Characterizing and Scaling Thermal Runaway

Yesaswi Chilamkurti, PhD
Battery R&D

BETA TECHNOLOGIES

About BETA

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At a Glance

BETA is an **electric aerospace company** developing aircraft and infrastructure to enable customers to complete all-electric, zero-carbon, air cargo, logistics, medical transport, and passenger missions.

Headquartered in Burlington, Vermont

Founded in 2017

Team of 1000+ employees

A Versatile Platform

ALIA VTOL - A250

All-electric vertical takeoff & landing aircraft for urban and rural routes

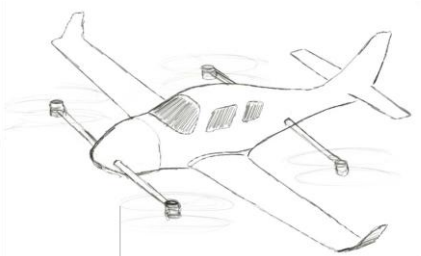
ALIA CTOL - CX300

All-electric, conventional takeoff & landing airplane for airport-to-airport missions

History

2017

BETA founded, First Vertical Flight (AVA)



2020

First Flight of ALIA CTOL

2022

First Flight of ALIA VTOL

2024

First piloted full transition

2025

First aircraft off the production line

4 CX300 Built
1 A250 Built
Multiple CX300 & A250 In Work

Production Facility

188,500 square foot facility in South Burlington, Vermont is capable of producing up to 300 aircraft per year.

The floor is optimized to move aircraft in a safe, climate-controlled, logical manner, and is designed with the future in mind.

BETA is already producing aircraft and chargers at this facility, rolling production-intent aircraft and installation-ready chargers off the line.

Battery Development & Test Center

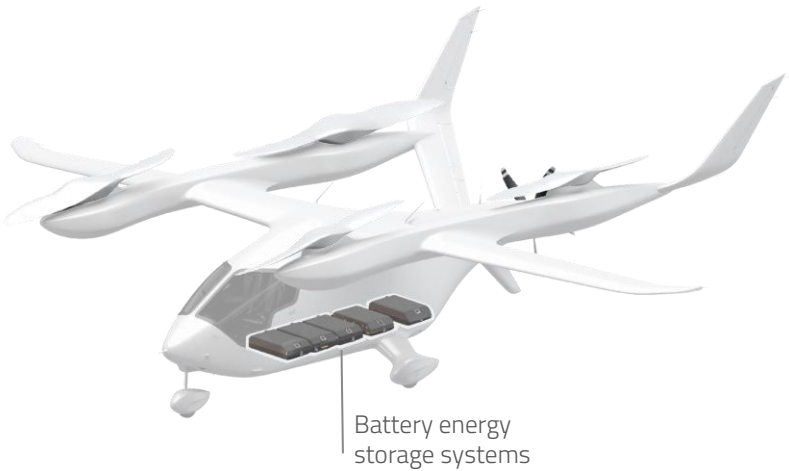
~40,000 sq ft facility gives BETA state-of-the-art test capability for nearly all certification credit tests.

Environmental, electrical function and integration, lifecycle durability, and thermal runaway safety testing all under one roof

Allows BETA to understand, improve, and verify our current aircraft batteries and equipment now and into the future.

Battery R&D

Overview



Nameplate Energy	45 kWh
Voltage	832 V max
Peak Power	400+ kW
Continuous Power*	115 kW
Features	Liquid Cooling for Fast Recharge, Internal BMS, Mid Pack Fuse, Contactors
Safety	Subpack Thermal Runaway Containment, Redundant Fire Detection

The energy storage system that powers the aircraft is composed of multiple battery packs connected in parallel through a distribution system designed to provide safety and redundancy for all power requirements.

