Fire Hazards of Lithium Ion Batteries

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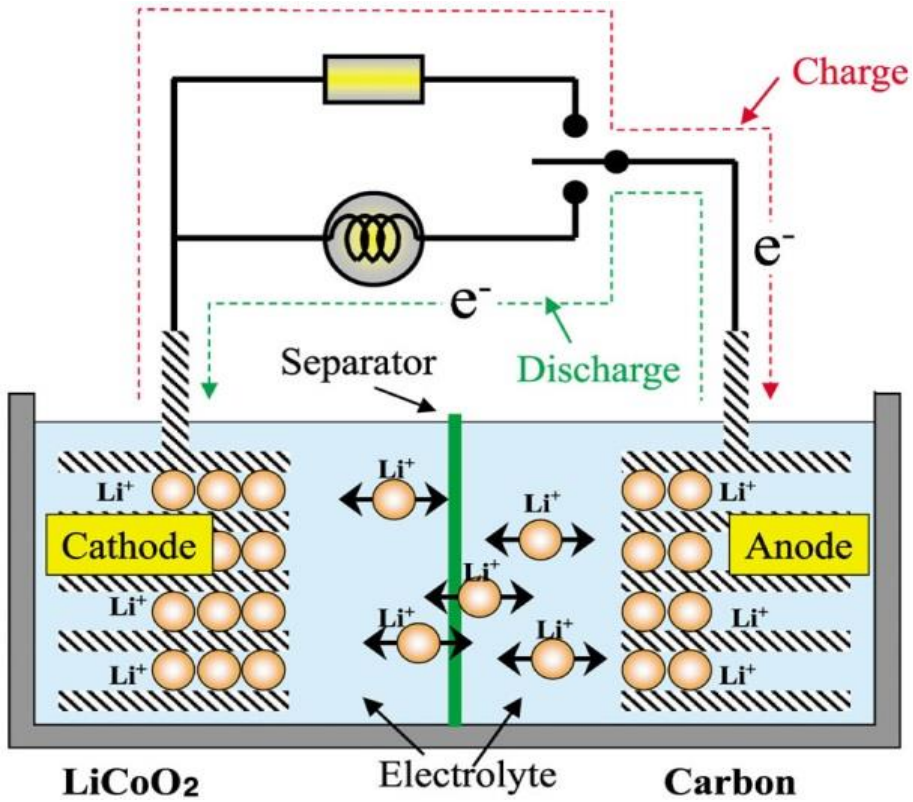
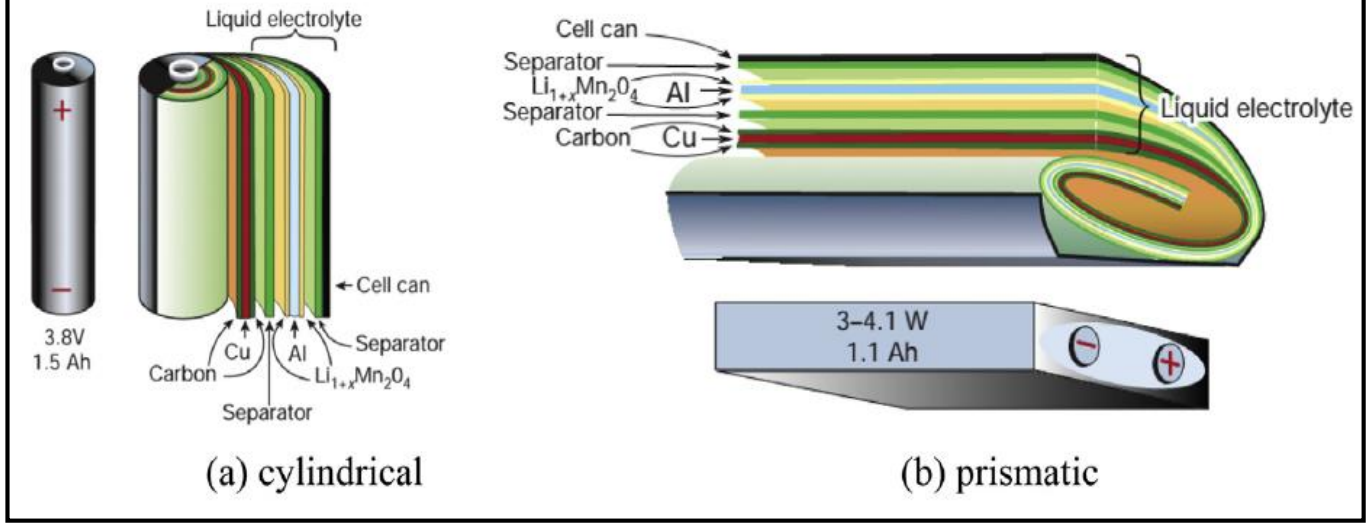
Lithium Ion Battery Energy Storage Solutions are an Emerging Fire Safety Problem

