Lithium Battery Combustion Hazard Analysis and Packaging Testing

Presented to: International Aircraft Materials Fire Test and Systems Fire Protection Forums

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Date: June 12, 2023

Federal Aviation Administration

Purpose

- The goal of aircraft fire protection research is to prevent fatal accidents caused by in-flight fires and improve survivability during post-crash fires.
- The Federal Aviation Administration (FAA) Technical Center conducted experiments to
  – assess the combustion hazard of lithium batteries that undergo thermal runaway through gas analysis.
  – assist in the development of the SAE G27 standard.

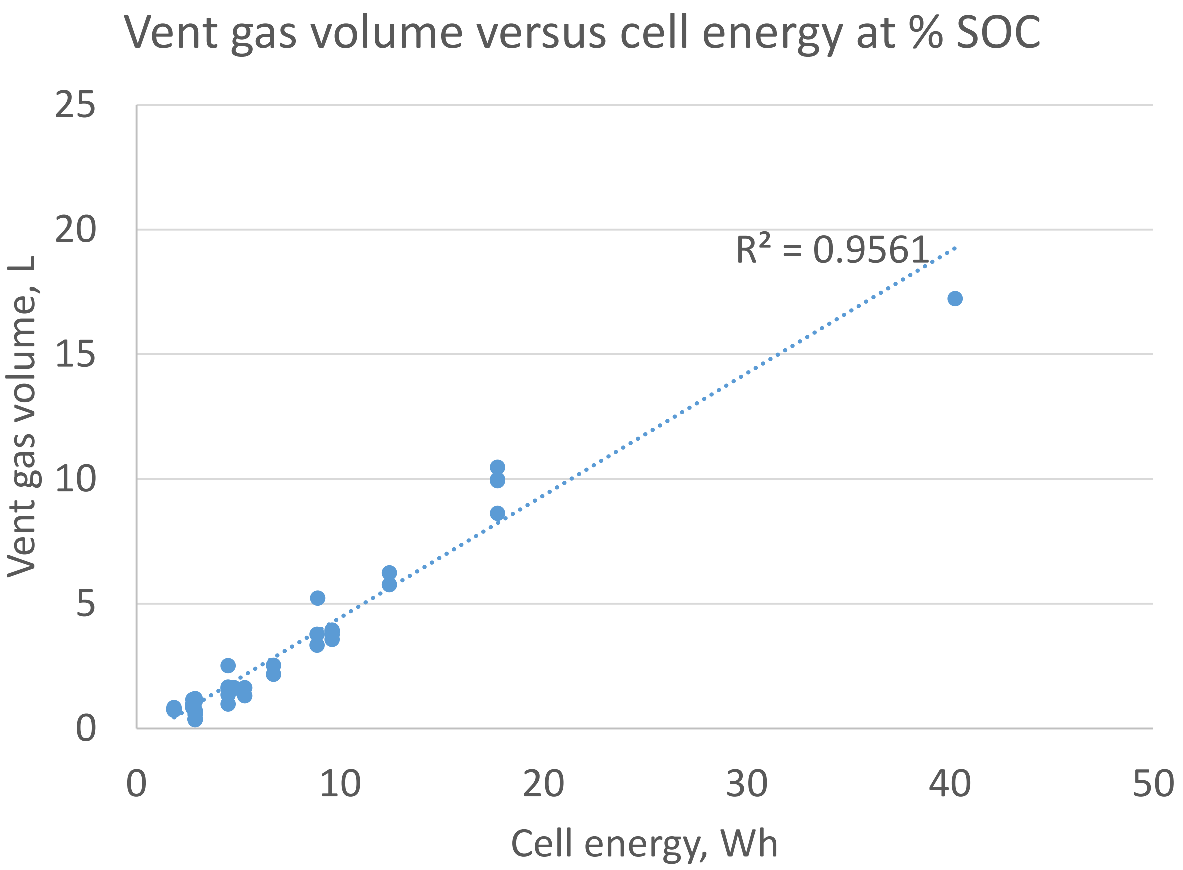
Background

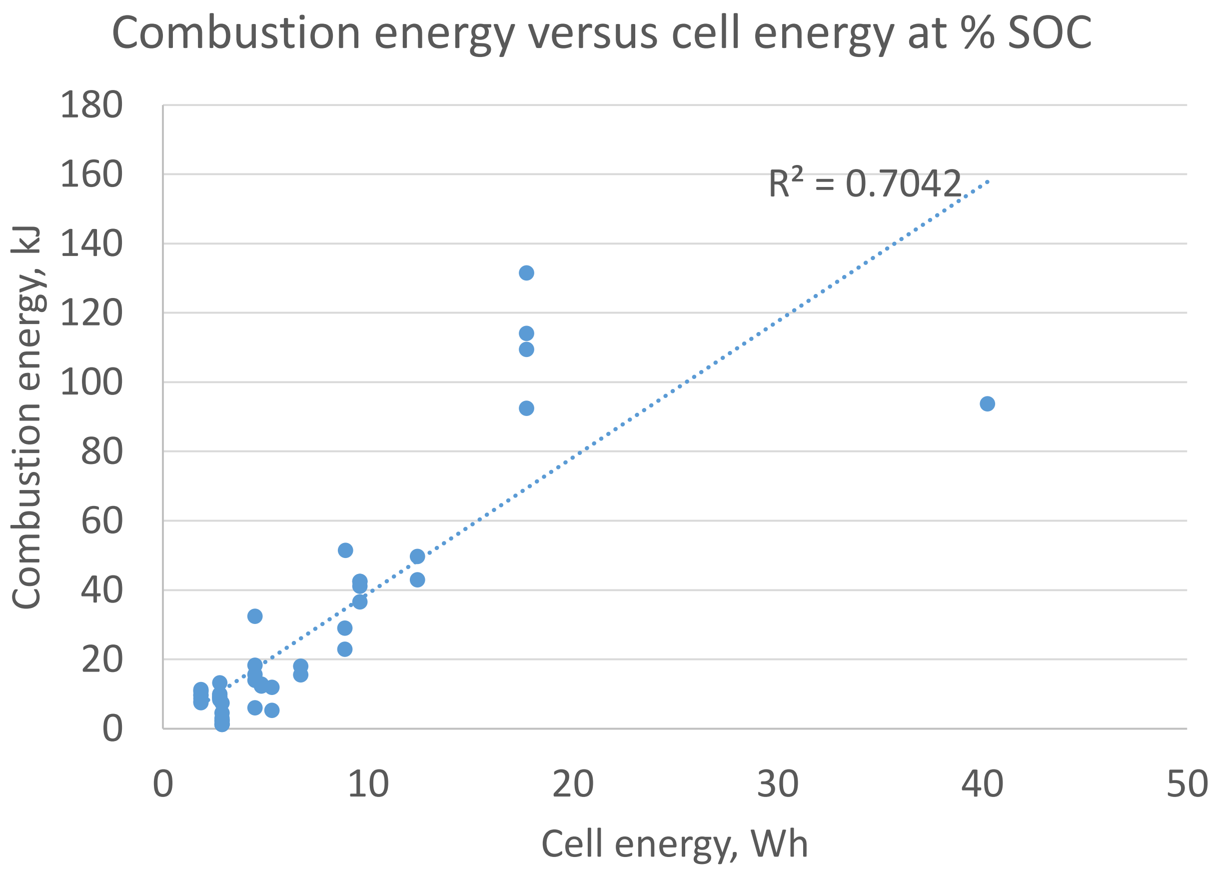
- **Large format cells becoming more prevalent.** Governments banning production of internal combustion engine (ICE) cars plus tax incentives for electric vehicles (Evs).
- **Approximately 1/3 of Ev fires start while the car is parked and not charging[1].**
- **Projected 465% increase in battery sales over 10 years** from 230 GWh in 2020 to 1300 GWh in 2030[2].
- **Three catastrophic in-flight aircraft cargo fires between 2006 and 2011** where lithium ion batteries were suspected cause of factor.
- **30% state of charge (SOC) limitation for lithium ion cells**
- **The SAE G27 committee was established to develop a package performance standard** for lithium cells and batteries for cargo in air transportation.