Approach to Thermal Runaway Safety

1. Start with highest quality cells
    - Conformity inspections
    - Built in safety features
2. Create a battery that operates safely
    - Design out Thermal Runaway triggers from single point failures
    - Add protections for abuse
    - Ensure the aircraft system uses the batteries in a safe and effective window
3. Monitor health of the battery
    - Collect state information
    - Add reliably detection systems
4. Add Thermal Runaway Protections
    - Against nominal/non-nominal cell failures, multi-point failures and unknown unknown failures

Battery R&D

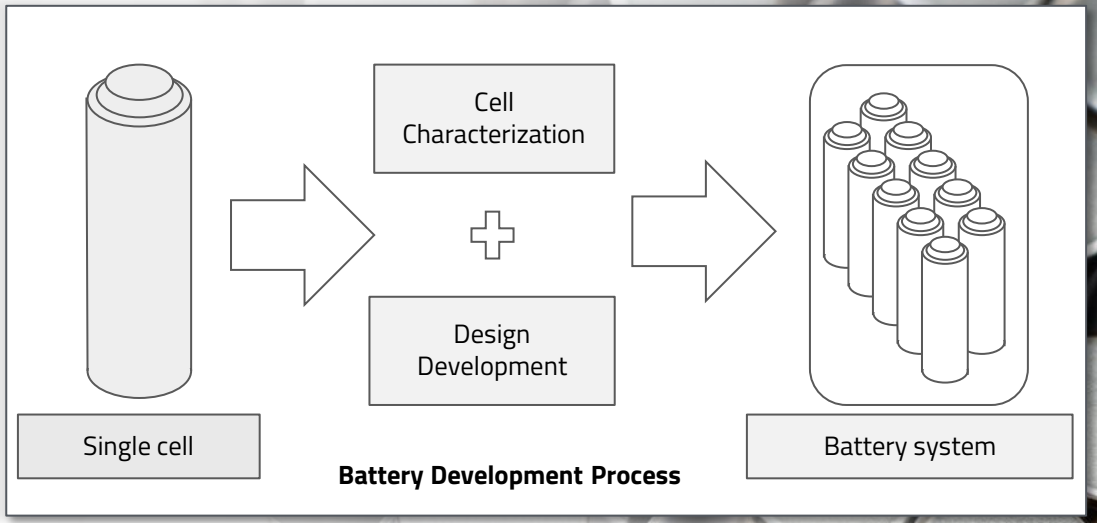
Cell Developments

Battery cell technology is currently experiencing a period of unprecedented growth. Specific power and energy metrics are rapidly increasing, every year

In electric aircraft, increases in cell performance promise increased range, capability, and longer cycle life for our customers

Our goal is to upgrade aircraft over time with drop-in battery replacements with minimal design development effort

How can we efficiently understand how a battery pack thermal runaway mitigation design will be affected by new cells?



