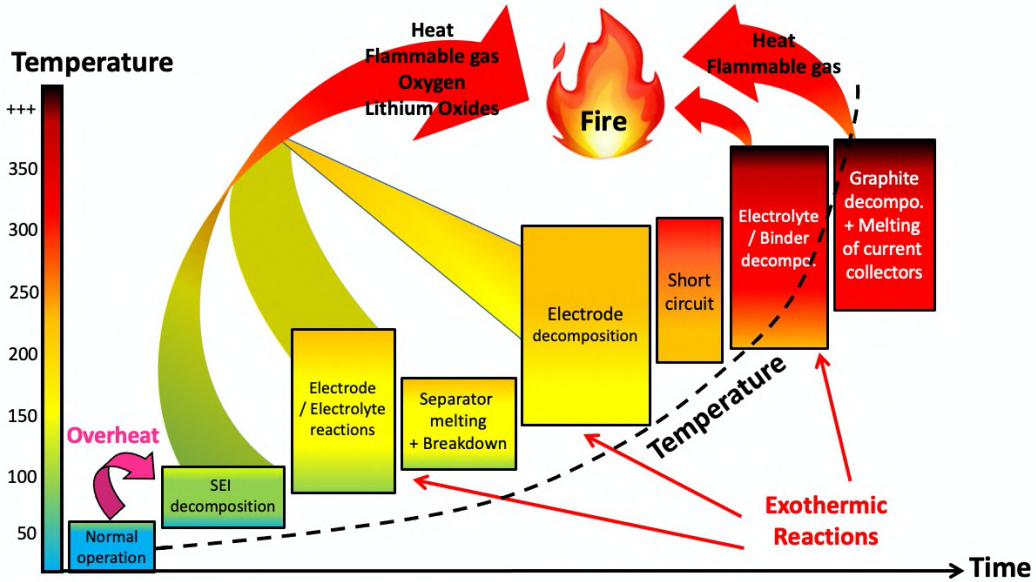
Thermal Runaway (1/2)

■ Batteries safely operate within a limited window of parameters (temperature, voltage, current...)
■ Manufacturing defects, ageing, abuses (fast charging, over-charging...) or (mechanical or chemical) damages can generate unwanted heat release



Runaway happens when additional overheat cannot be dissipated fast enough
It drives a series of exothermic reactions leading to uncontrolled temperature increase

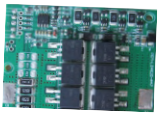
- At ≈ 60 °C , SEI (#EV9) starts decomposing electrode + electrolyte enter in contact exothermic reactions. At ≈ 90 °C, SEI breakdown
- At ≈ 140 °C, Cathode material decomposes releasing oxygen in a very exothermic reaction + separator starts melting creating internal short circuit
- At ≈ 240 °C, decomposition of Cathode + electrolyte + binders (#EV13) which releases large amount of energy rapidly increasing the Temp above 800 °C
- At > 1000 °C, Copper foils melt, complete collapse of the internal structure
- Gas releases, particulate, toxic emission, Fire
- Increase internal pressure potential explosion

OROVEL

Battery

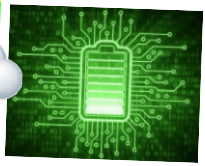
Temperature Effect

- Temperature modifies chemical reactions (Arrhenius equation) → change of electro-chemical reaction rates, ionic conductivities of electrodes. etc.
- High can result from operating conditions (fast charging ...). Generated Heat:
  - "reversible process" = reversible electrochemical reactions
  - "irreversible process" = polarisation, ohmic heating, phase change in electrode, mixing (due to inhomogeneous ion distribution) etc.
- Outside optimal → Performance degradation + ageing + Safety
- Battery performance and safety depends on → Measuring and controlling temperature are critical



- If is too high or out of control → Thermal runaway (#EV15)
  - Some highly exothermic chemical reactions → Temp ↗
- Electrolyte decomposition (irreversible Lithium loss) → Capacity fading
- PVDF (#EV13) migration on electrode surface stopping Lithium intercalation → Impedance increase → Power fade
- Binder (#EV13) decomposition → Loss of mechanical stability
- High accelerates ageing = Loss of performance + reduced lifetime