1) EV Fires: Less Common But More Problematic?.

2) C. Pillot, "The Rechareable Battery Market and Main Trends 2020-2030," in *Batteries Event 2021*, Lyon, France, 2021.

Combustion analysis

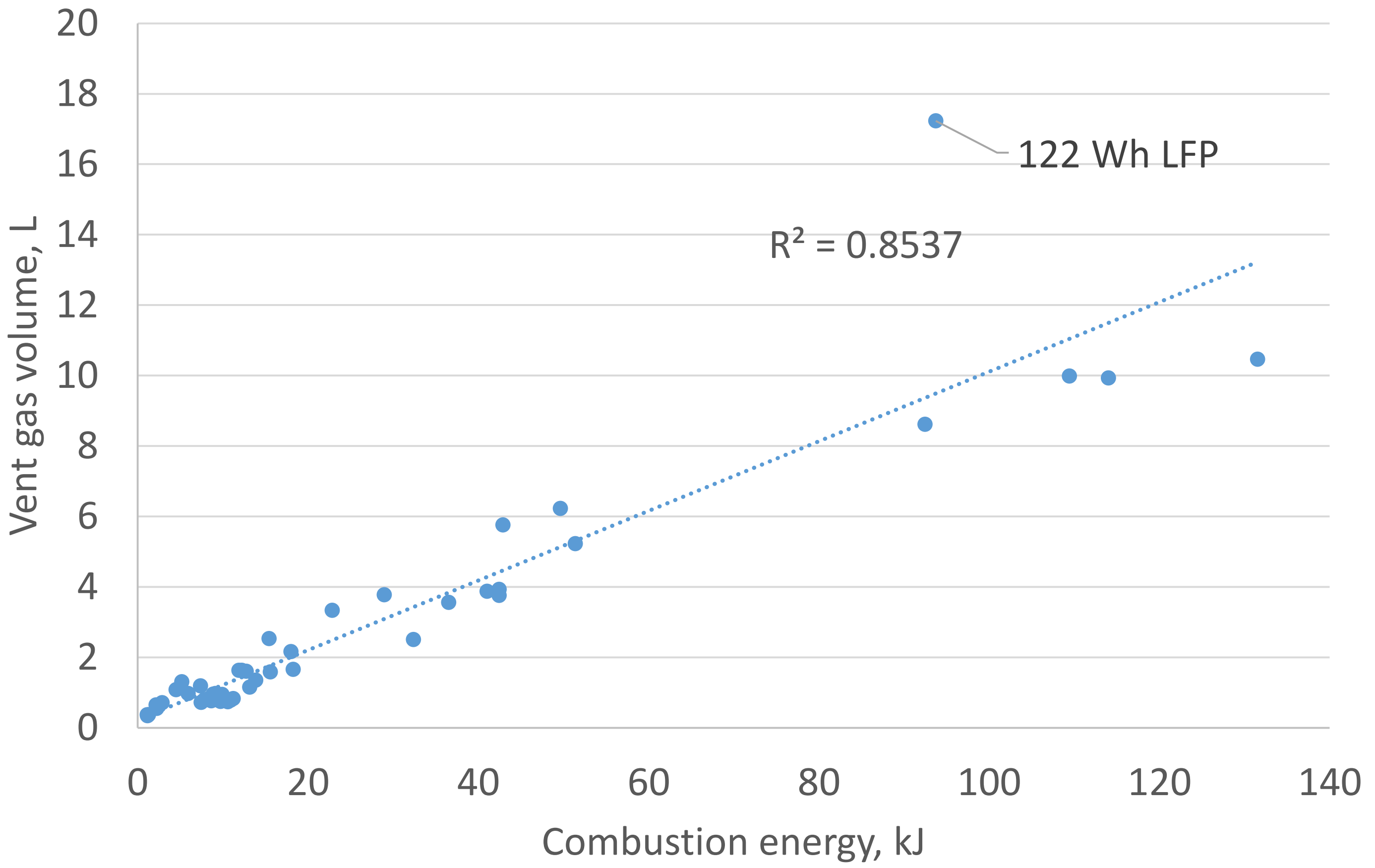




Forty-nine cells composed of ten different types were individually tested. Within this study, five cell chemistries, five SOCs, and five heating rates

