17:40	Personnel on site calls 911 to report suspected fire
17:48	Fire department arrival time
20:02	Front door of container opened by emergency responders
20:04	Explosion occurs

Voltage drop.

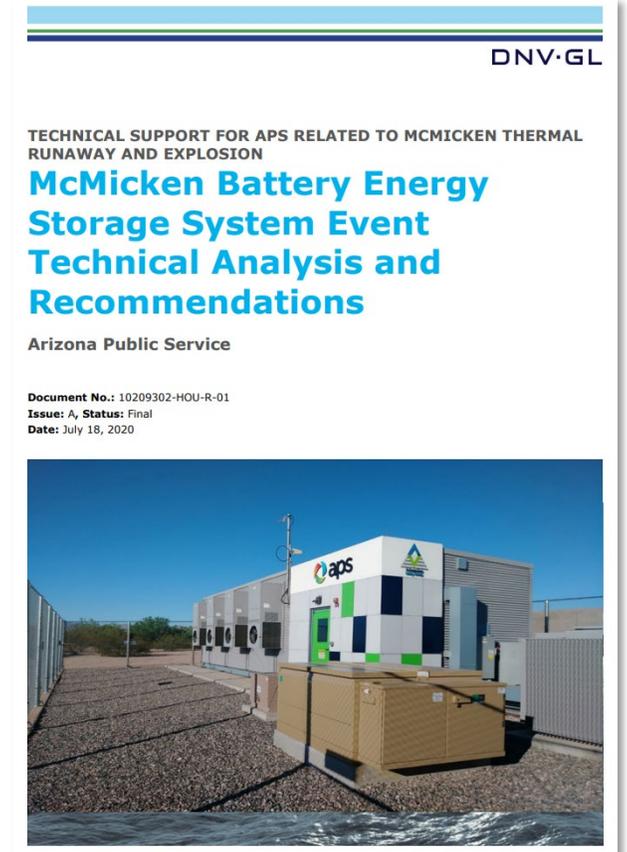
Increased temperature.

Smoke detected.

Fire suppression system discharged and 911 is called.

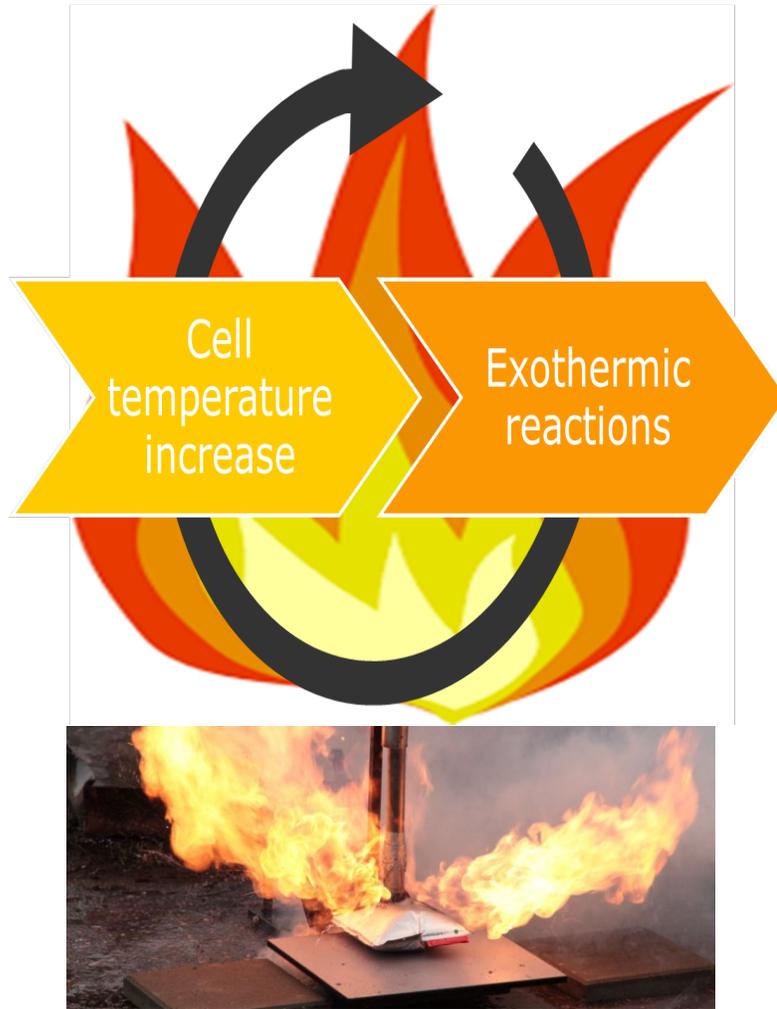
Door is opened

Explosion

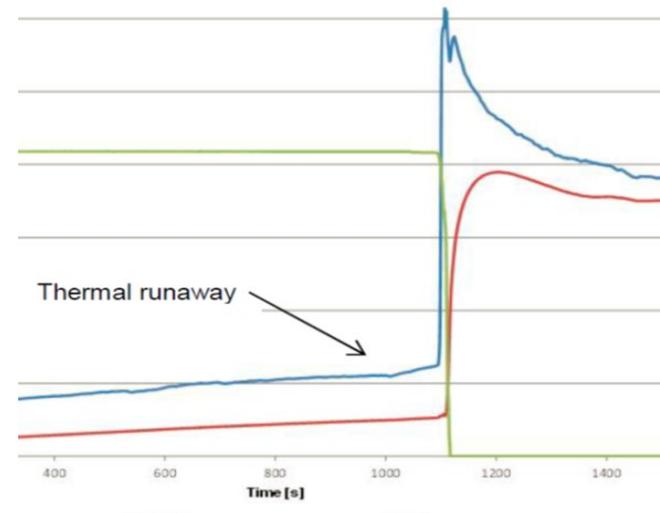


<https://www.aps.com/-/media/APS/APSCOM-PDFs/About/Our-Company/Newsroom/McMickenFinalTechnicalReport.aspx?la=en&hash=50335FB5098D9858BFD276C40FA54FCE>

# Temperature increase -> Thermal Runaway



Thermal Runaway stage	Consequence	Hazard management
Stage 1	Toxic, Flammable off gas with explosion risk	Ventilation
Stage 2	Burning heat	Extinguishing
Stage 3	Total Combustion	Thermal Management