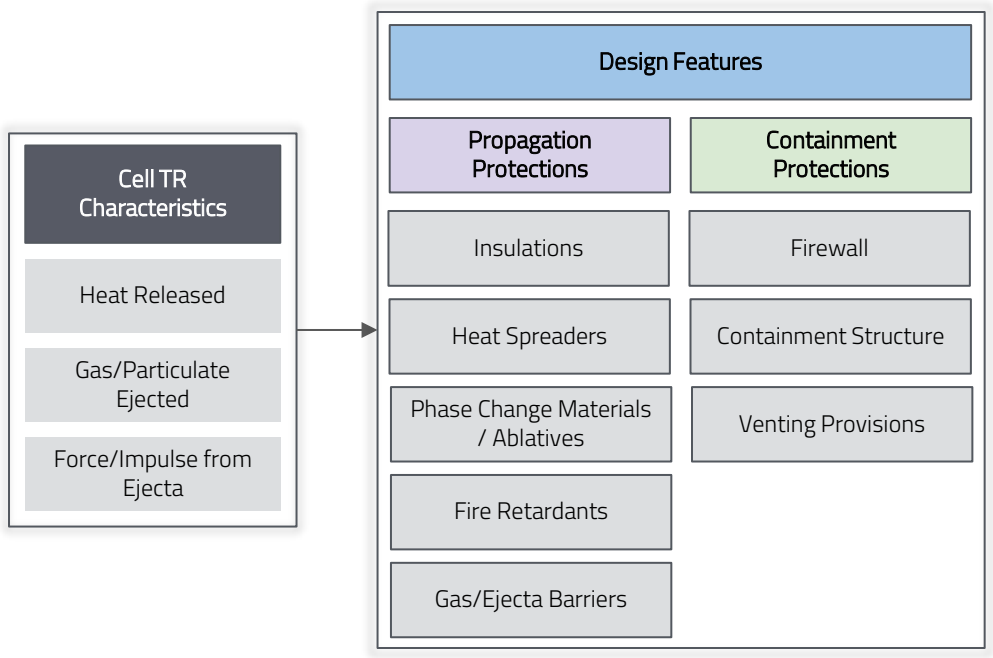
Thermal Runaway Safety

Thermal Runaway protections strategies can be classified in to

- **Propagation** Protections
- **Containment** Protections

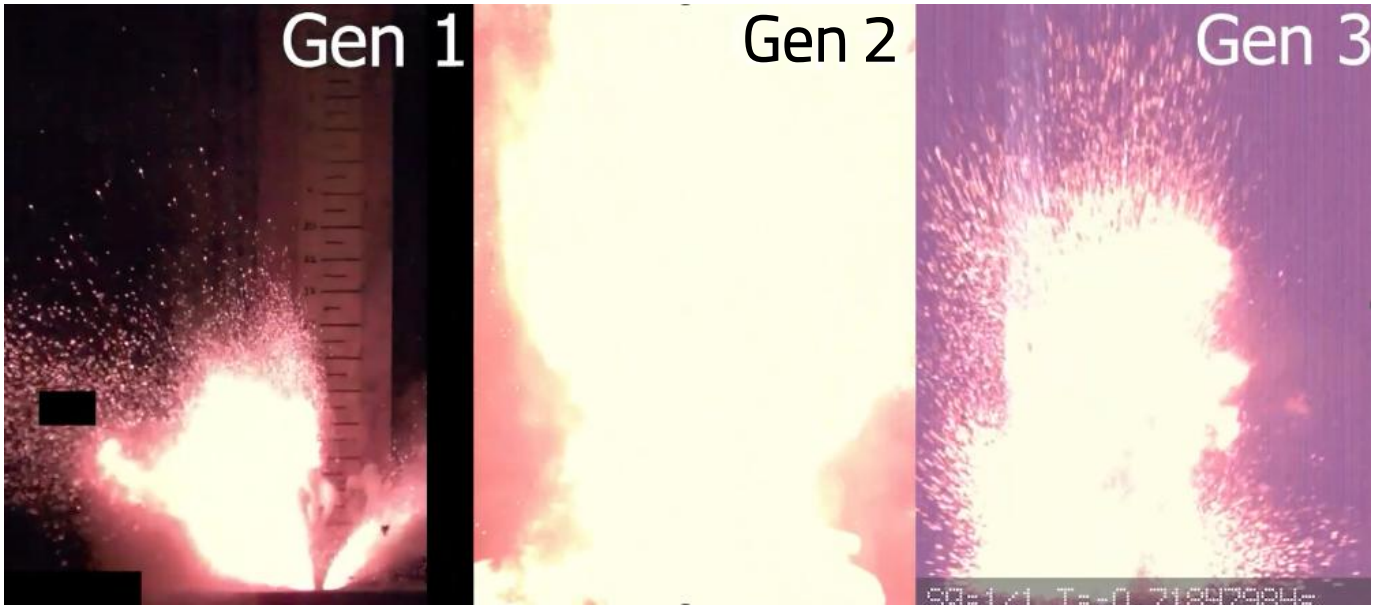
Theoretically, cell level characteristics should be able to provide the necessary information to optimize system-level design features

So, let's run this exercise on three generations of cells, with increasing capacity, but in the same form factor. And observe if thermal runaway behavior scales up in a predictable manner – from cells to the system