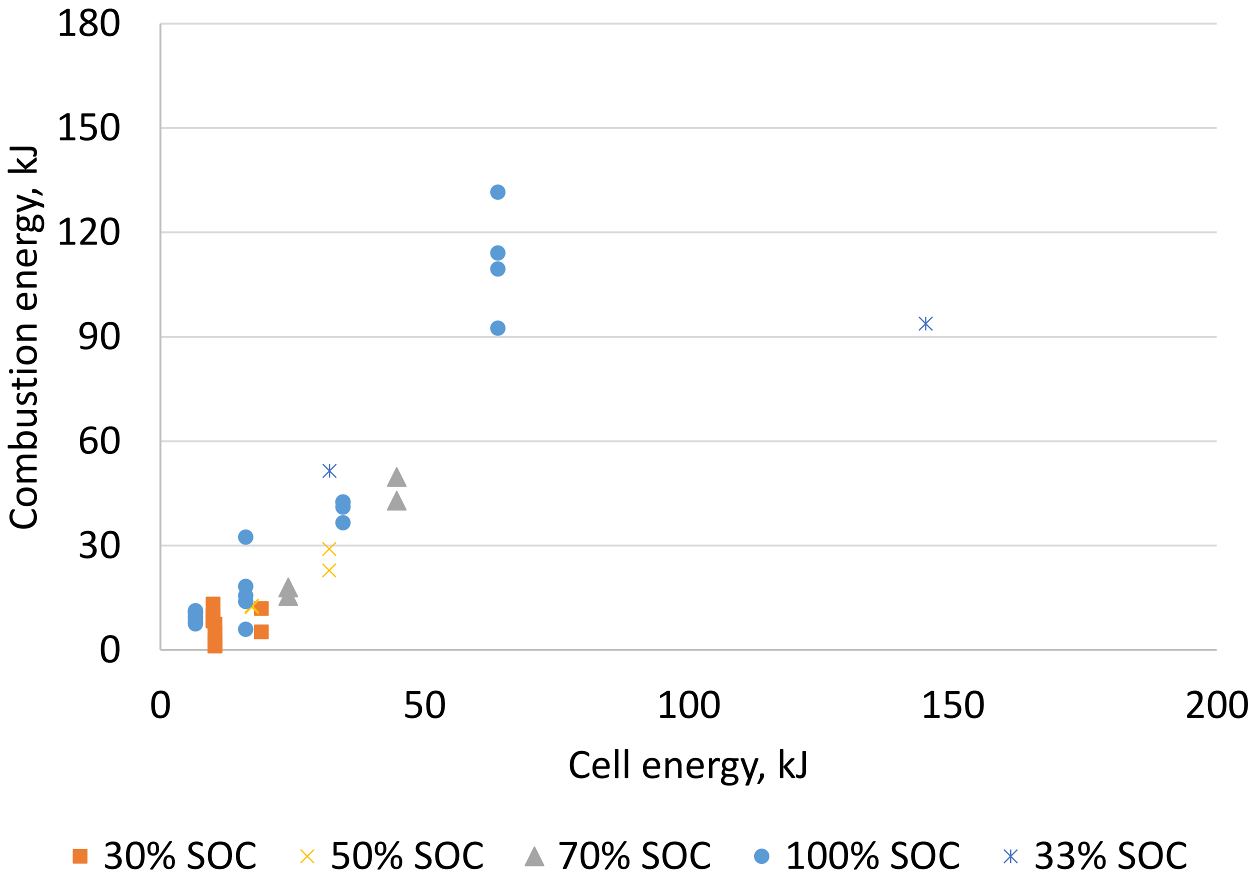
Vent gas volume and combustion energy

- The volume of vent gas is a good indicator of the combustion energy
- Non cobalt cell chemistries such as lithium iron phosphate (LFP) might produce less flammable gases and decrease the combustion energy



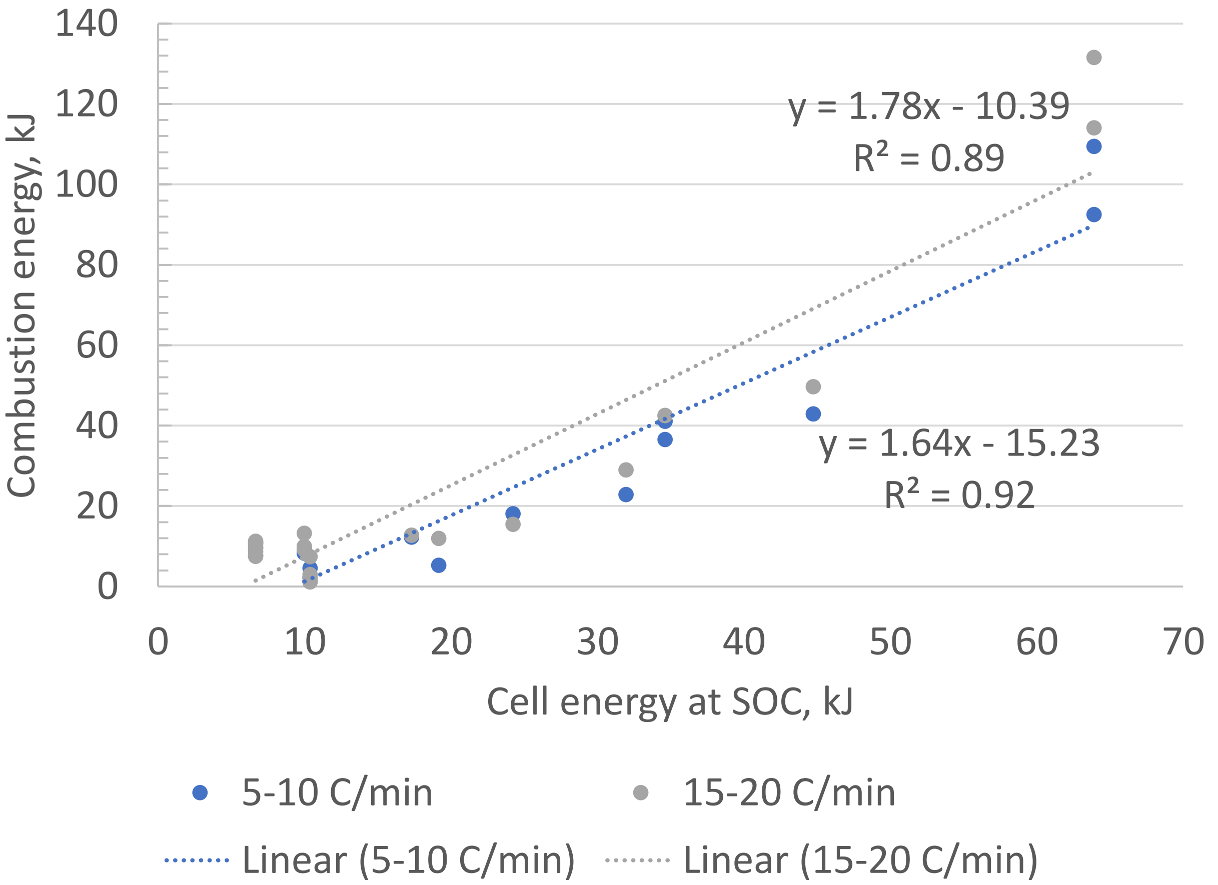
State of charge comparison

- Positive correlation between cell energy and combustion energy but no correlation between SOC and combustion energy.



Heating Rate Comparison

- Cells of similar energy at SOCs heated between 15 and 20 °C/min typically have greater combustion energy than cells heated between 5 and 10 °C/min.



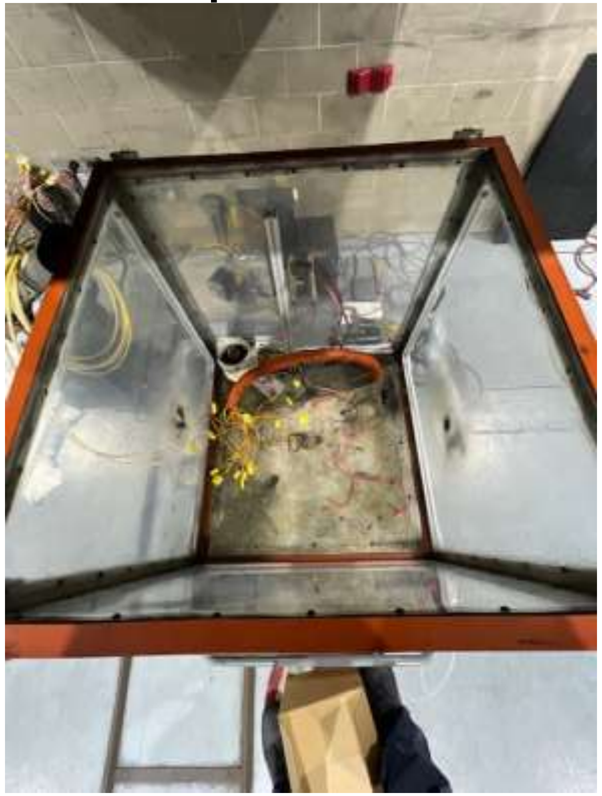
G27 test with large format cells

- 122 Wh lithium iron phosphate (LFP) at 33% SOC (40.2 Wh)
- 27 Wh nickel cobalt aluminum (NCA) at 33% SOC (8.9 Wh)
- 18650 sized cell **for size reference only**