Lithium Ion Battery (LIB) Chemistry and Design

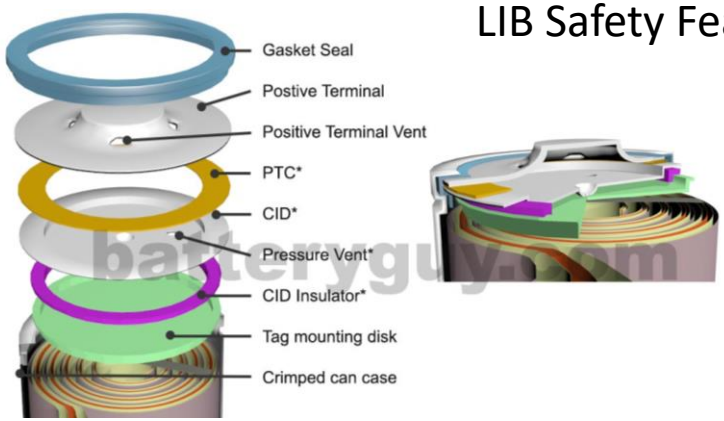
LIB Charge Cycle



LIB Structure

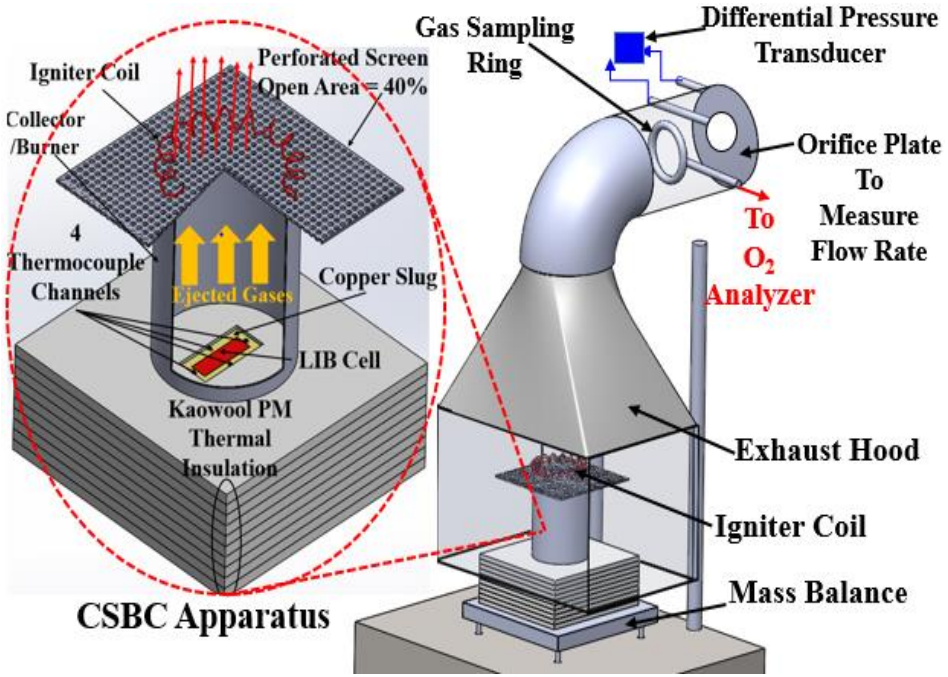


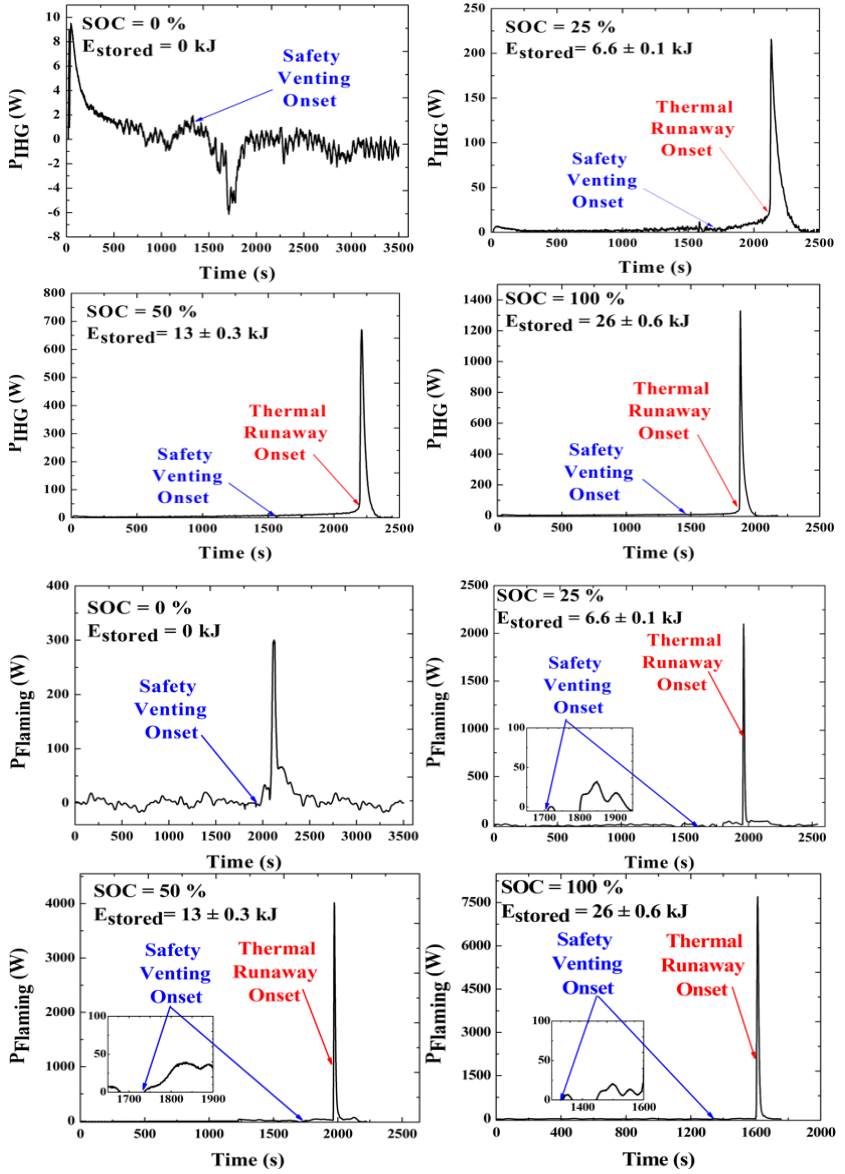
LIB Safety Features



https://doi.org/10.1016/j.pecs.2019.03.002

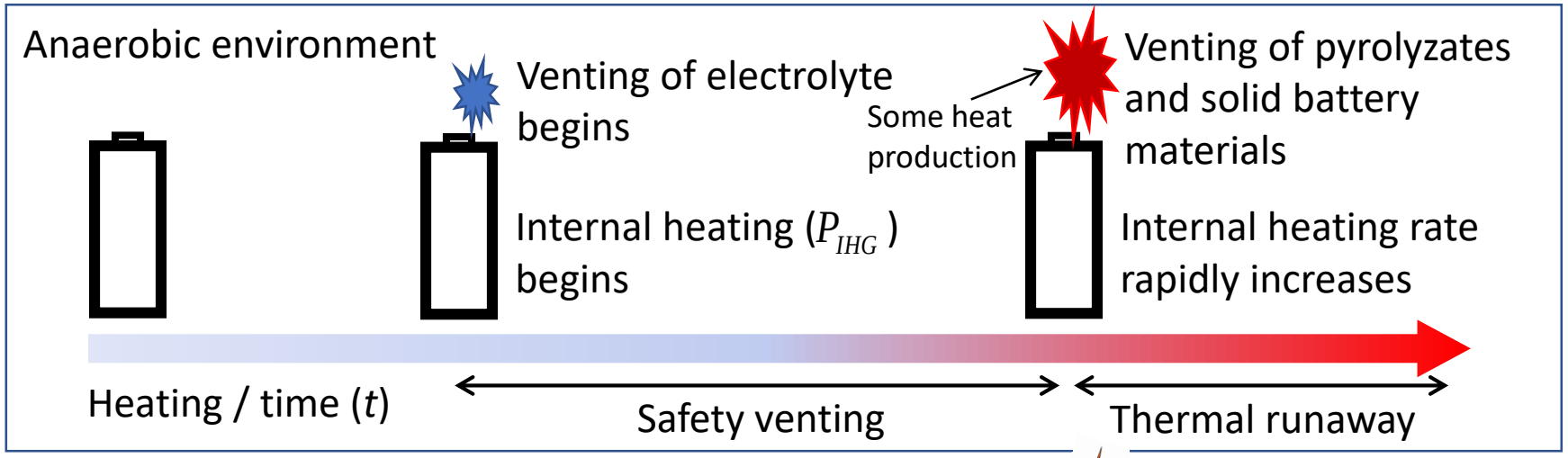
Energetics of Failure as a Function of the State of Charge (SOC) by means of Copper Slug Battery Calorimetry (CSBC)

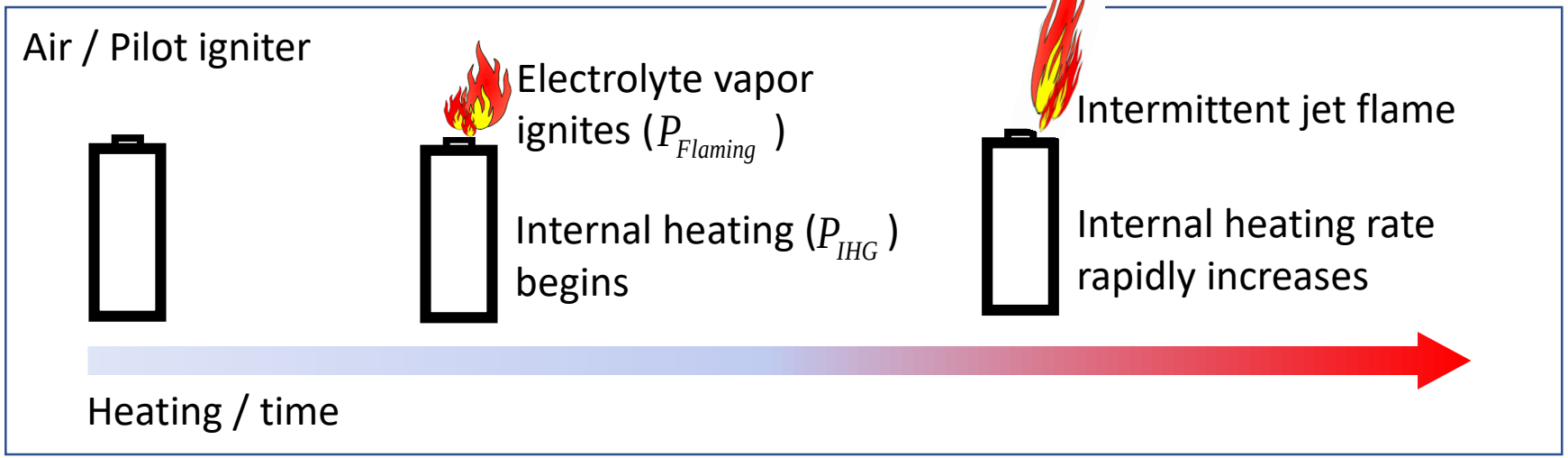




https://doi.org/10.1016/j.proci.2018.05.066

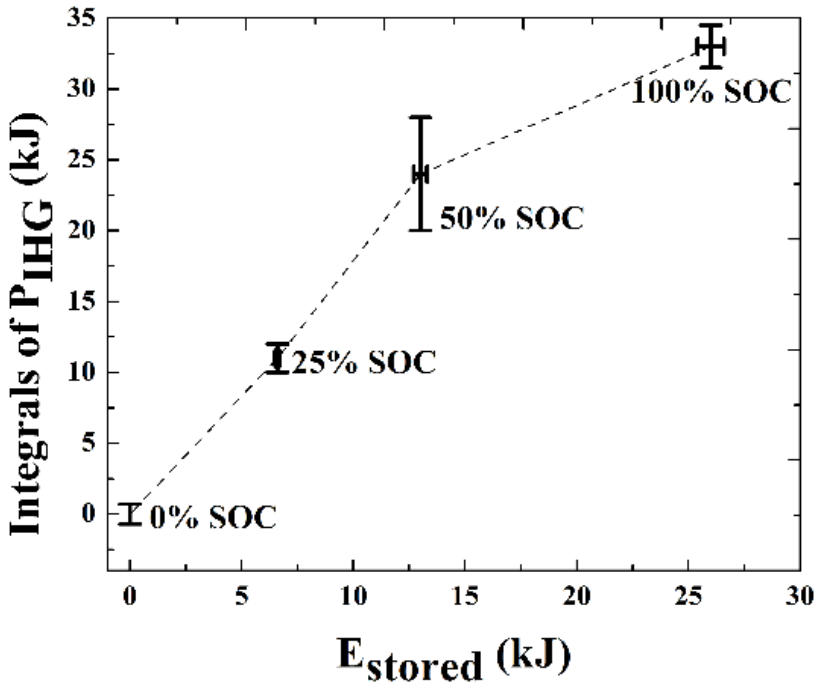
Thermally Induced Failure of a Lithium Ion Cell in Pictures