Single Cell Thermal Runaway Characterization

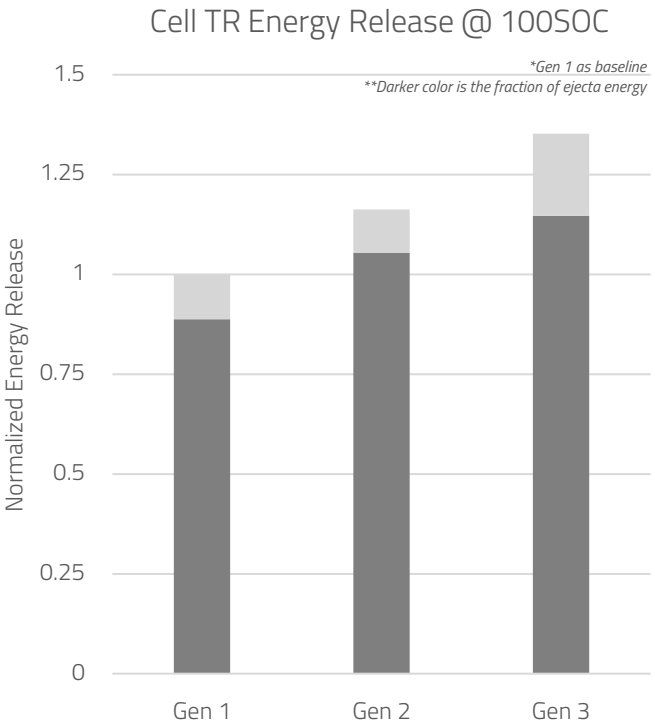
Failure Modes

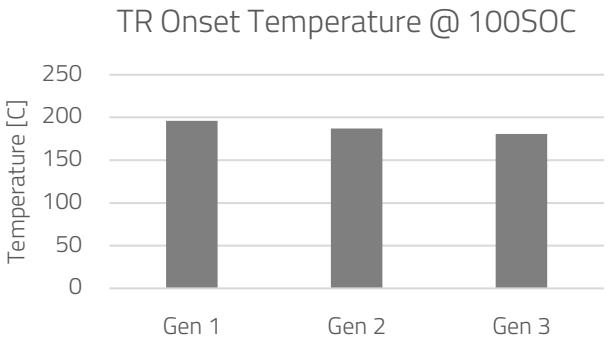


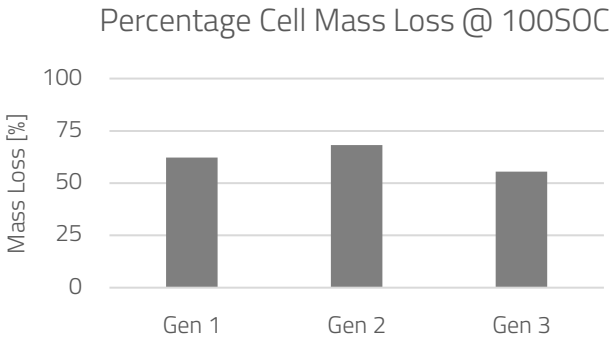
Gen 2 is more explosive and instantaneous than Gen 1 and Gen 3. The other two have a long flare-like failure

Gen 3 has more gas volume

Fractional Thermal Runaway Calorimetry (FTRC)