G27 test chamber configuration

- 0.3 m^3 free space volume
- Fan at corner facing vertically
- Spark ignitor halfway between the top of the package and chamber ceiling

Top view

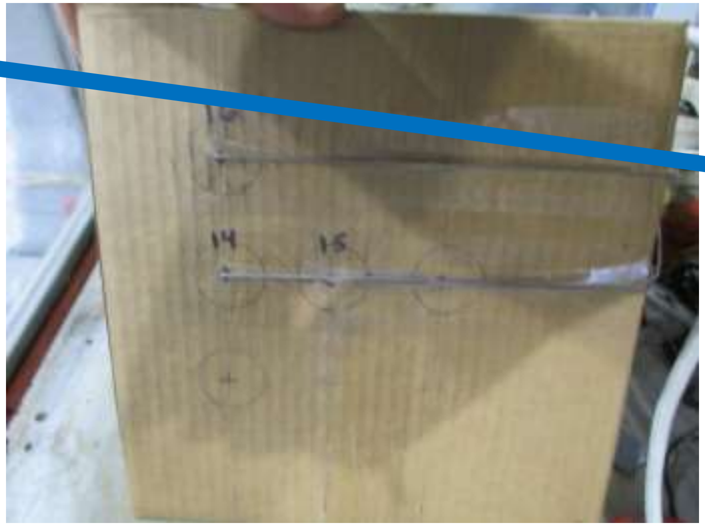


Side view

Test configuration 27 Wh cell

- 10” X 10” X 10” cardboard box
- One 735 W cartridge heater
- Thermocouples located at center of cell
- High density foam packaging
- Proportional-integral-derivative (PID) controller set at 20 °C/min

Side view



Interior view

Visual results 27 Wh cell

Top layer

Middle layer

Bottom layer

Visual results 27 Wh cell cont.

Charred interior

Visual results 27 Wh cell

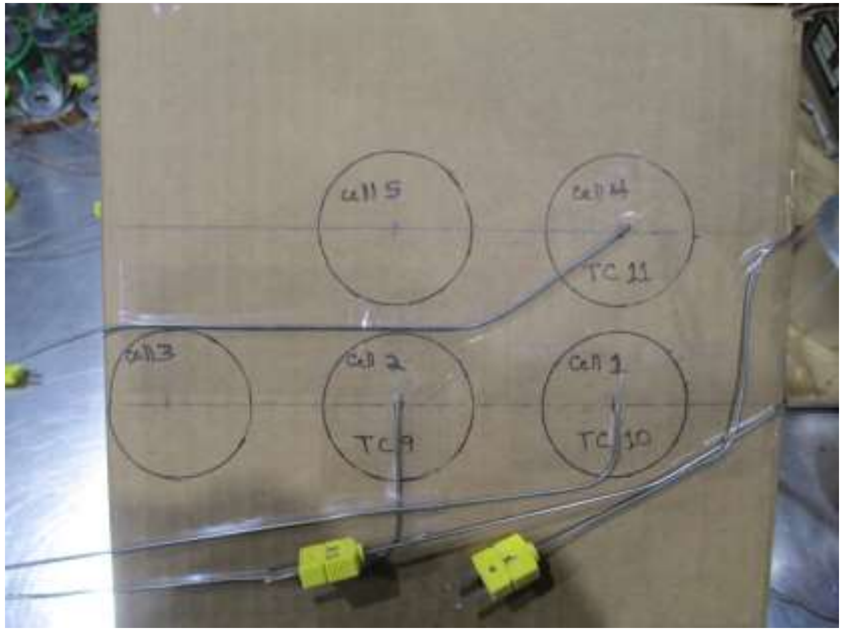
Visual observation for exiting flame

- Four second difference and visual observation is gone.
- Smoke is quickly mixed with fan.

Test configuration 122 Wh cell

- 10” X 10” X 10” cardboard box
- One 735 W cartridge heater
- Insulation between heater and wall
- Thermocouples located at center of cell
- Low density foam packaging
- PID set at 20 °C/min

Side view



Interior view

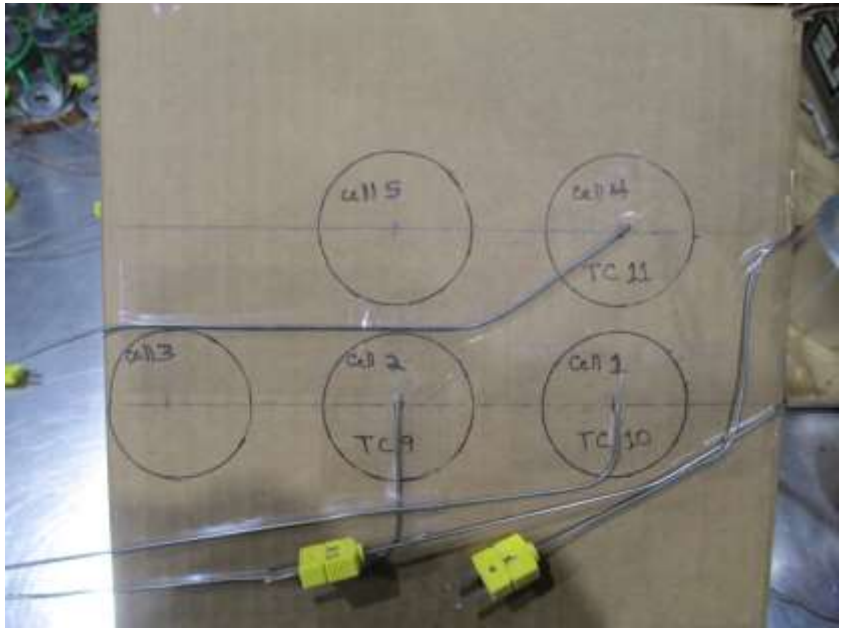
Visual results 122 Wh cell

- Cell reached 100 °C
- Foam melted
- Box caught on fire
- Test stopped before thermal runaway

Test configuration 122 Wh cell mod

- 10” X 10” X 10” cardboard box
- One 735 W cartridge heater
- Heater fully insulated
- Thermocouples located at center of cell
- Low density foam packaging
- PID set at 20 °C/min

Side view



Interior view

Visual results 122 Wh cell

- Two flashovers occurred after one cell went into thermal runaway and vented
- Fan visually mixed gases quickly
- Visual observation quickly disappears

Visual results 122 Wh cell

Top layer

Bottom layer

Visual results 122 Wh cell cont.