# Causes and consequences

## Causes

## Consequences

Safeguards

Safeguards

Safeguards

Safeguards

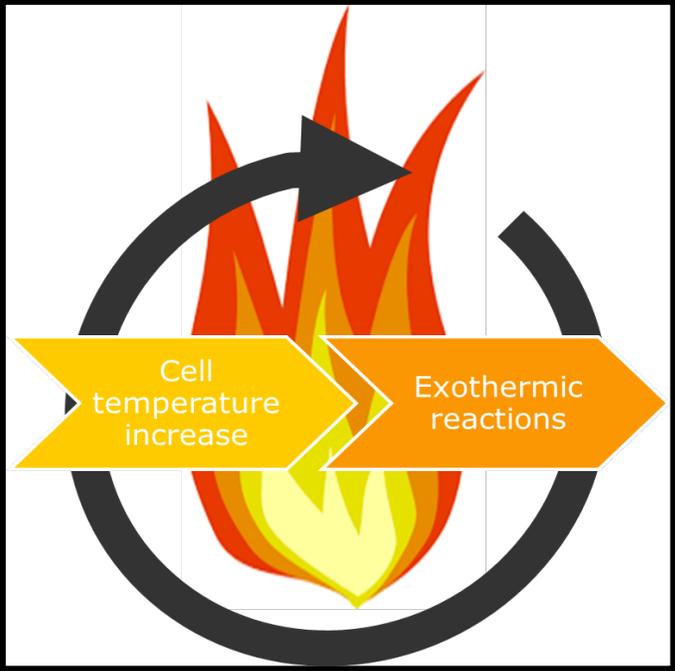
External abuse

- Mechanical abuse
- Electrical abuse
- External fire
- Cooling failure

Internal failures

- Dendrites
- Particles

### Thermal Runaway

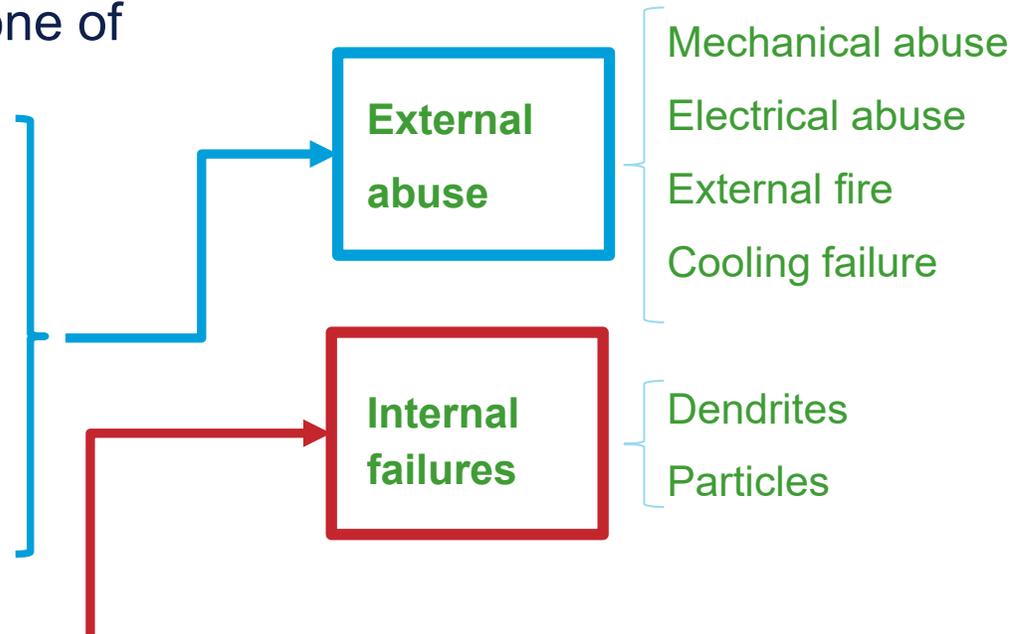


- Explosive off gas
- Toxic off gas
- Fire

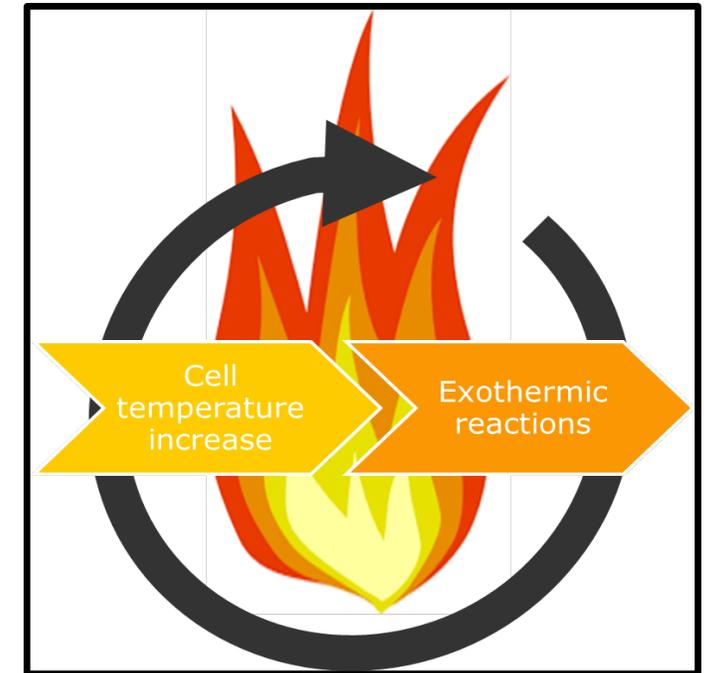
# Root causes for battery failures in media

- Safety incidents commonly reported in media can be traced to one of following\*):

1. Low ambient pressure
2. Overheating
3. Vibration
4. Shock
5. External short circuit
6. Impact
7. Overcharge
8. Forced discharge

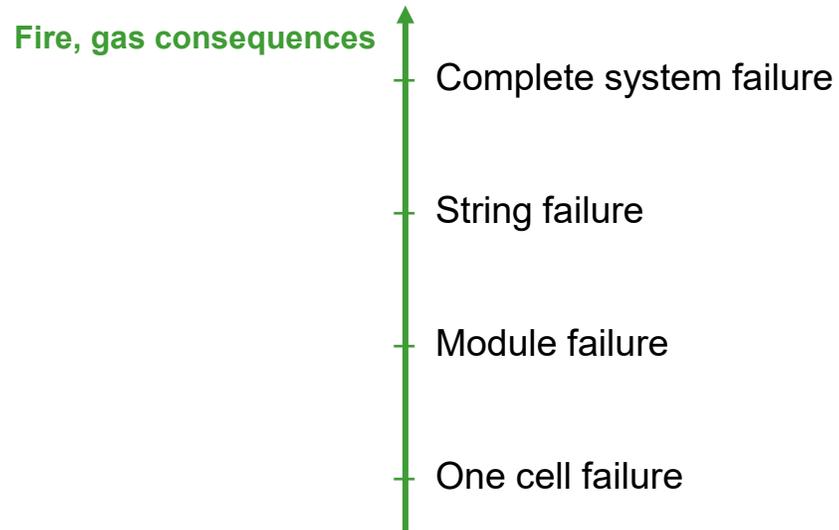


- Contaminants in the battery weaken the ability of the battery to withstand instances of these eight abuse factors.