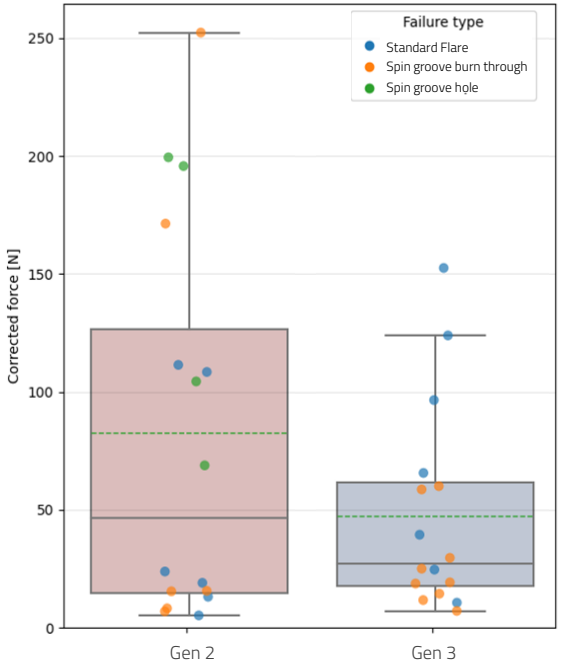


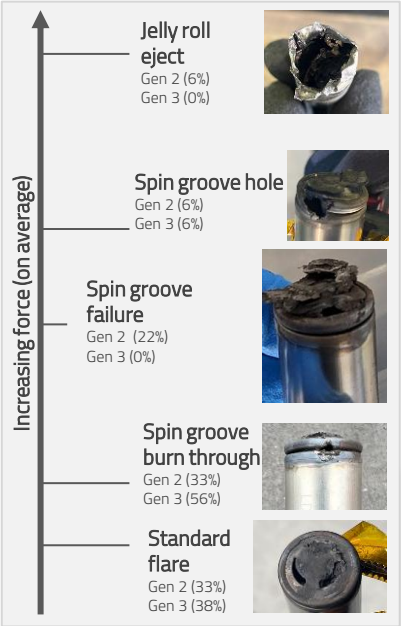


Energy release increased by 15% with each generation, while safety onset temperatures fell by an average of 4%

No discernable trend in mass loss

Ejecta Force/Impulse





Gen 2 had higher impact force than Gen 3

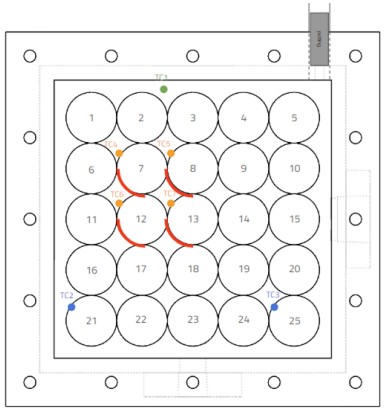
Gen 3 had more consistent failure modes than Gen 2

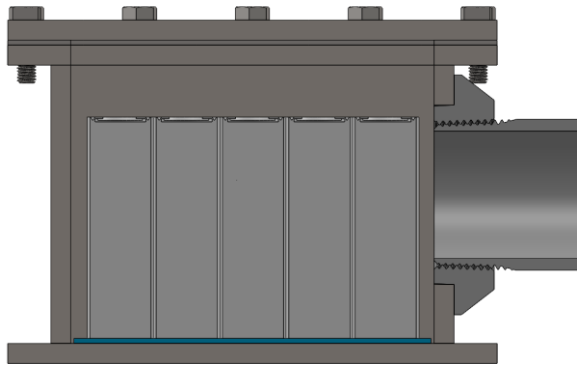
Observable trend between failure modes and force/impulse

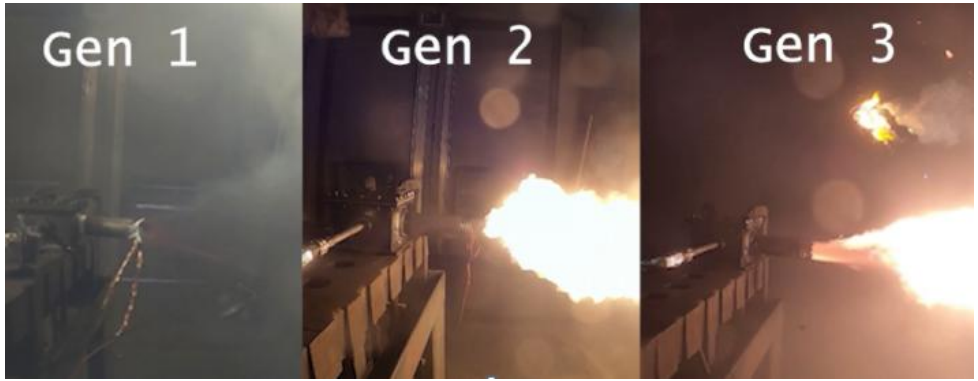
***Hamza Arshad et al 2025 Meet. Abstr. MA2025-01 639*