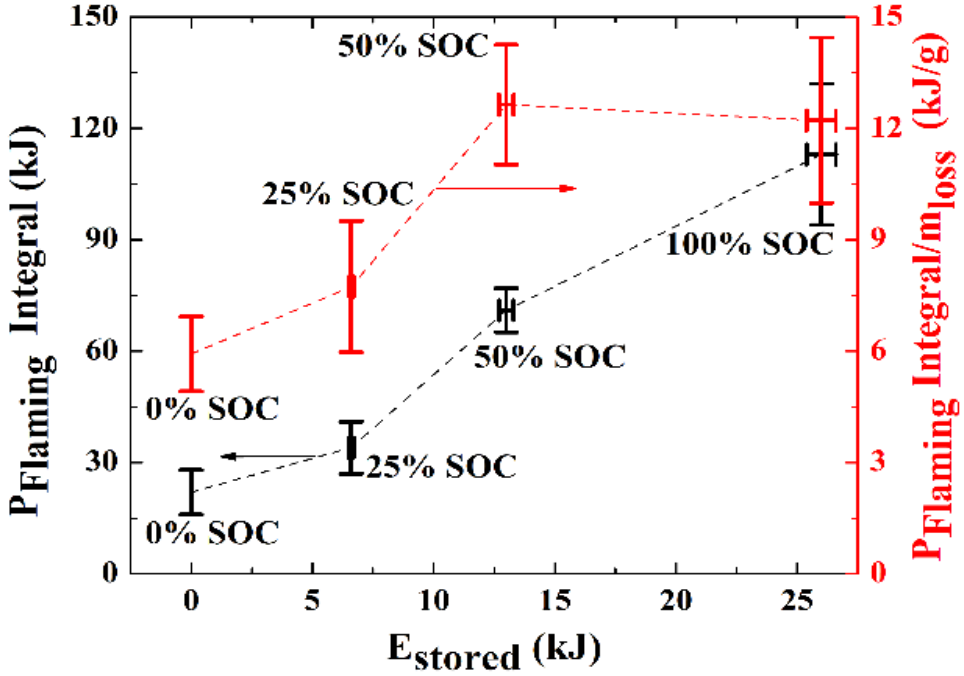




Failure Energetics of a Prismatic Lithium Cobalt Oxide Cell

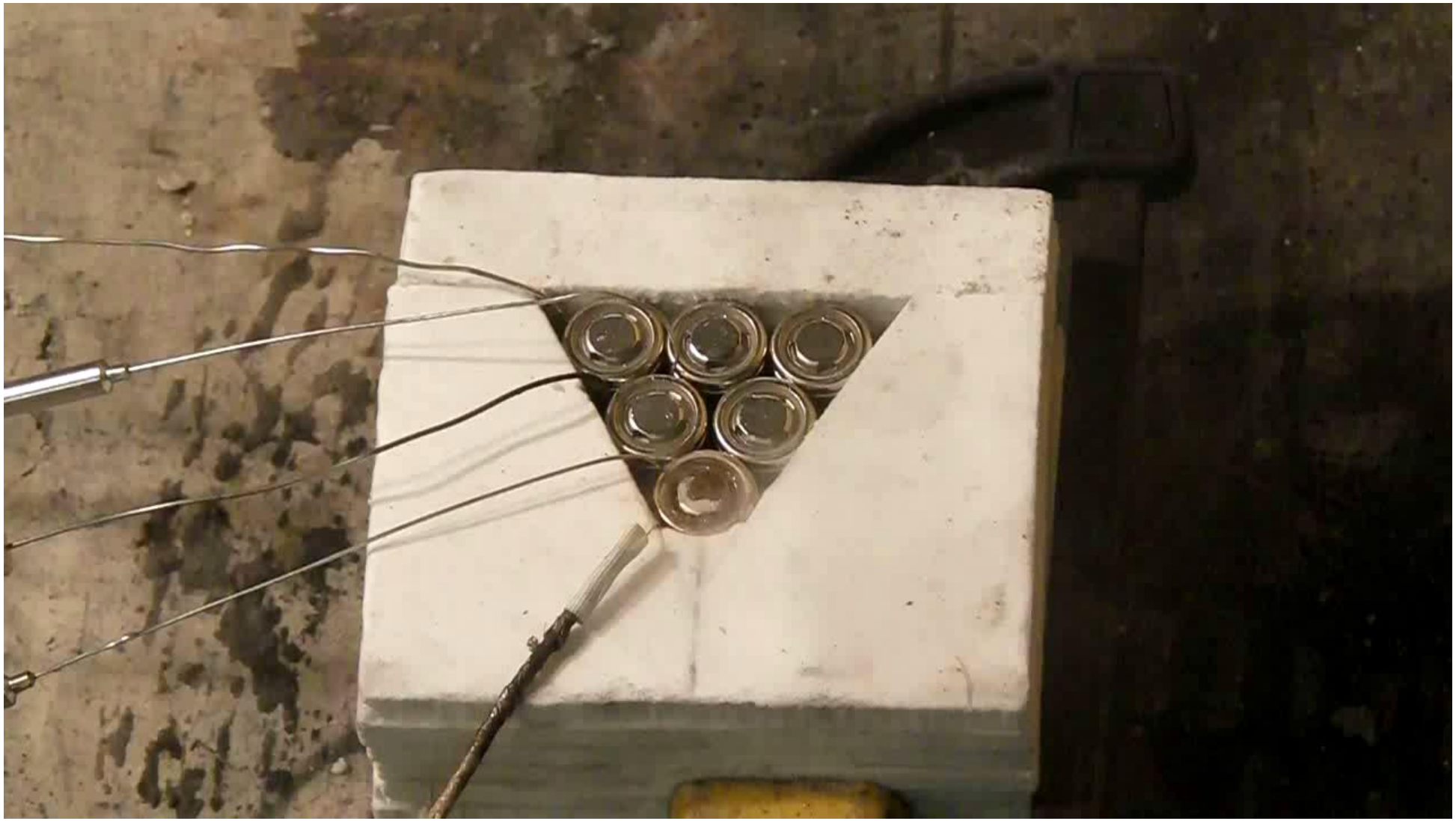
Sanyo UF103450PN
Initial mass: 36 g
Capacity: 1880 mA h





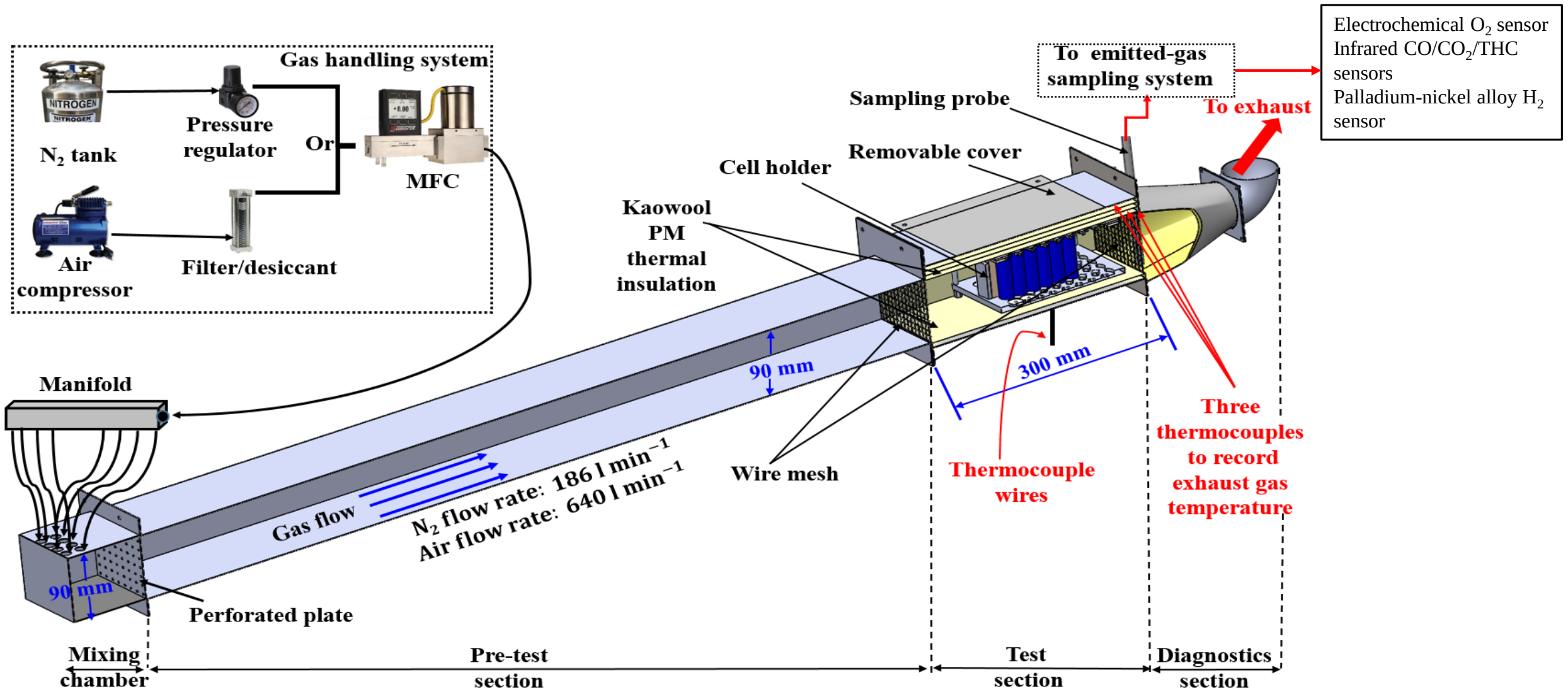
https://doi.org/10.1016/j.proci.2018.05.066