Charred exterior

Findings and suggestions

- **Cell energy rather than SOC may be an indicator a cell's fire hazard**
  - Positive correlation between cell energy and combustion energy but no correlation between SOC and combustion energy.
- **The combustion energy from a single cell can critically damage an airplane**
  - A single large cell (122 Wh LFP) that undergoes thermal runaway at 33%SOC can fail the G27 test with two flashovers and could possibly dislodge a cargo compartment pressure relief panel
- **Packing material is important for risk mitigation**
  - Some battery packing material have a low ignition temperature and will aid in propagation
  - Possible to suppress propagation of lithium cells with packing material (ie a wet sponge[3] or fire retardant foam)

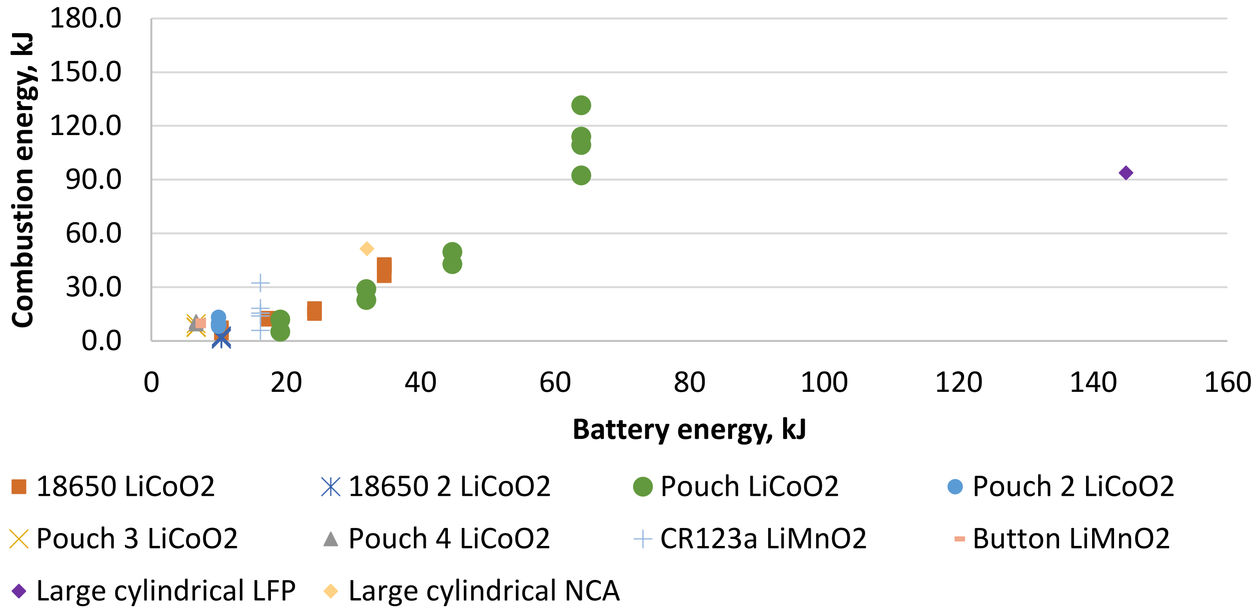
3) On a method to mitigate thermal runaway and propagation in packages of lithium ion batteries J.G. Quintiere