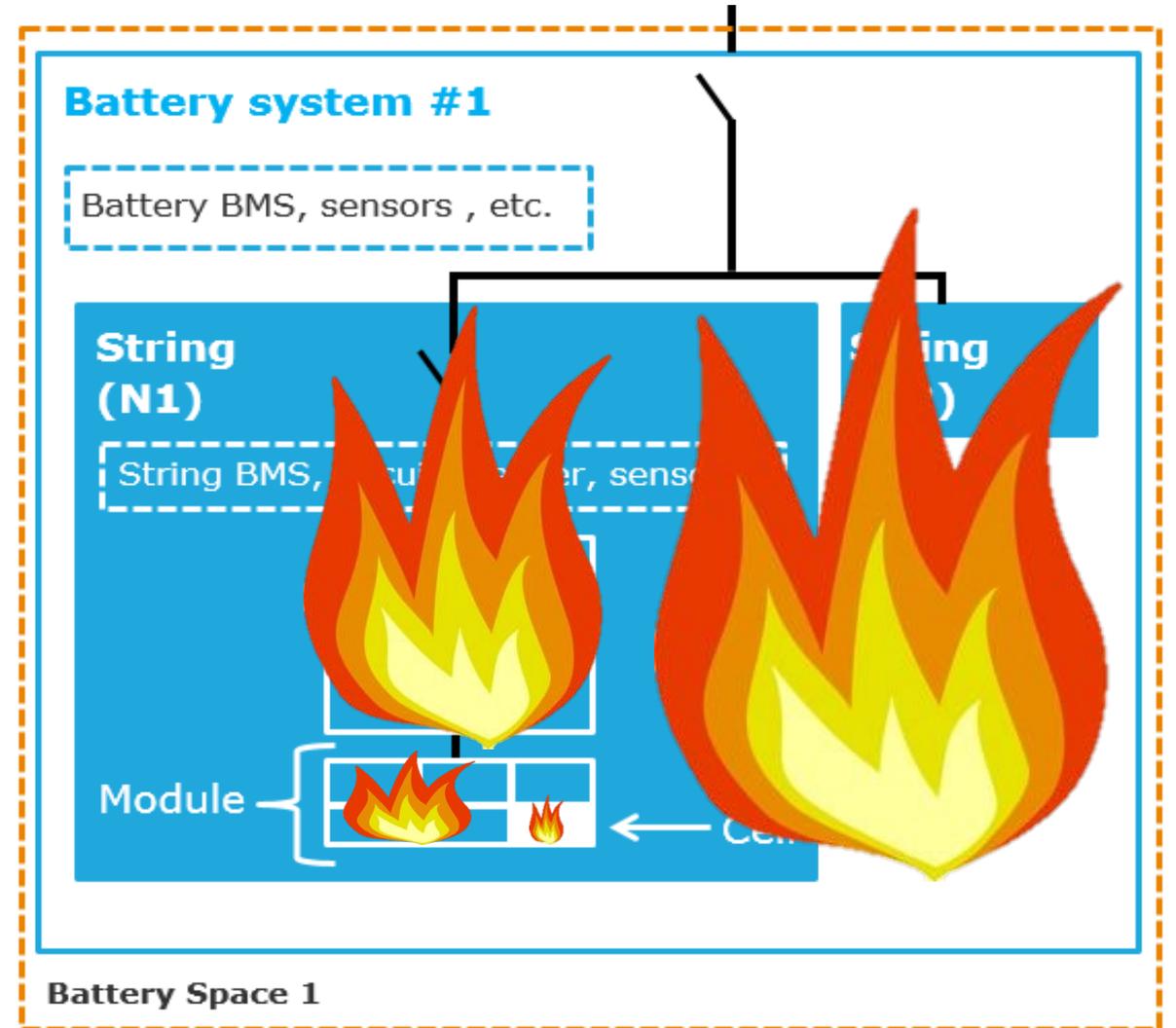
<sup>\*)</sup> DNV GL "Considerations for ESS Fire Safety", Feb. 9<sup>th</sup>, 2017  
<https://www.dnvgl.com/publications/considerations-for-energy-storage-systems-fire-safety-89415>

# Where to draw the line?



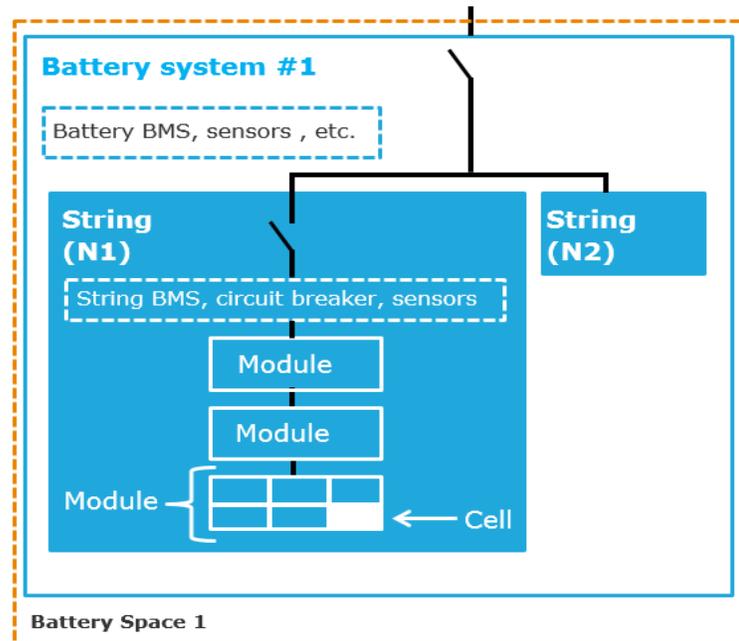
## Need to limit the fire

- Thermal runaway cannot be stopped by fire extinguisher. The process needs to die out.
- Need to avoid that the thermal runaway spreads to other cells rather than extinguishing it.
- Key is to detect the thermal runaway early and limit the fire to a small part of the system by the battery design.