LIB Cascading Failure



https://iopscience.iop.org/article/10.1149/2.0111813jes

LIB Cascading Failure Setup

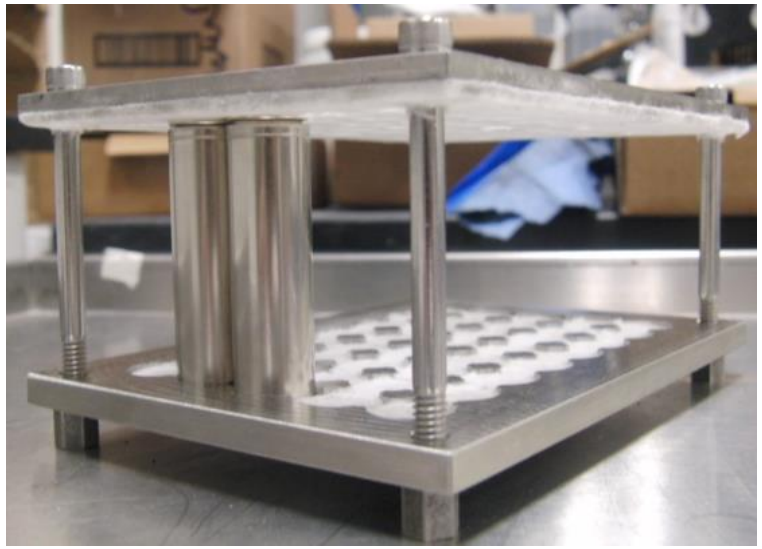


https://doi.org/10.1016/j.apenergy.2019.04.141

Cell Holder

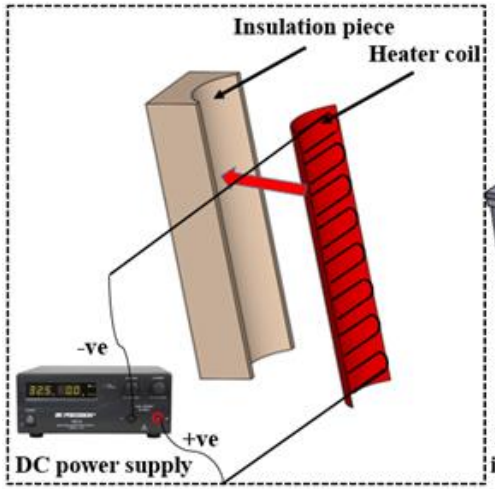
Cell Installation:

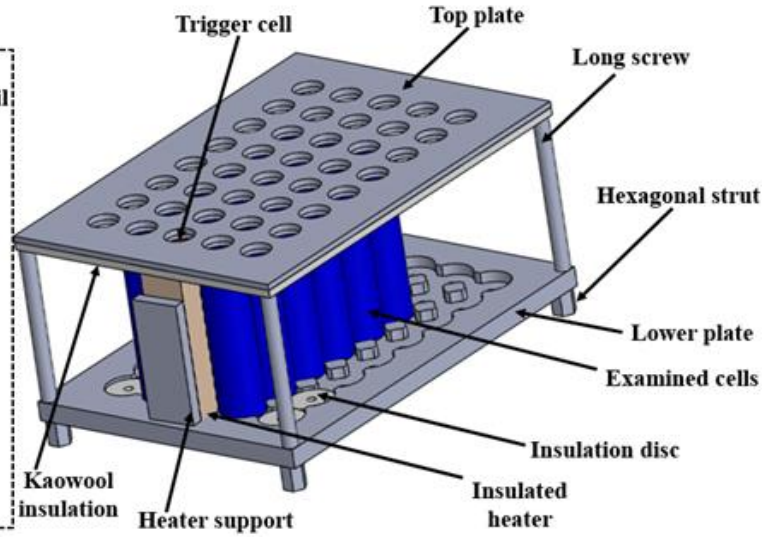
- A thermocouple bead is fixed at the bottom of each 18650 cell
- Kaowool PM insulation discs are placed below each cell
- Ejected gases are released through top perforations



Surface Heater:

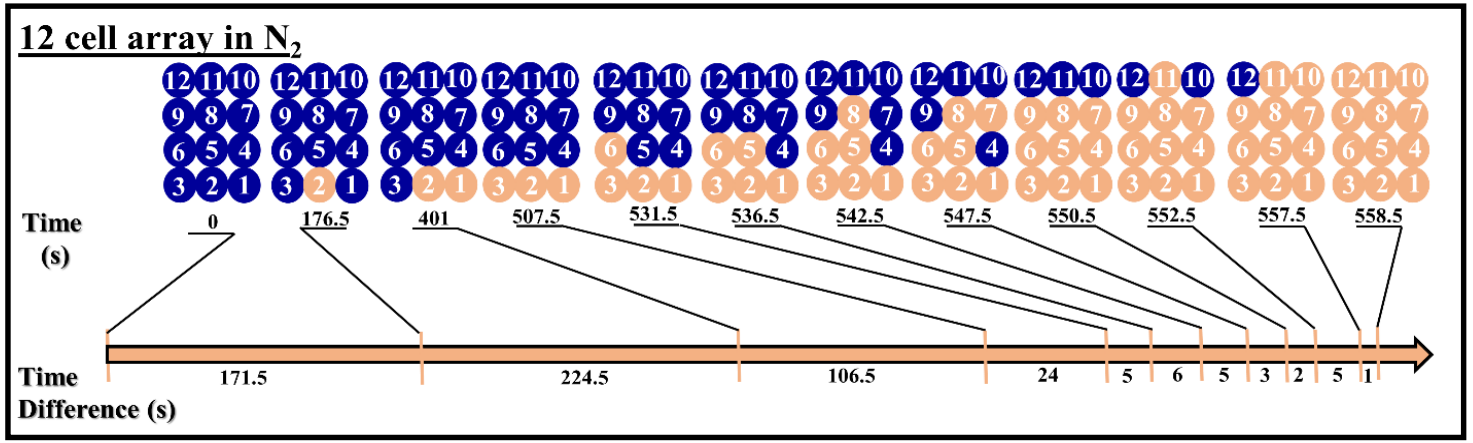
- Triggers the failure process
- Made from nickel chromium wire and glass tape
- DC trigger power = 105 - 115 W
- Surface Area = 0.0016 m^2
- Trigger heat flux = 65 – 72 kW m^{-2}