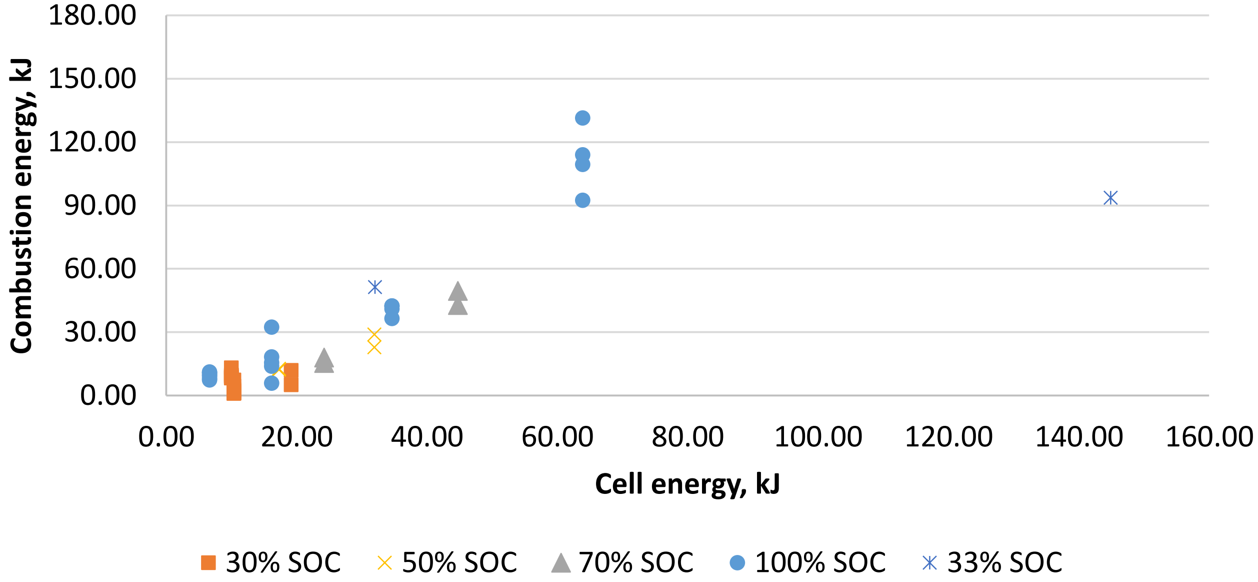
Questions and answers

- **Matthew Karp**
- **Matthew.Karp@faa.gov**

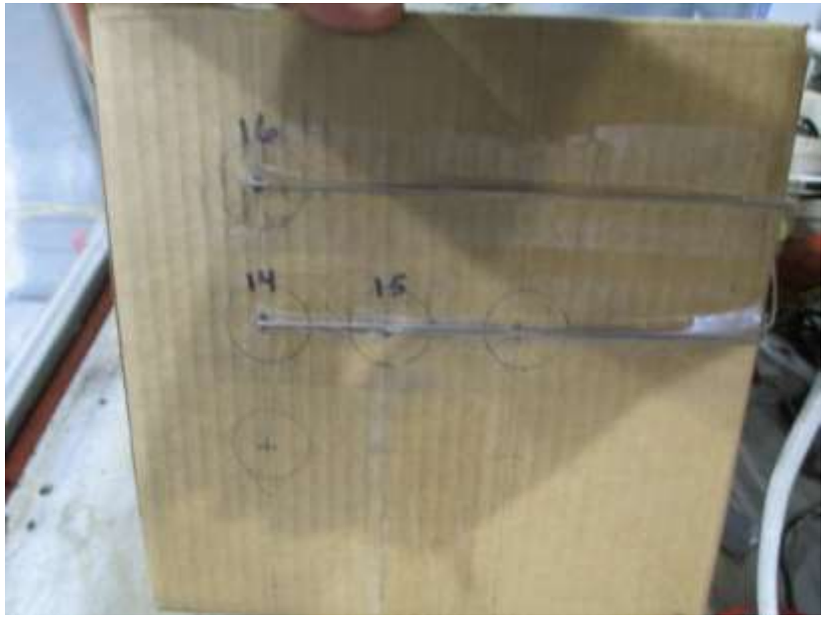
Findings

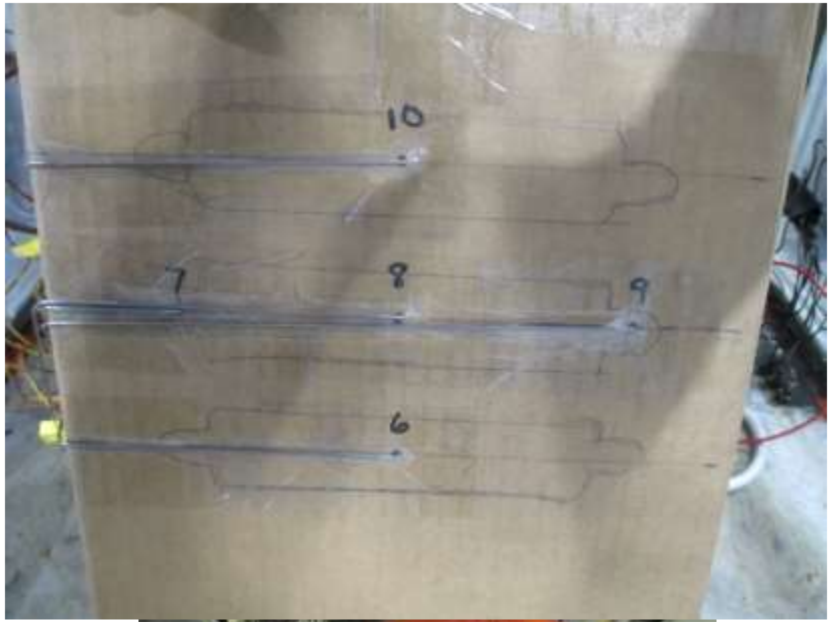
- Positive correlation between cell energy and combustion energy but no correlation between SOC and combustion energy.
- The volume of vent gas is a good indicator of the combustion energy.
- Cells of similar energy at SOCs heated between 15 and 20 °C/min typically have greater combustion energy than cells heated between 5 and 10 °C/min.
- The vent gases consist of 18.2±7.2%vol hydrogen.