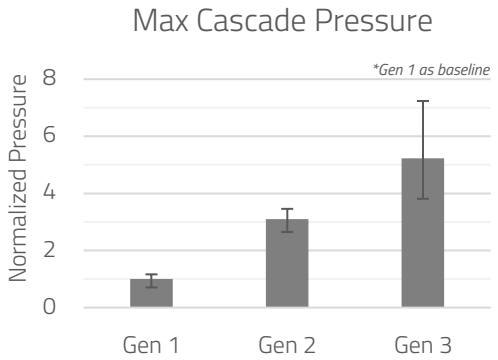
Thermal Runaway Cascade Characterization

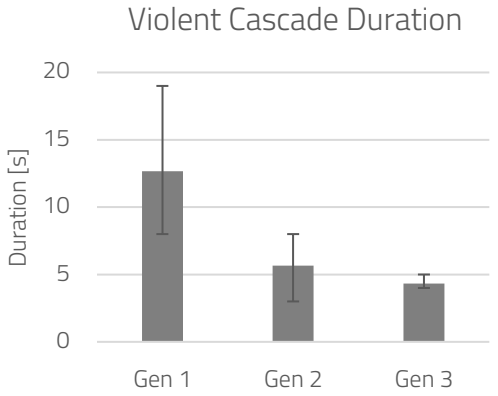
25 Cell Study









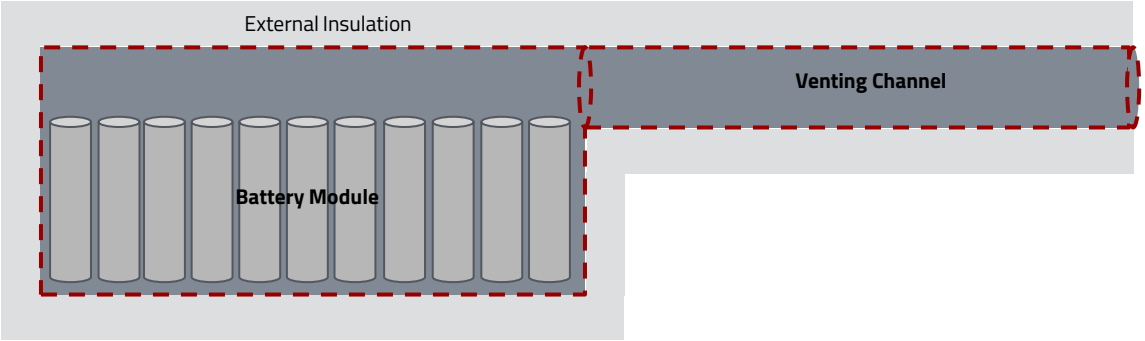


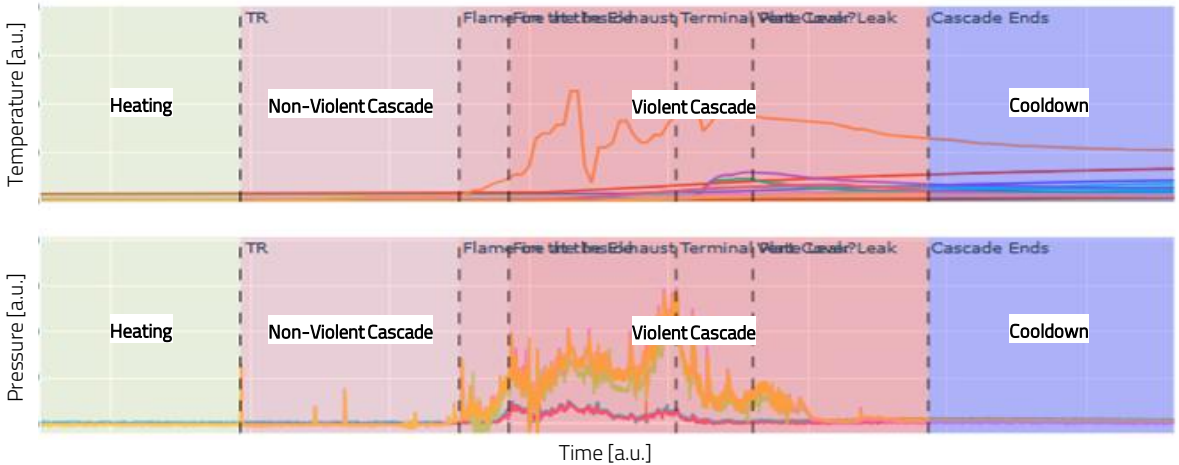
Modified UL2596 test to understand containment behaviour of a cell, with no propagation protections installed