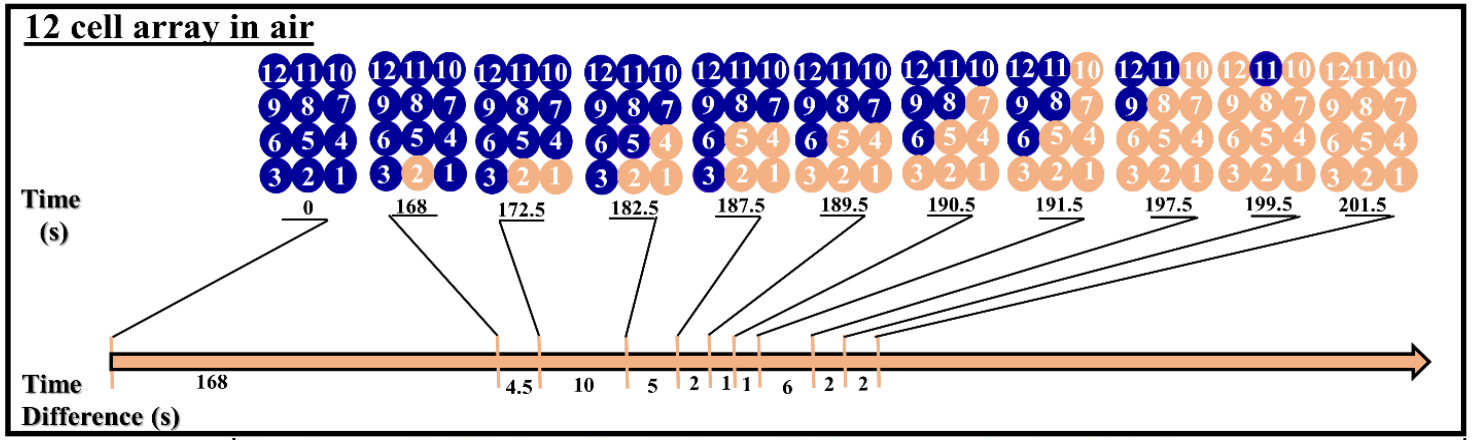




Cascading Failure Dynamics in Pictures

Tenergy ICR18650, lithium cobalt oxide, 2600 mA h

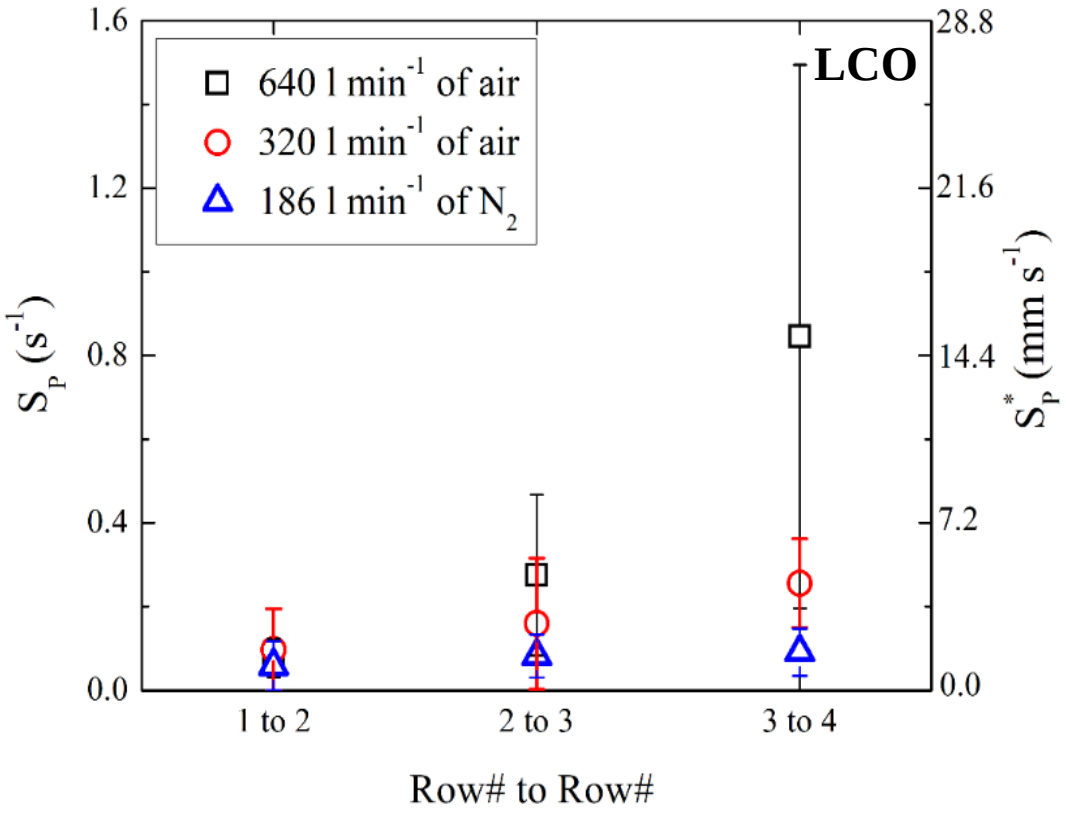




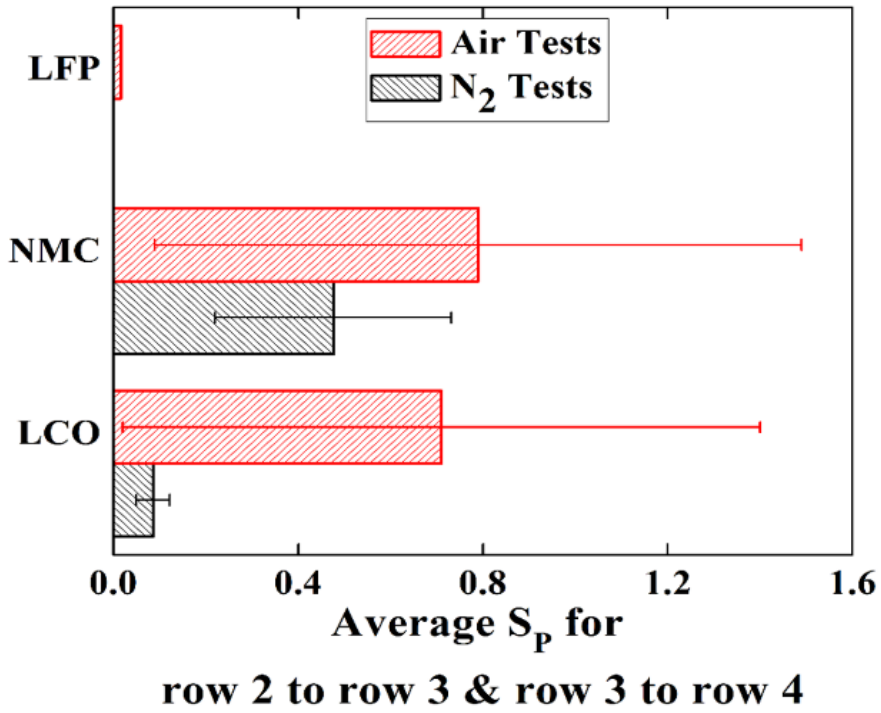
https://doi.org/10.1016/j.apenergy.2019.04.141

Cascading Failure Dynamics Quantified

$$S_{P_{(1\ to\ 2)}} = \frac{1}{(time_{Therm.Run.}|_{row\ 2} - time_{Term.Run.}|_{row\ 1})}$$

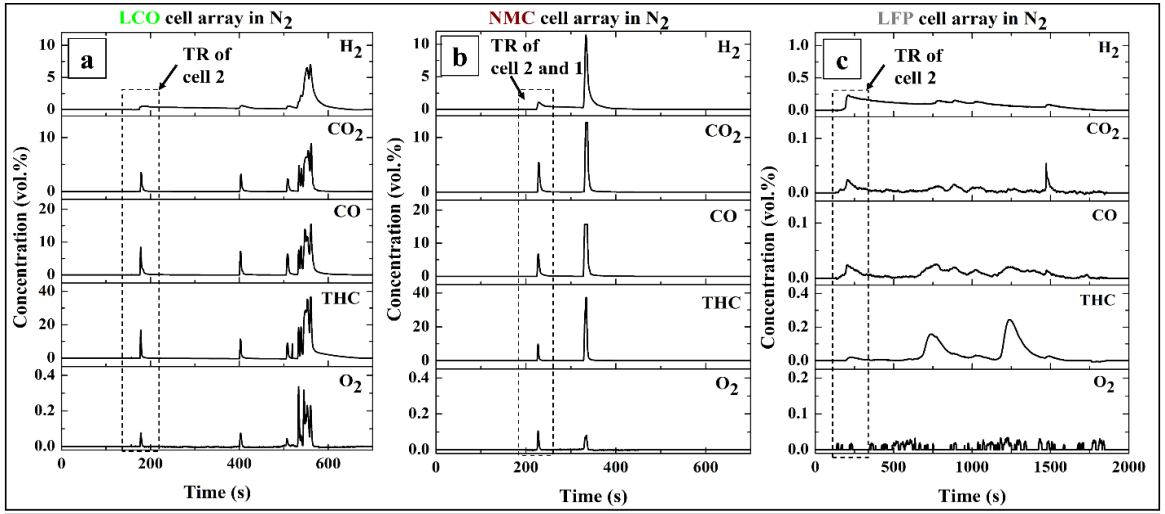


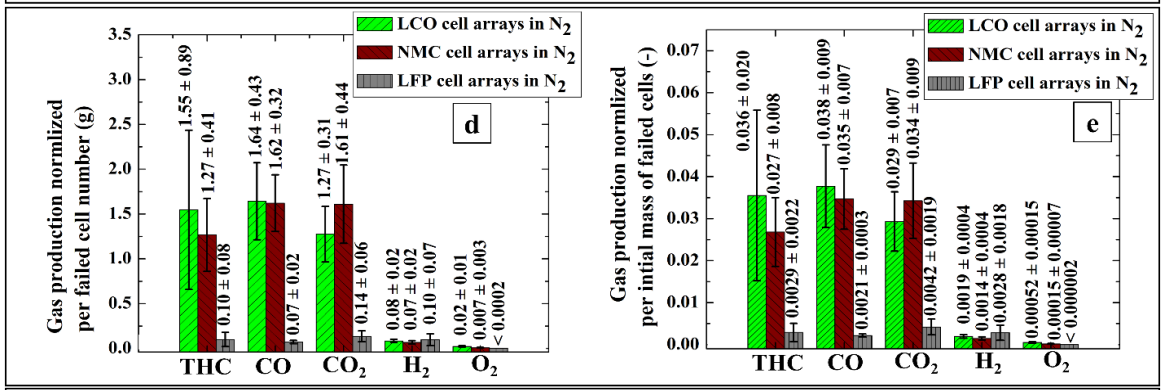
Lithium Cobalt Oxide (LCO) -- 2600 mA h
Lithium Nickel Manganese Cobalt Oxide (NMC) -- 3000 mA h
Lithium Iron Phosphate (LFP) – 1500 mA h