# External short circuit

- Many root causes can be traced back to creep currents, earth faults and arcs.
- Circuits should be proper isolated and with proper distance between contactors.



Mechanical abuse

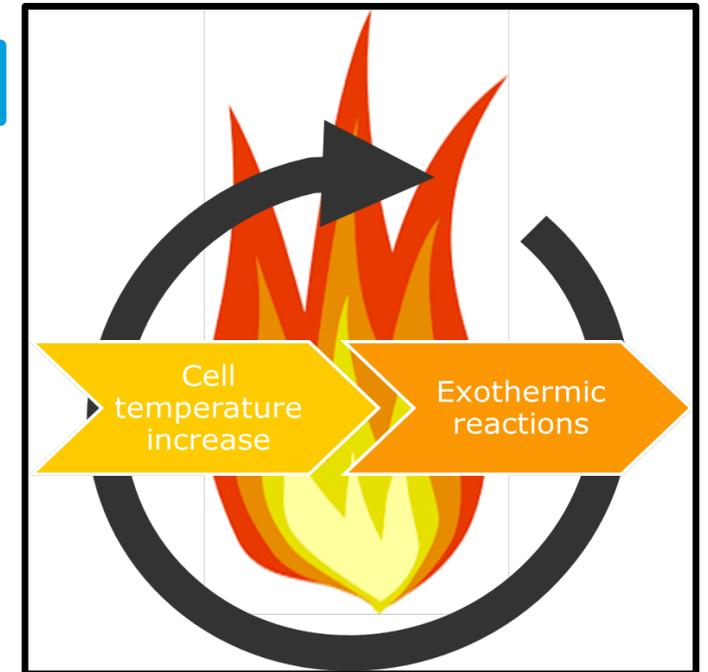
Electrical abuse

External fire

Cooling failure

Dendrites

Particles

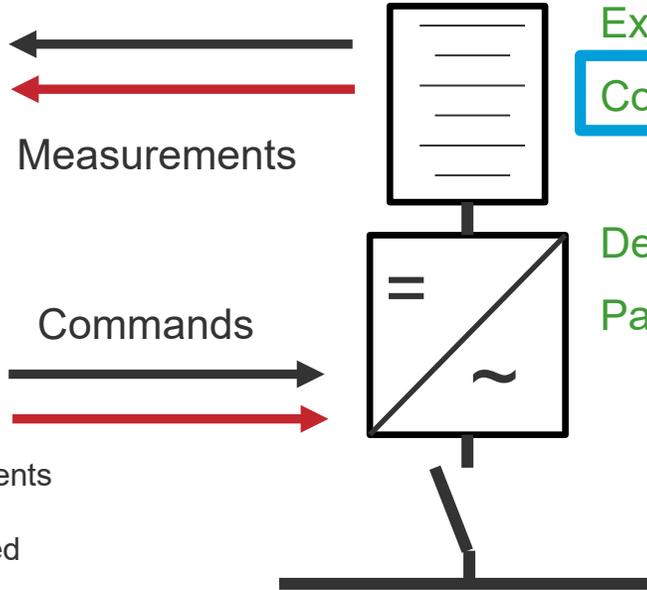


# Battery Management System



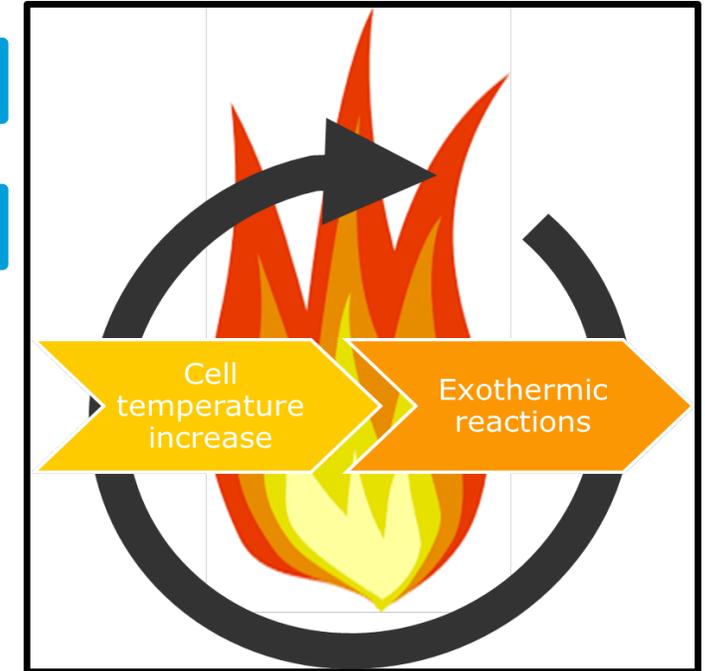
**Independent shutdown system**

**Battery Management System**



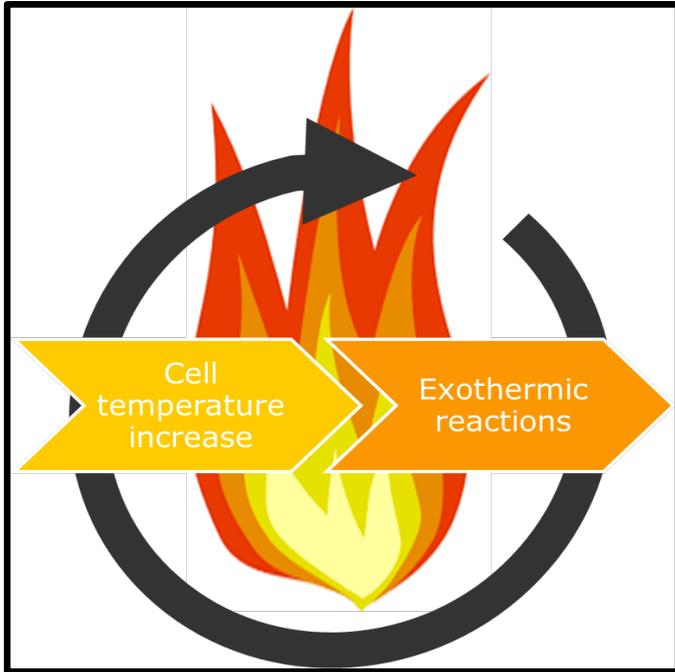
Mechanical abuse  
Electrical abuse  
External fire  
Cooling failure