Binders (cf #EV13)



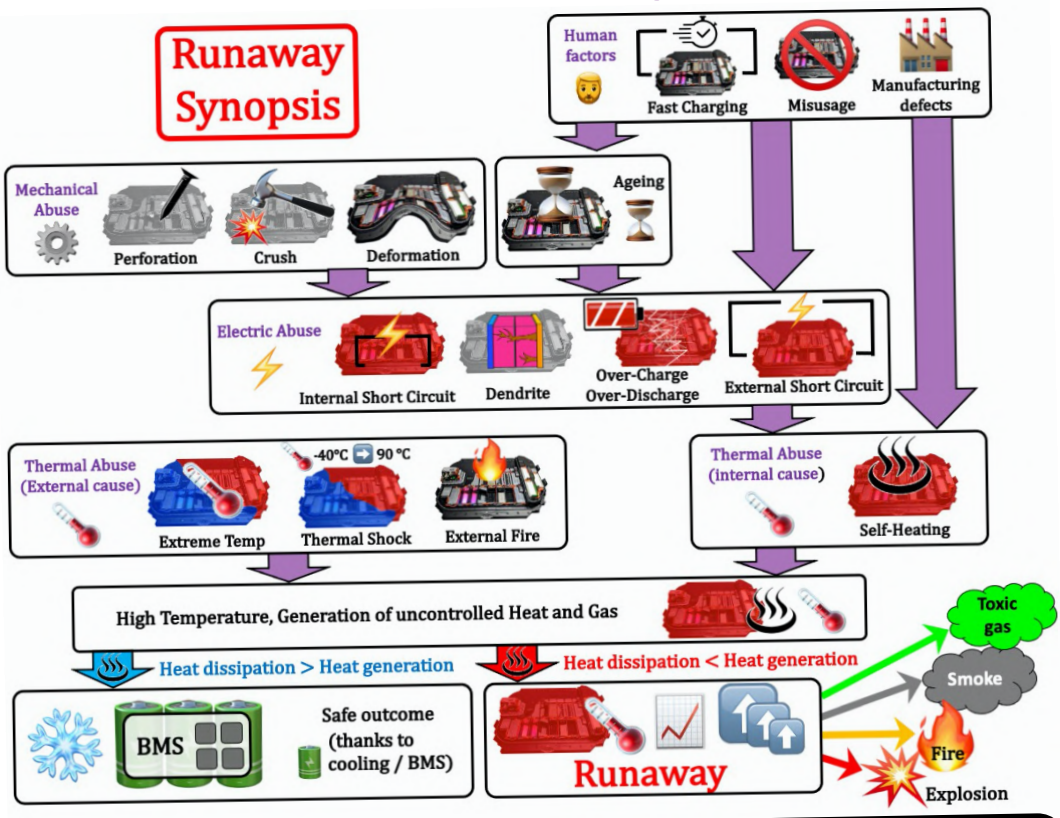
25 °C – 40 °C
Maximum Cycle Life

15 °C – 25 °C
Better Energy Storage Capacity

- Slow chemical reactions and slow Lithium ion diffusion
- Electrolyte viscosity increases reducing ionic conductivity
- Internal resistance increases due to directional migration of ions
- Lithium plating (= Li deposit on electrode surface) due to polarization → Capacity loss
- Dendrite formation that may penetrate the separators = internal short circuit
- Combined loss of capacity and increase of internal resistance → Loss of power

#EV14

Thermal Runaway (2/2)



- Runaway: most safety-critical failure mode of Batteries
- Safe window of conditions (temperature, voltage, currents ...)
  Crossing these limits ➡ Runaway (see mechanism in #EV15)
- Scenario and severity depend on cell chemistry, Battery ageing, State Of Charge, design (plastics, cables, electronics...), load and abuse event history...
- From possible scenarios, manufacturing defects = most worrying because cannot be predicted nor easily corrected by BMS (Battery Management System)
- Crucial to early detect abnormal rise in temperature and take safety actions