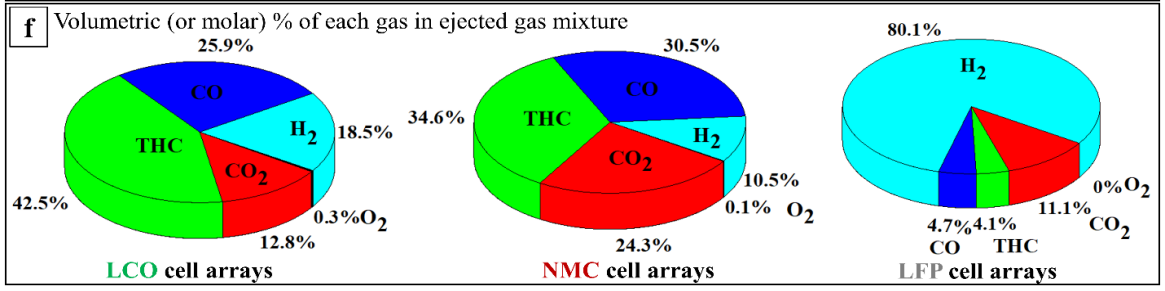


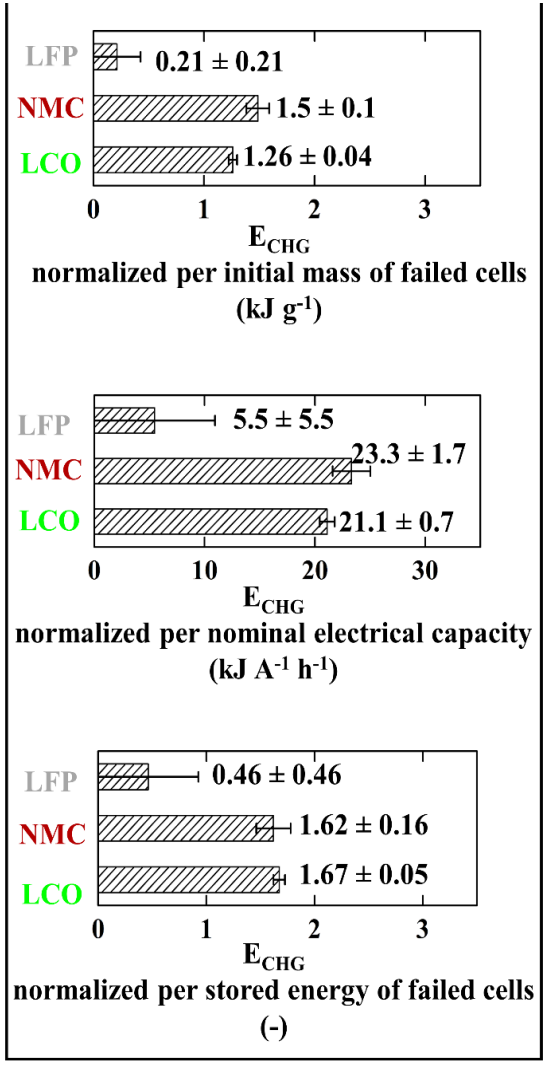
https://doi.org/10.1016/j.jpowsour.2019.227347

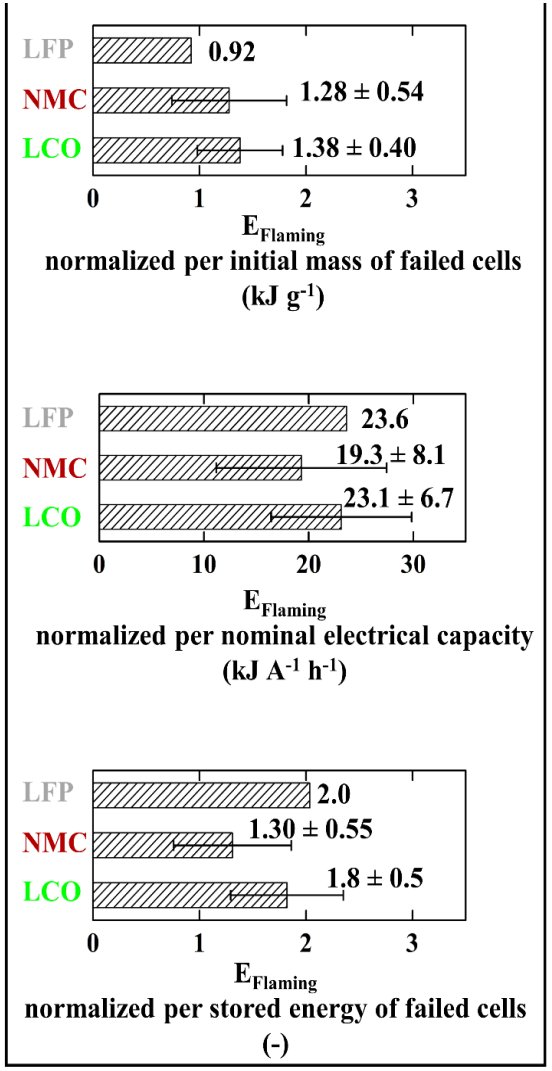
Species Production in N_2 and Failure Energetics in N_2 and Air