Non-linear increase in pressures with each generation; Gen 3 pressure is 5x of Gen 1

Observable correlation between cascade duration and pressure

System Level Tests



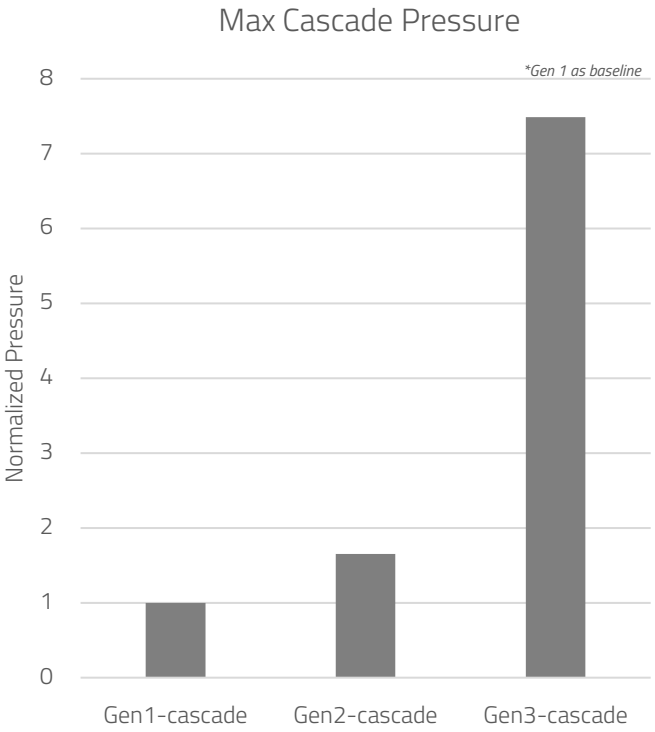


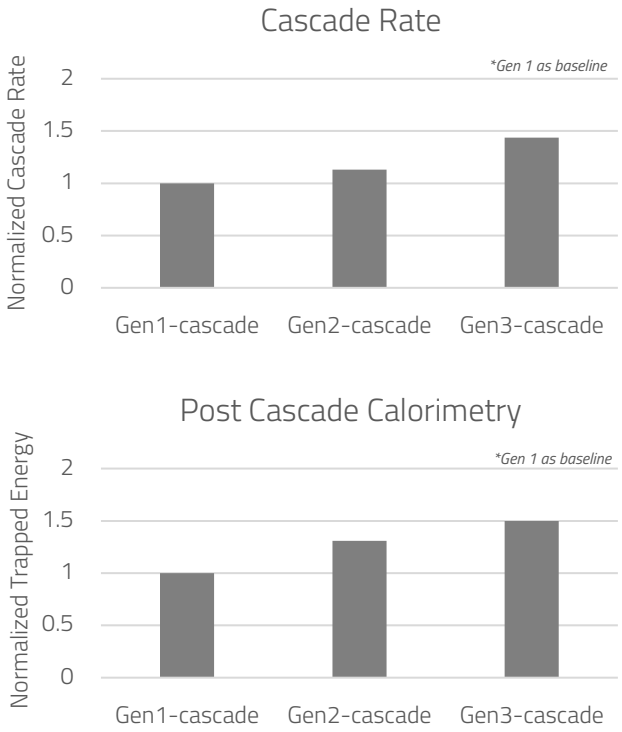
Cascade initiated by forcing enough cells to defeat propagation protections in the design