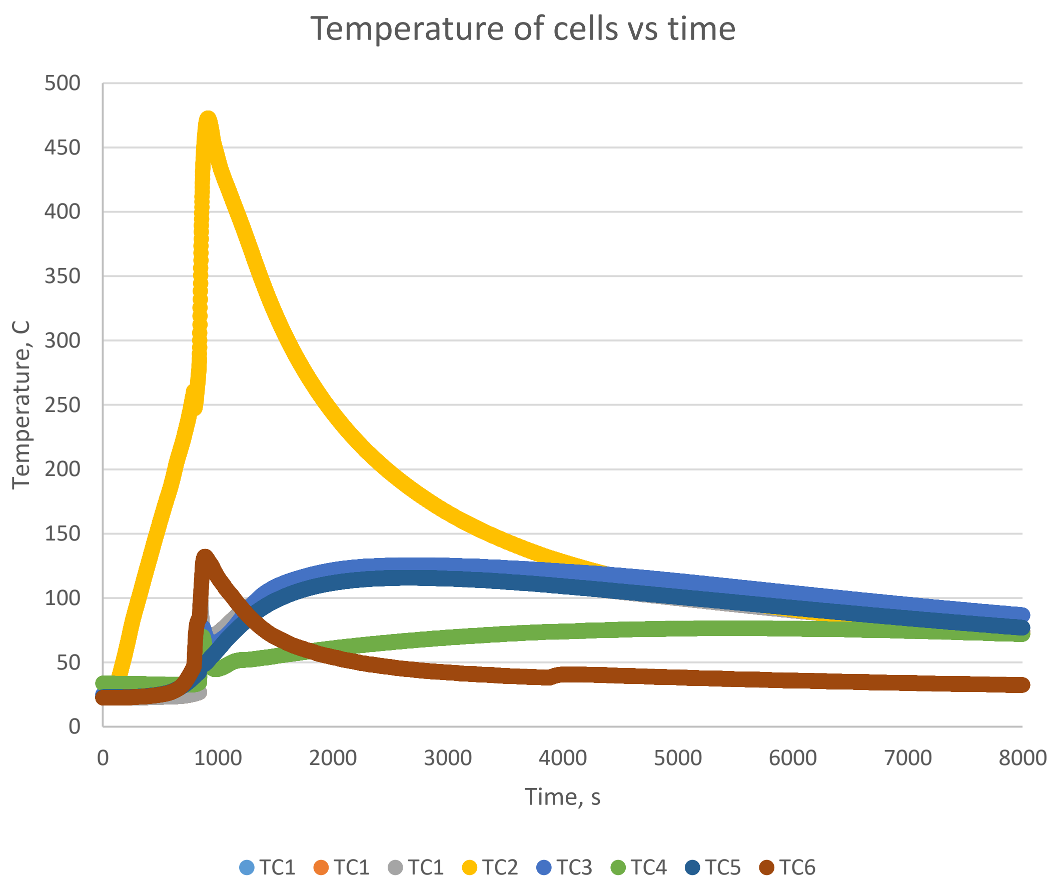
Test configuration 27 Wh cell





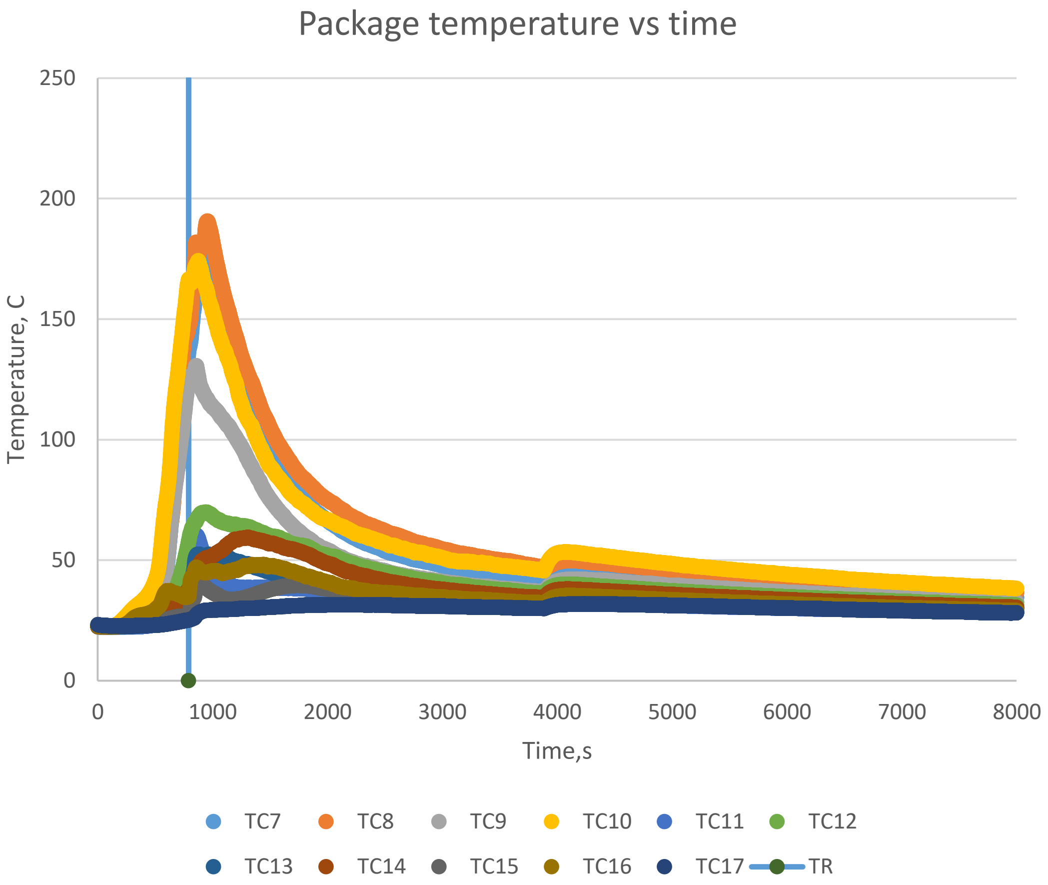
Cell case temperature

- Heating rate – 20C/min
- Onset temperature – 250C
- Max temperature initiating cell – 472C
- Max temperature neighboring cell – 132C



Package surface temperature

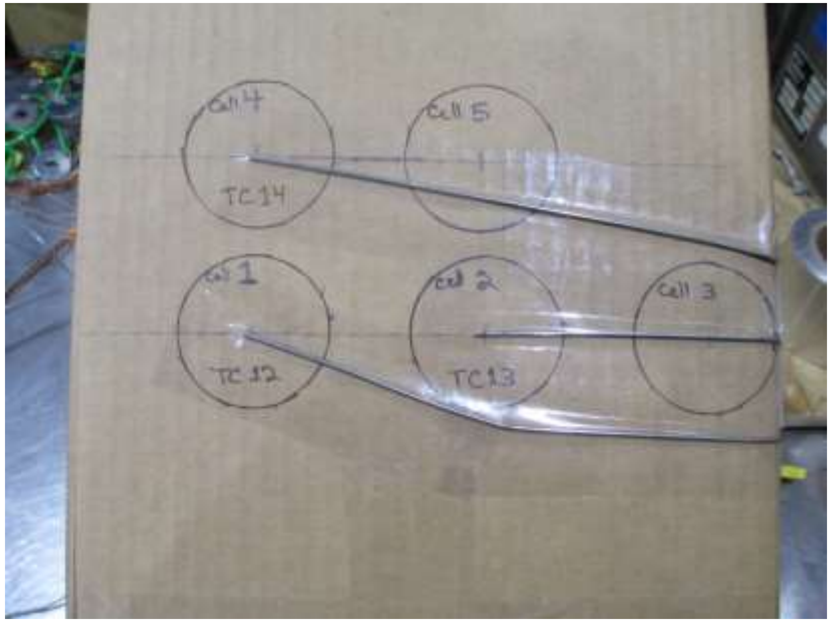
- Max package temperature – 190C
- Max package temperature rise after thermal runaway – 59C

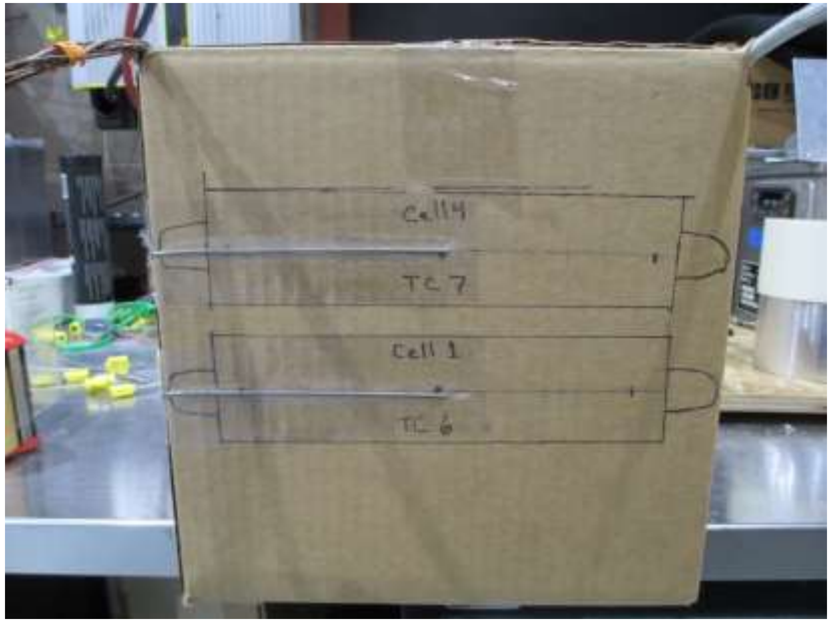


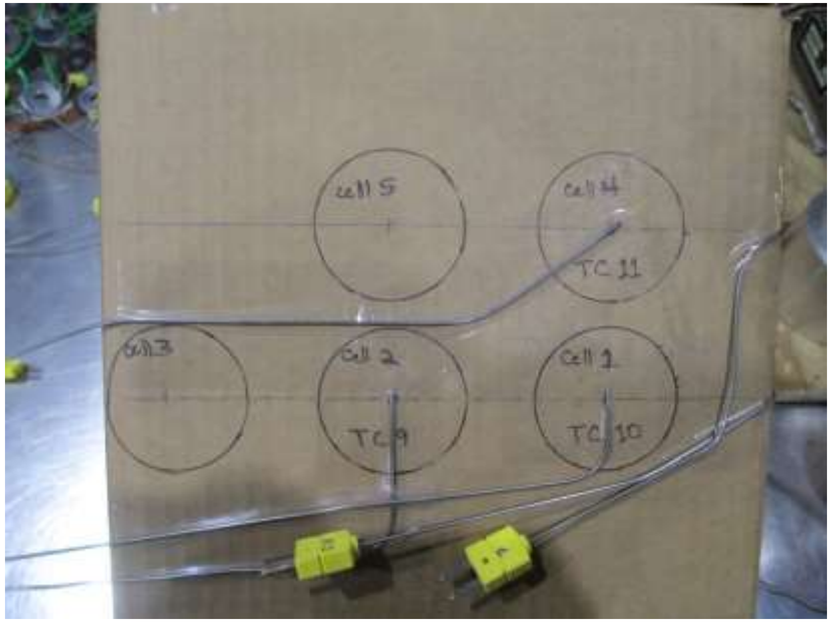
Findings from 27 Wh testing

- It requires a powerful heater to initiate thermal runaway of large format cells
- The walls get temperatures exceed 150C before thermal runaway initiated
- Visual observation for flames exiting package is impossible
- 200C is too low of a thermal runaway initiating threshold for some cells