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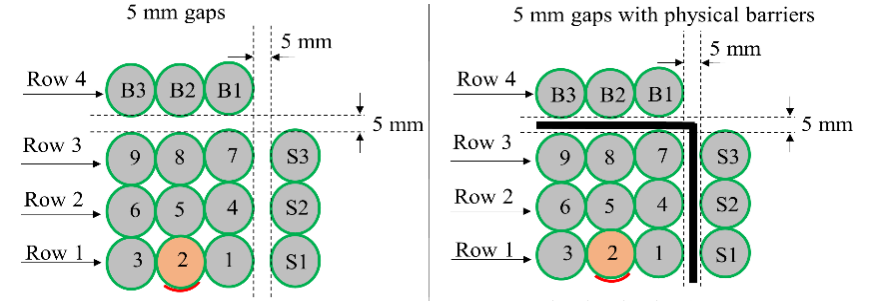
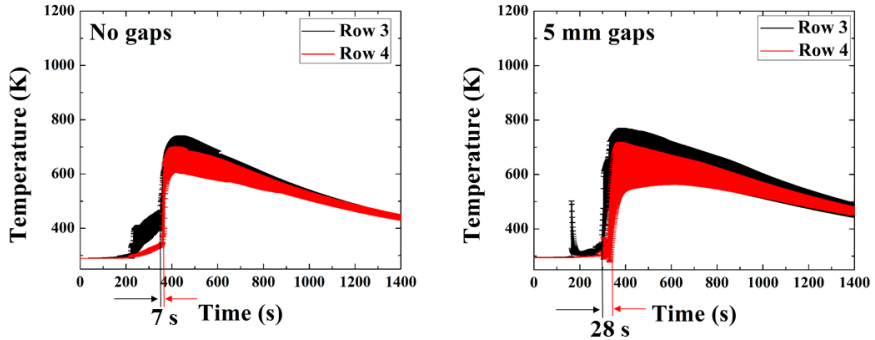
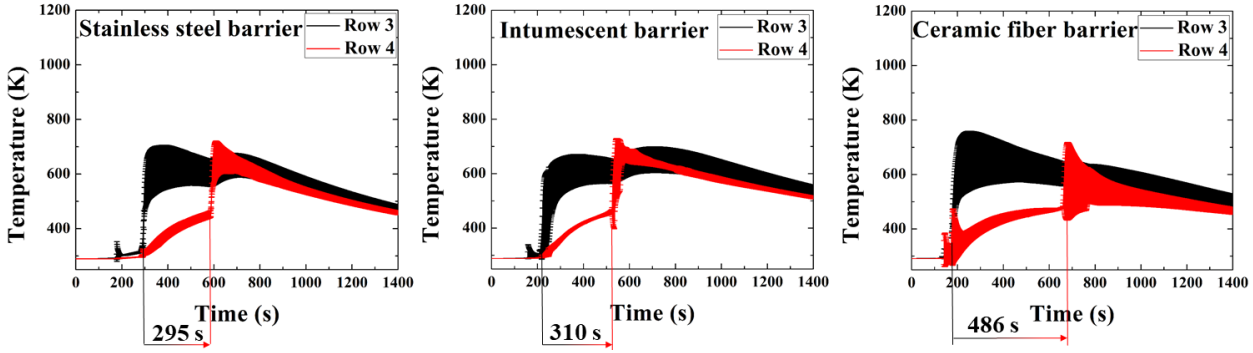
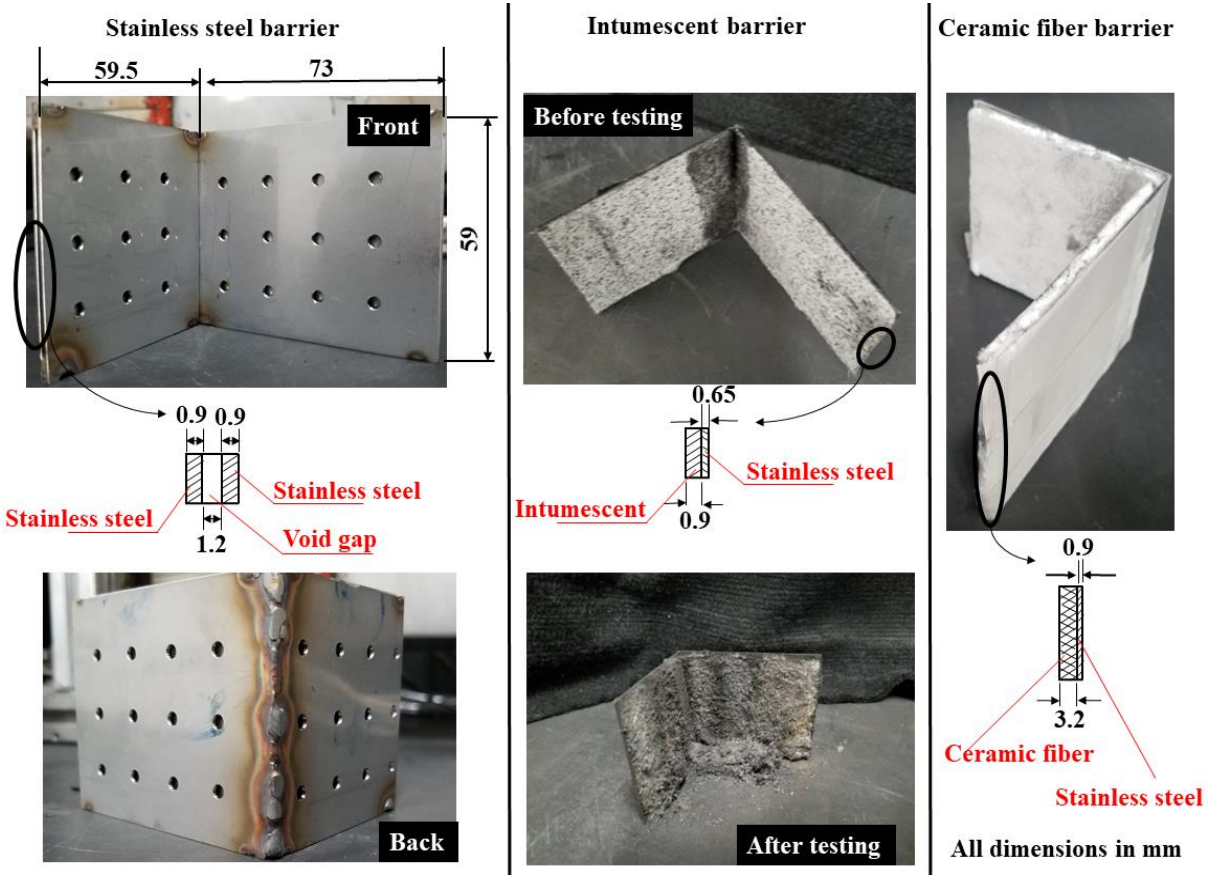
Impact of Physical Barriers on Cascading Failure in N_2