Dendrites  
Particles



- Current, voltage and temperature measurements
- Three levels of actions should be implemented
  - Alarm
  - Disconnect module/string with issues
  - Shut down of complete system
- Full redundant system

# Toxicity



Toxic off gas

Fire

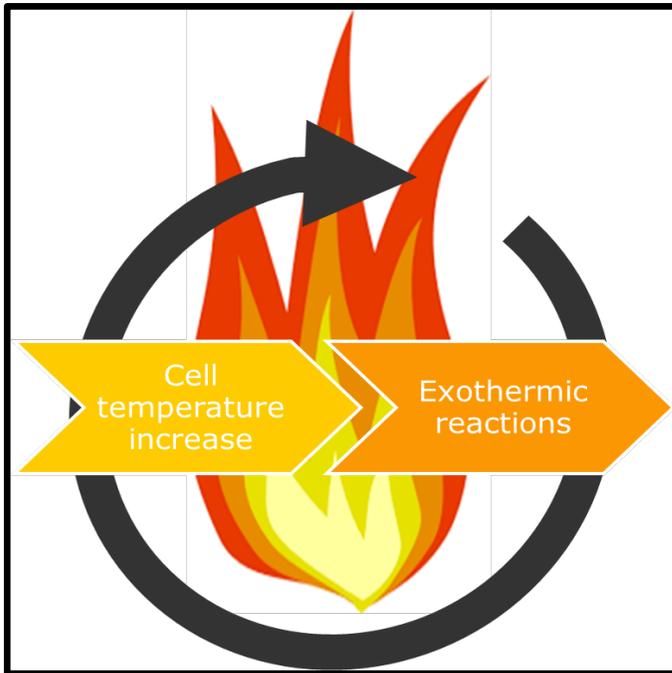
Explosion

Gas	Immediately dangerous to life or health (IDLH) [ppm]	Relative Vapor density (air = 1)
CO	1200	0.97
Nitrogen Dioxide	20	2.62
Hydrogen Chloride	50	1.3
Hydrogen Fluoride	30	0.92
Hydrogen Cyanide	50	0.94
Benzene	500	2.7
Toluene	500	3.1



- **Very small gas concentrations will make the atmosphere toxic, and the gas will dilute fast.**
- **Sensor detecting the toxic gases to be placed in the breathing zone.**
- **Personal Protection Equipment should be used** when re-entering the battery space
- NOVEC 1230 will also produce HF if exposed to hot surfaces over time

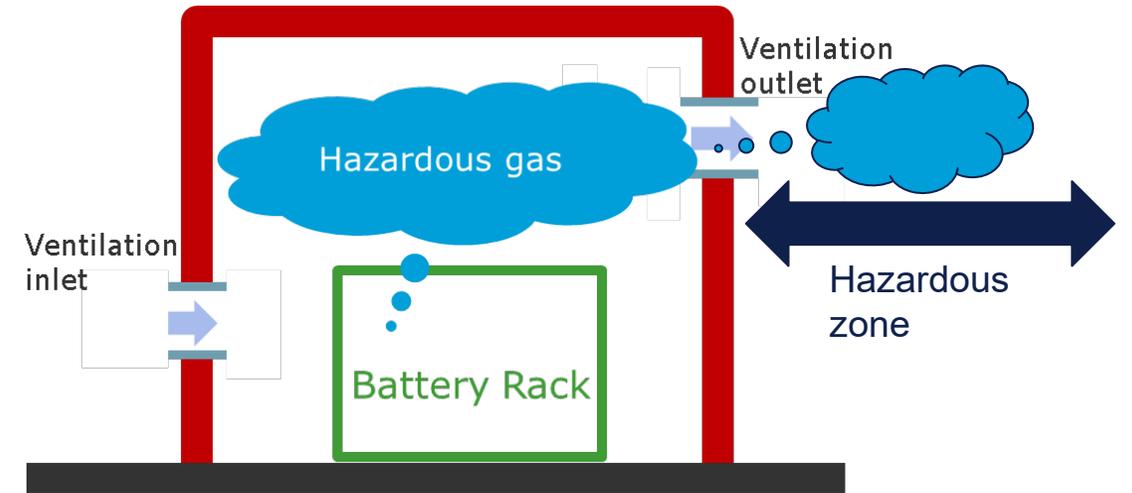
# Dilute explosive gas



Toxic off gas

Fire

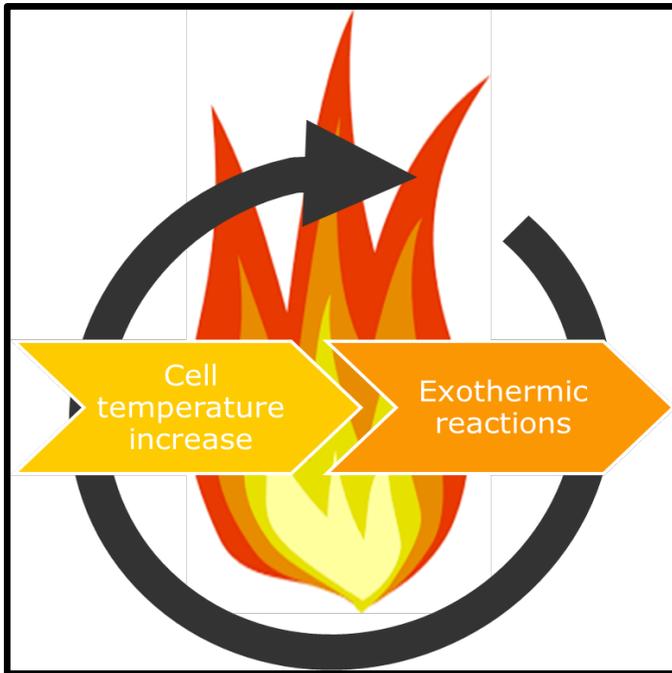
Explosion



## DNV Class rules:

- Independent ventilation system
  - Ventilation through ducts with inlets and outlets to outside air.
  - Spark free fans in ventilation
- Emergency mechanical fan if space is hazardous:
  - Shall start automatically upon gas detection
  - Fire cannot propagate between cells: 6 ACH
  - Fire cannot propagate between modules: Need to do a an analysis
- De-energize electric circuit when gas is detected
- Safe zone outside the battery room