Test configuration 122 Wh cell

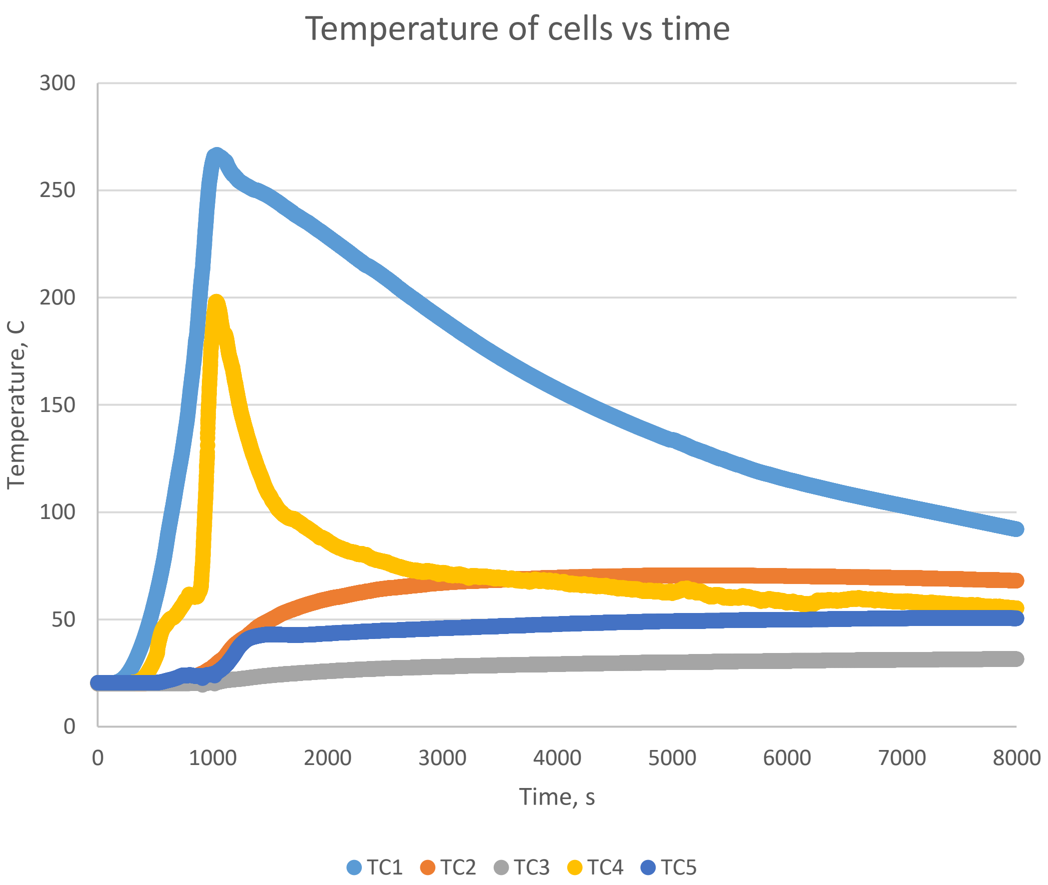






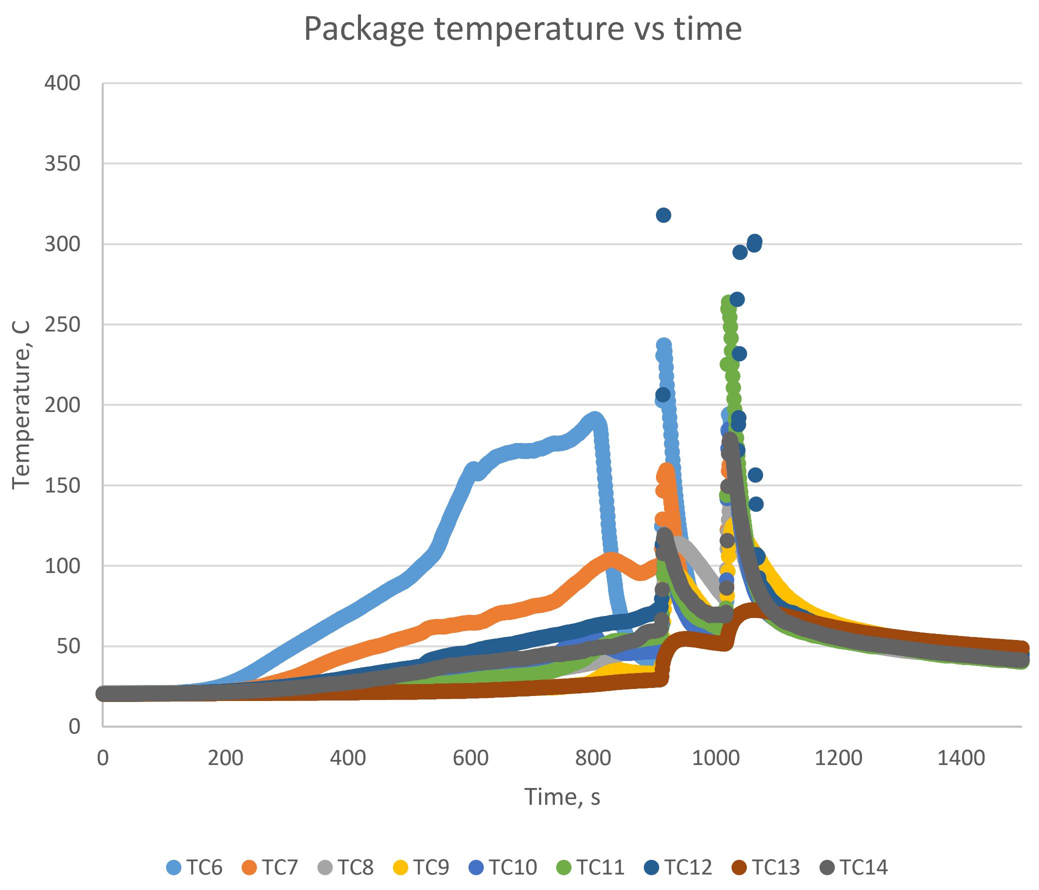
Cell case temperature

- Heating rate – 20C/min
- Onset temperature – 20C
- Max temperature initiating cell – 266C
- Max temperature neighboring cell – 198C
- Initiating cell is slow to cool
- The neighboring cell fell onto initiating cell after packing material melted
- Maybe came close to propagating



Package surface temperature

- Max package temperature – 263C
- Max package temperature rise after thermal runaway – 227C (over 150C for 9 seconds)



Federal Aviation Administration

Findings from 122 Wh testing

- The tested low density foam material melts and ignites at a low temperature
- Low hanging fruit for improving shipping safety is to specify packing materials
- More insulation is needed