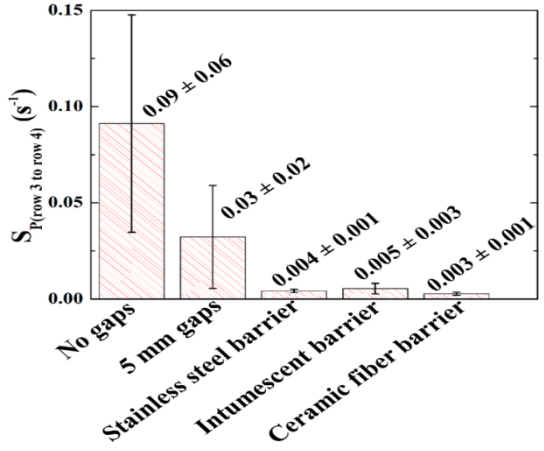


LCO cells at 100% SOC





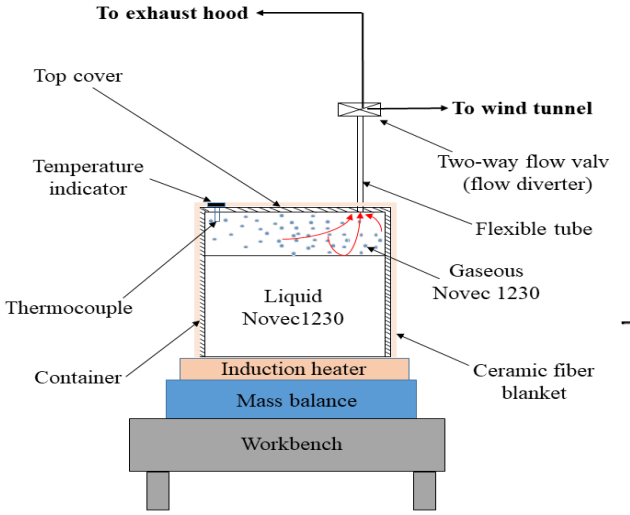


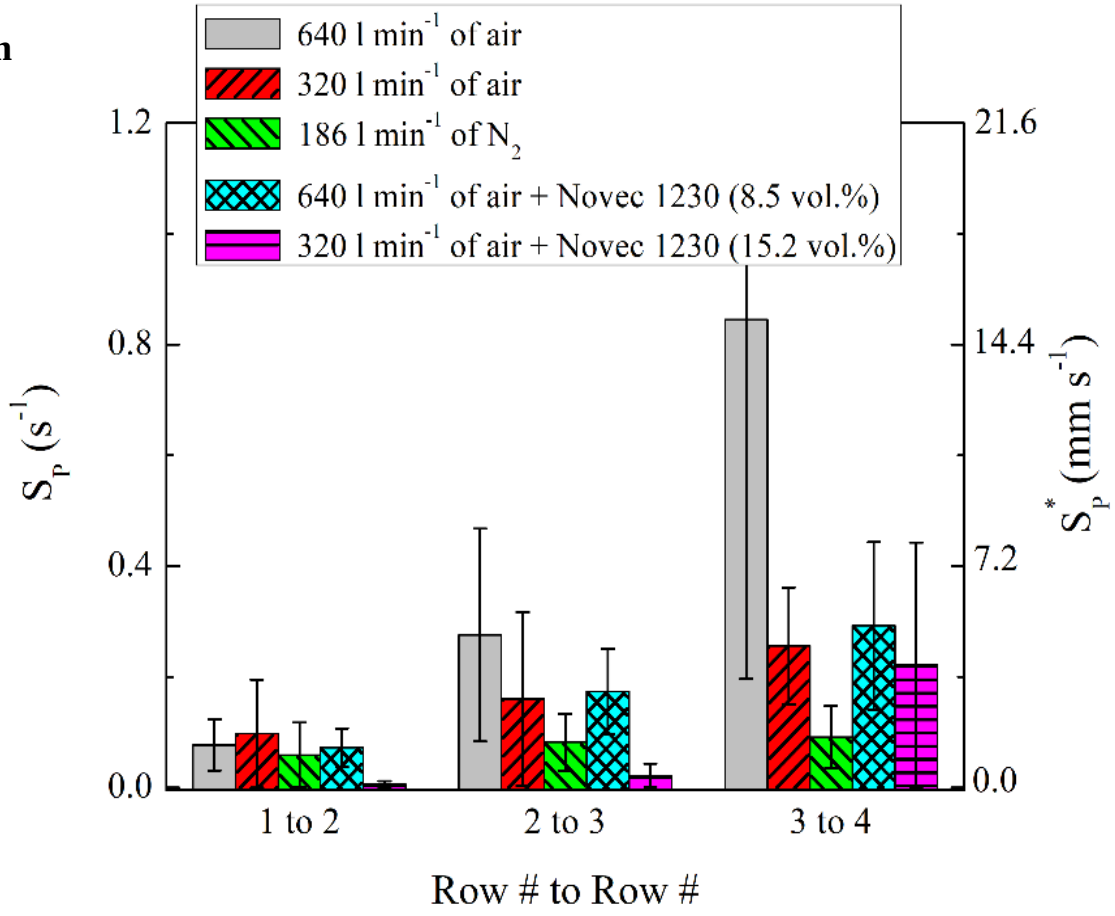


https://iopscience.iop.org/article/10.1149/1945-7111/ab8978

LIB Fire Suppression with a Clean Agent, Novec 1230

Novec 1230 Vapor Generation System

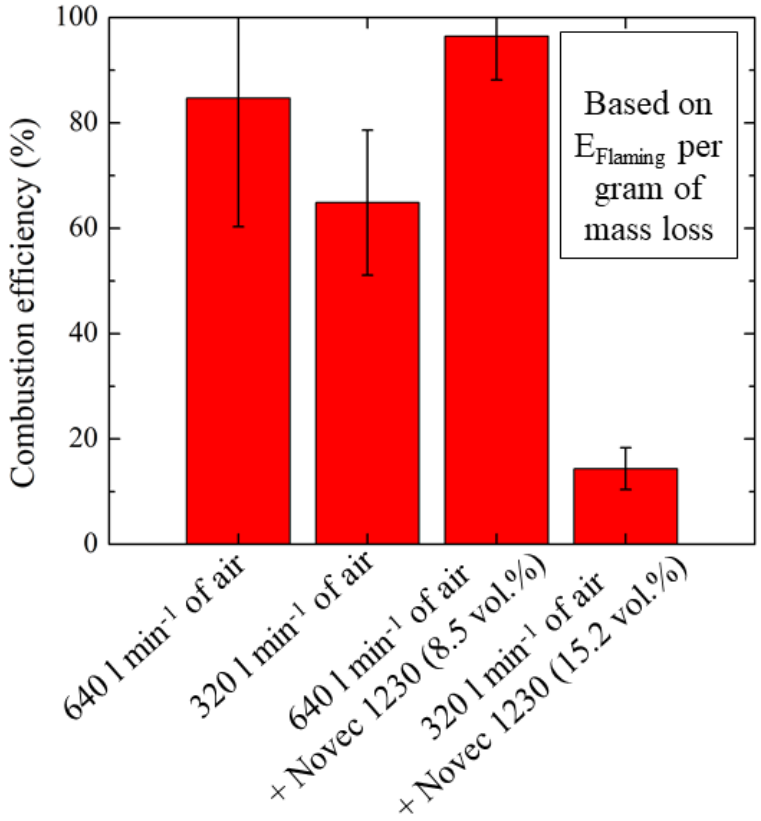


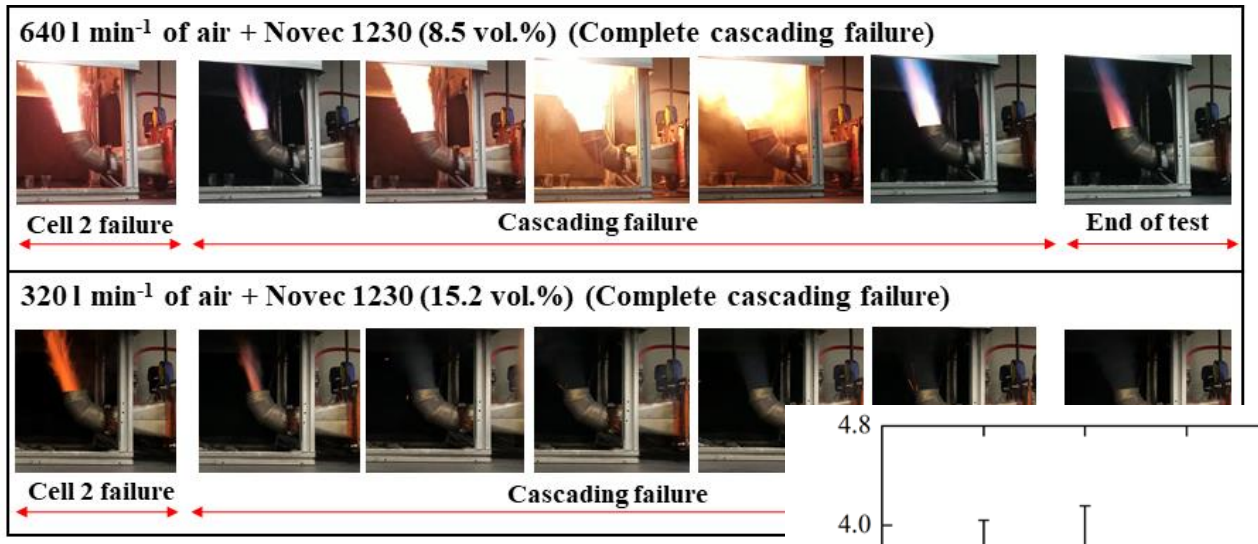


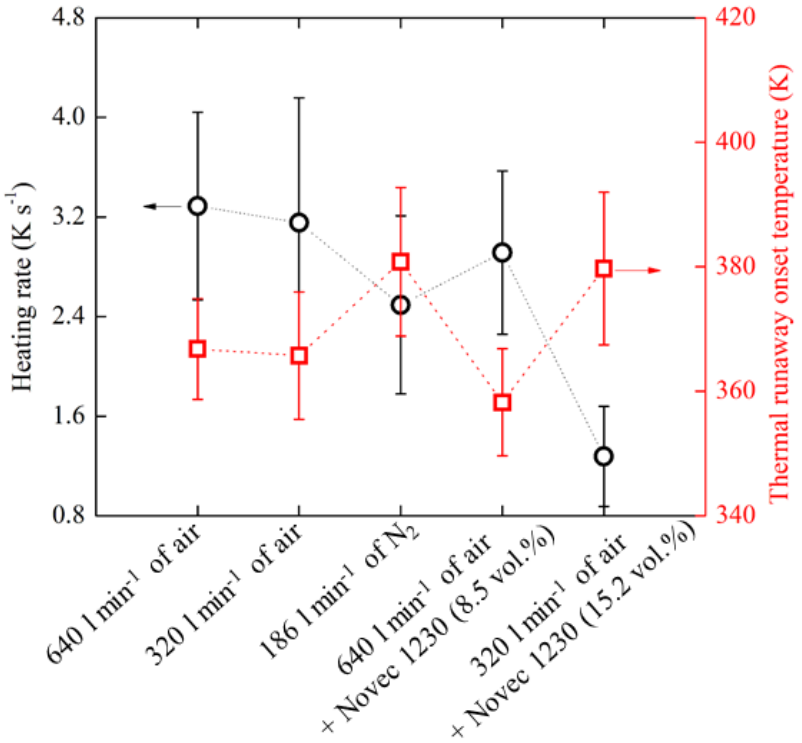
- In 8.5 vol.% Novec 1230 tests, 100 % of LCO cells underwent thermal runaway.
- In 15.2 vol.% Novec 1230 tests, only 43% of LCO cells underwent thermal runaway.

https://doi.org/10.1016/j.firesaf.2021.103296

Suppression Mechanism







https://doi.org/10.1016/j.firesaf.2021.103296

Conclusions

- Upon failure, a single LIB cell may release heat up to 5 times larger than the stored electrical energy. This heat release is a result of reactions between battery components as well as flaming combustion of some ejected battery materials, which requires external oxygen.
- When normalized by the initial cell mass, this heat is 2 – 5 kJ g^{-1}, which is several times lower that the heat of combustion of traditional flammable solids.
- In the absence of flaming combustion, LIB cells produce large amounts of hydrocarbons, CO, CO_2 and H_2 upon failure.
- LIB cell hazards are primarily associated with their tendency to undergo and propagate thermal runaway in response to a wide range of triggers. Presence of LIB cells does not alter dynamics of traditional fires. Cascading failure in a multi cell module may lead to formation of large volumes of pre-mixed gaseous fuel and air, which creates a significant explosion hazard.
- Lithium iron phosphate appears to be the safest LIB chemistry, but, look out for hybrids.
- Physical barriers, even when a subject of spatial constraints, can be effective in slowing down cascading failure.
- A halocarbon clean agent, Novec 1230, can be used to suppress thermal runaway propagation and fire growth within LIB modules. However, the agent concentration must be are several times higher than those used for traditional fires and a direct injection of the agent into the module and continuous purge are required.

We would like to thank United Technologies for sponsoring this work.