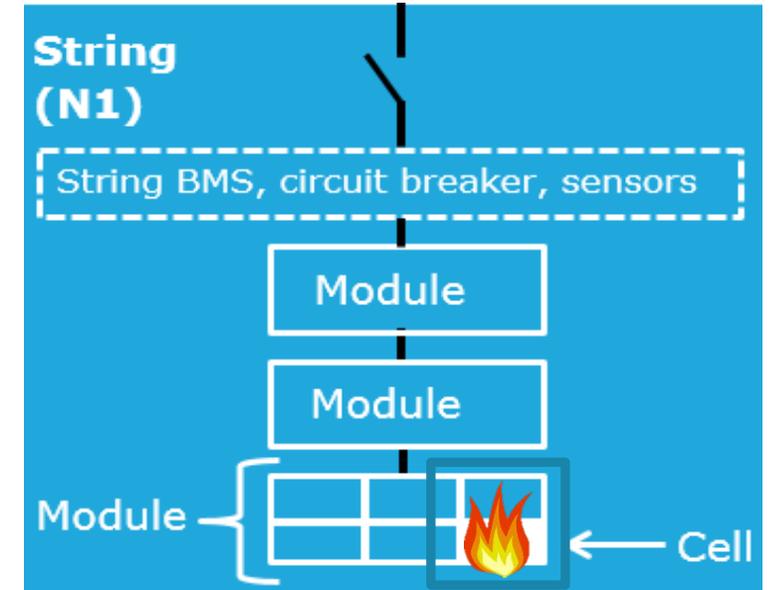
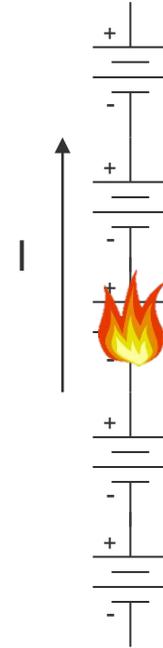
# Fire



Toxic off gas

Fire

Explosion



- Battery strings are built of hundreds of cells
- The string is only **as strong** as its **weakest link**
- Failures that **can cause a thermal event in multiple cells**, will **probably cause** just the **weakest module/cell** to fail

## NMA requirement and DNV Class rules:

- Battery system needs pass a fire propagation test.
  - Limit the fire to one cell or one module

# Ventilation - Heat risk vs explosion risk

## Option 1

Increased ventilation,  
oxygen increases



### Heat generation

Fire propagate to the rest of the battery system,  
other equipment in the room and adjacent rooms

Risks related to heat goes up.

Risks related to explosion goes down

## Option 2

Closed ventilation,  
oxygen is limited



### Gas generation

The atmosphere becomes both explosive and  
toxic

Risks related to heat goes down.

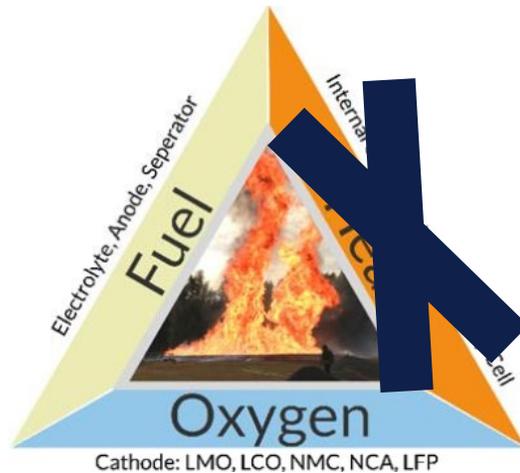
Risks related to explosion goes up

# Fire suppression – Water vs gas

Ideal suppression media need to be highly thermal conductive and highly electrically insulating.

## Water based

Water is thermal conductive AND electrically conductive

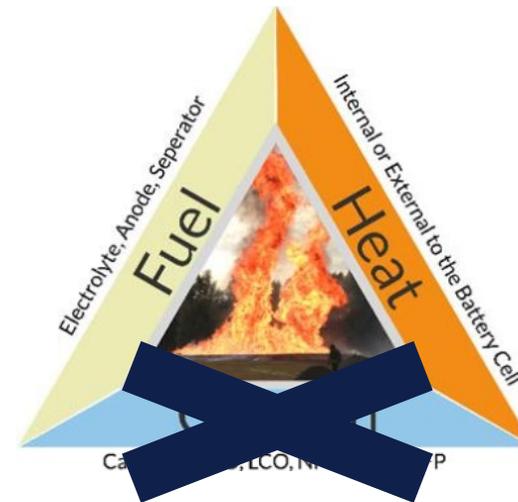


Able to remove heat

Short circuit risk goes up

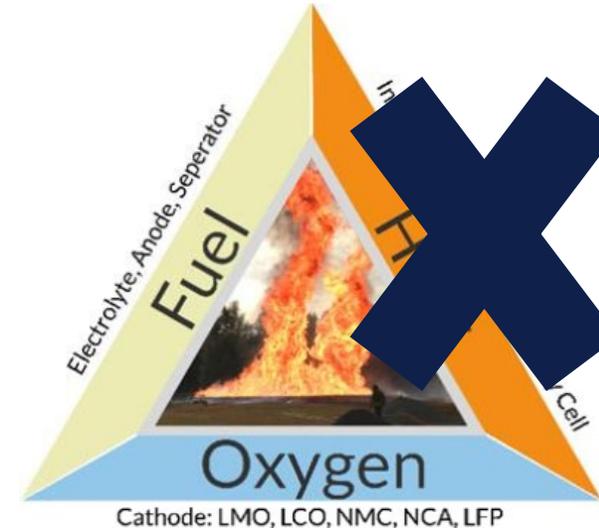
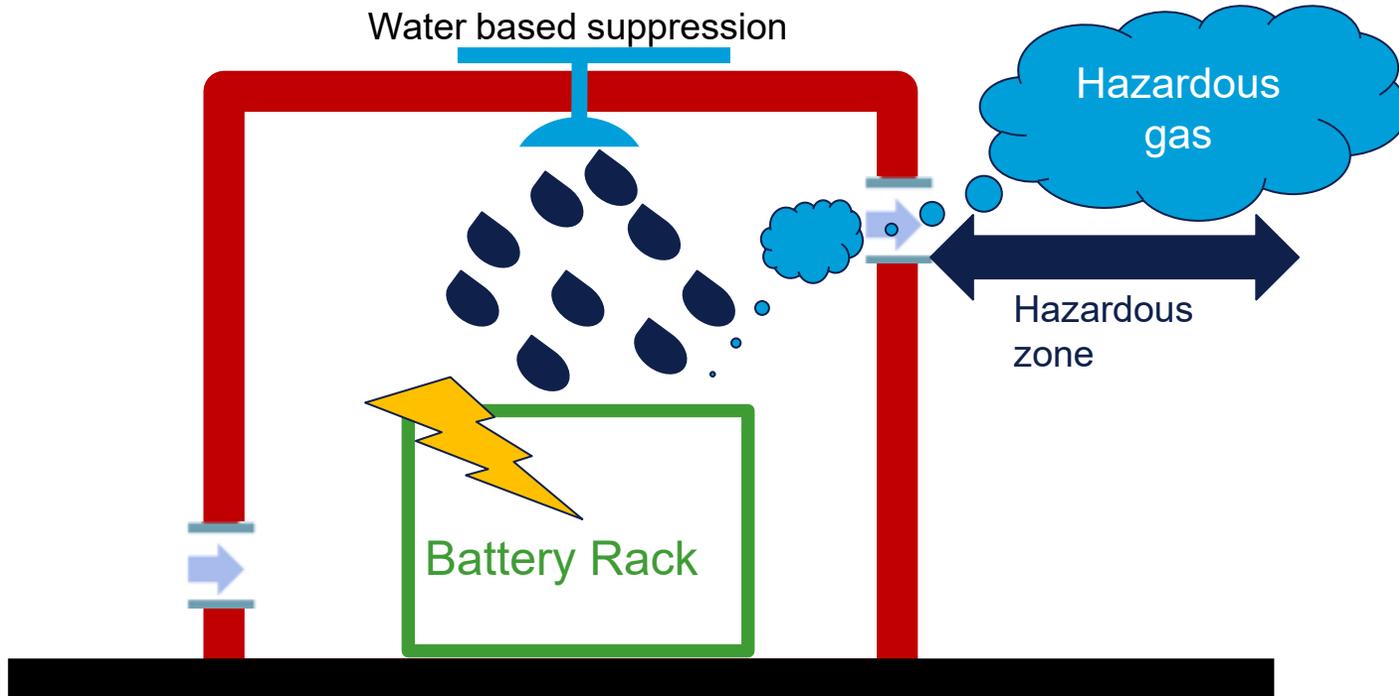
## Gas based

Gas is thermal insulating AND electrically insulating



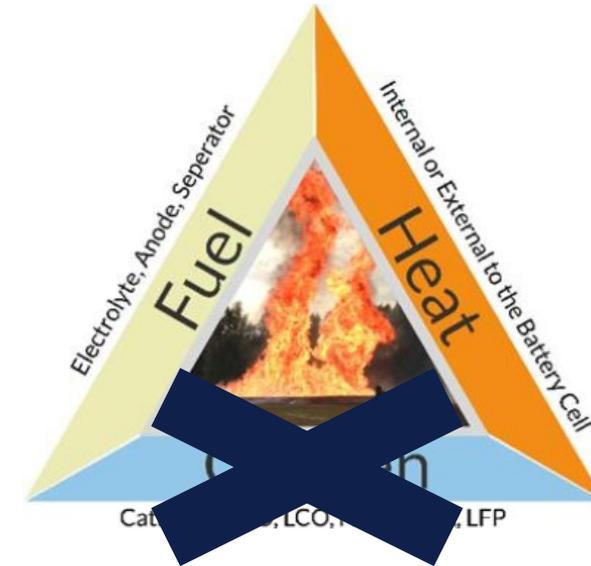
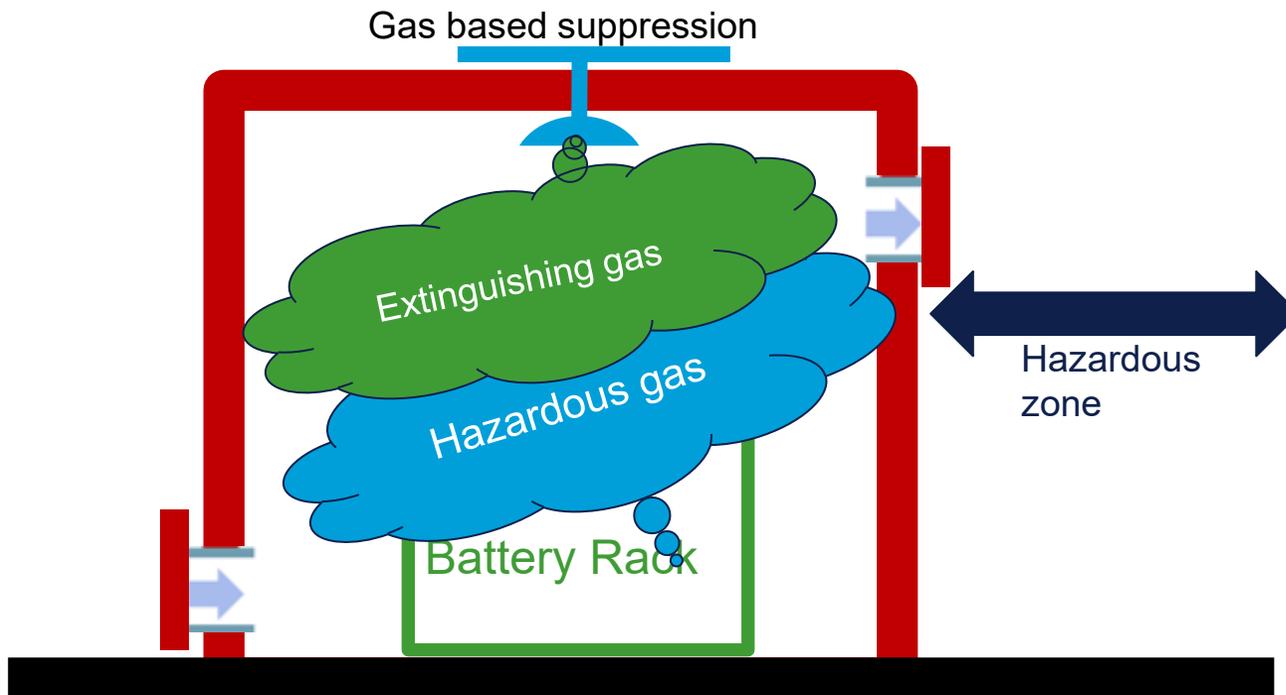
Not able to remove heat and ventilation needs to be closed

# Water based suppression system



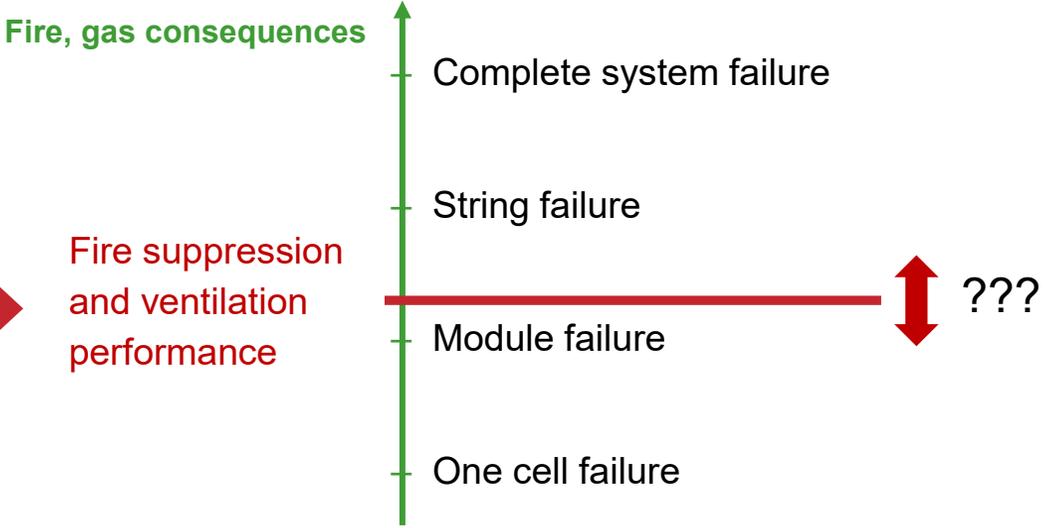
- Can run with ventilation and dilute the gas
- Risk of short circuiting
- Fresh water to be used.
- Sea water only for backup (should be avoided)
- Battery cabinets needs to be IP protected. Currently requires IP44

# Gas based suppression system



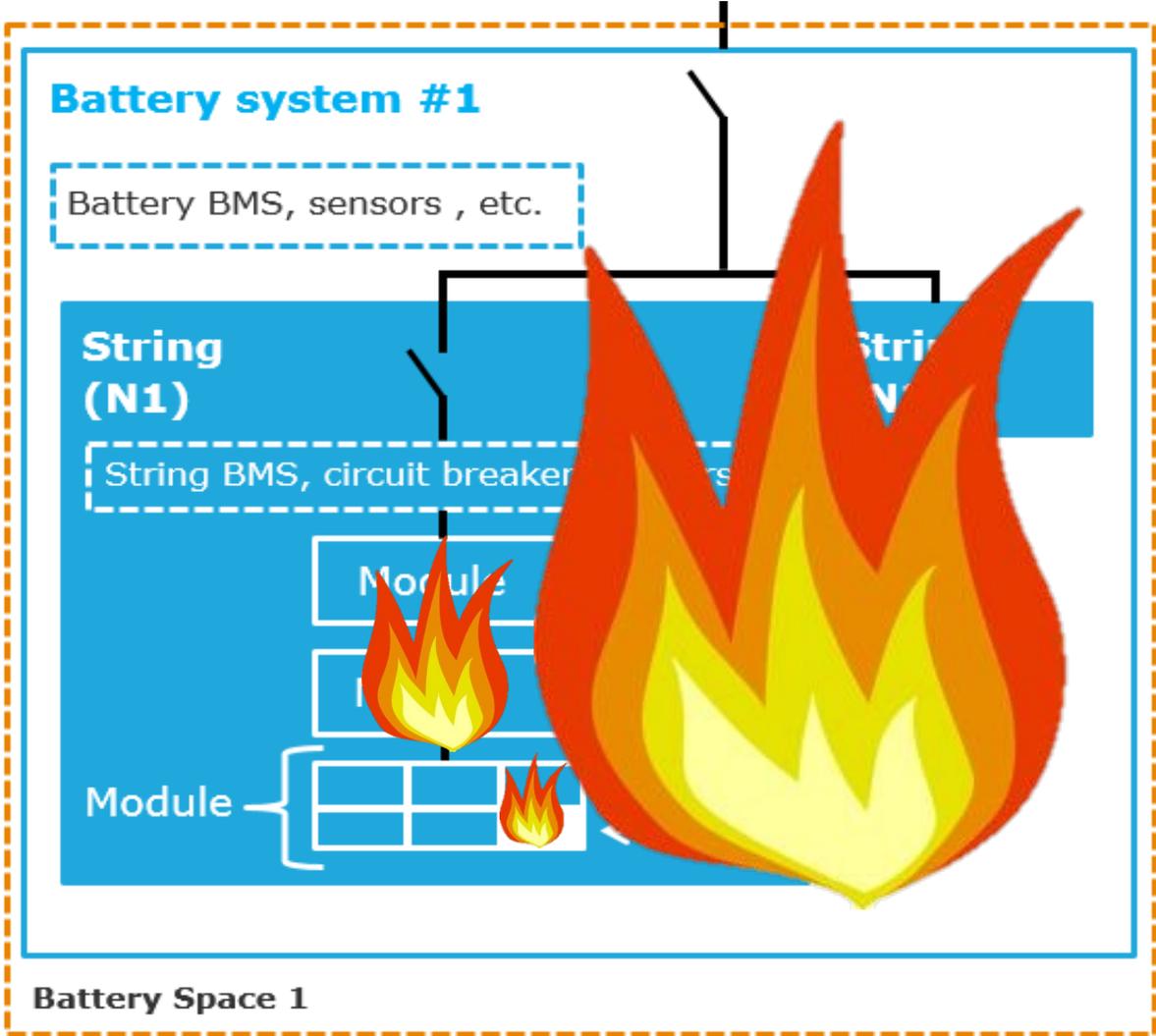
- Closing ventilation
- Remove the oxygen in the room
- The heat is still there, so the module must be designed such that heat are not spread easily
- Still a lot of ignition sources
- The gas mix needs to be removed from the room before the oxygen is introduced.
- Brim – The vessel was purges with nitrogen

# Where to draw the line?



**Need to rely on preventive safety barriers**

- Secure the battery system from mechanical damage
- Shield the battery system from external heating
- Independent ESD system
- Make sure that a battery fire in one cell/module does not spread to the rest of the system



# Risk handling of Lithium-ion batteries

Thank you

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