Instrumentation
- Thermocouples
- Pressure Sensors
- Audio/Video Recorders
- Infrared Video
- Pre/Post Mass

Derived Metrics
- Cascade Rate
- Phases of Cascade
- Ejecta Flow Rate
- Post-Cascade Energy Trapped
- Exhaust Ignition Conditions

System Level Tests





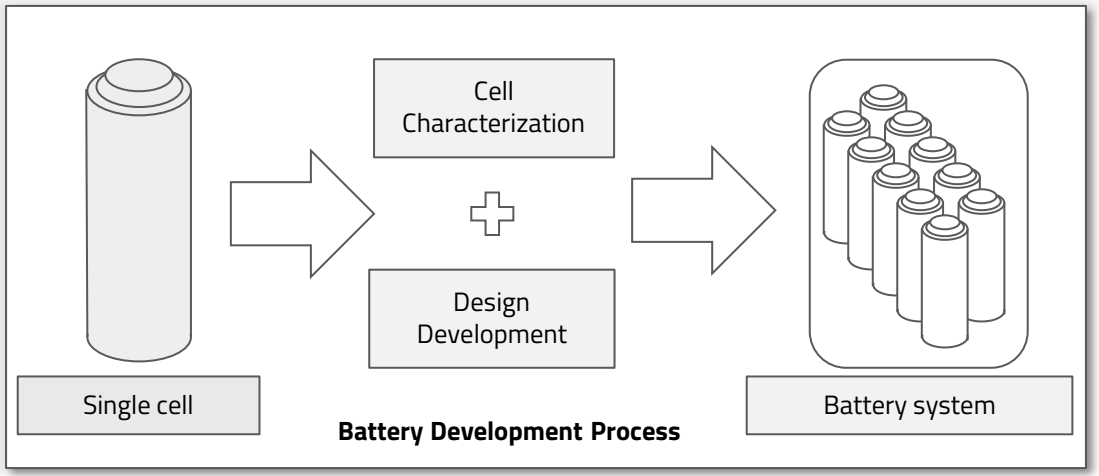
65% increase of pressure from Gen 1 to Gen 2. 350% increase from Gen 2 to Gen 3

Cascade rate increased with each cell, but not as drastic as pressures

Energy trapped also increased similarly among each generation

The scale-up from single cell to system

Can we drop-in new cells into the same design?

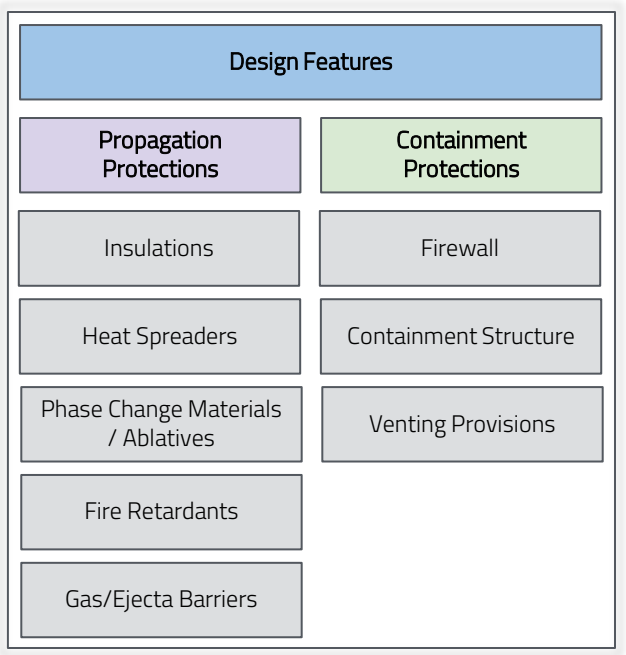


Single cell TR behavior indicated 15% energy release increase with each generation

But at a system level, even with all the other TR protections in place, we observed the behaviour being well outside the design point

So, there's a potential design development burden associated with it

Let’s do a quick design development exercise



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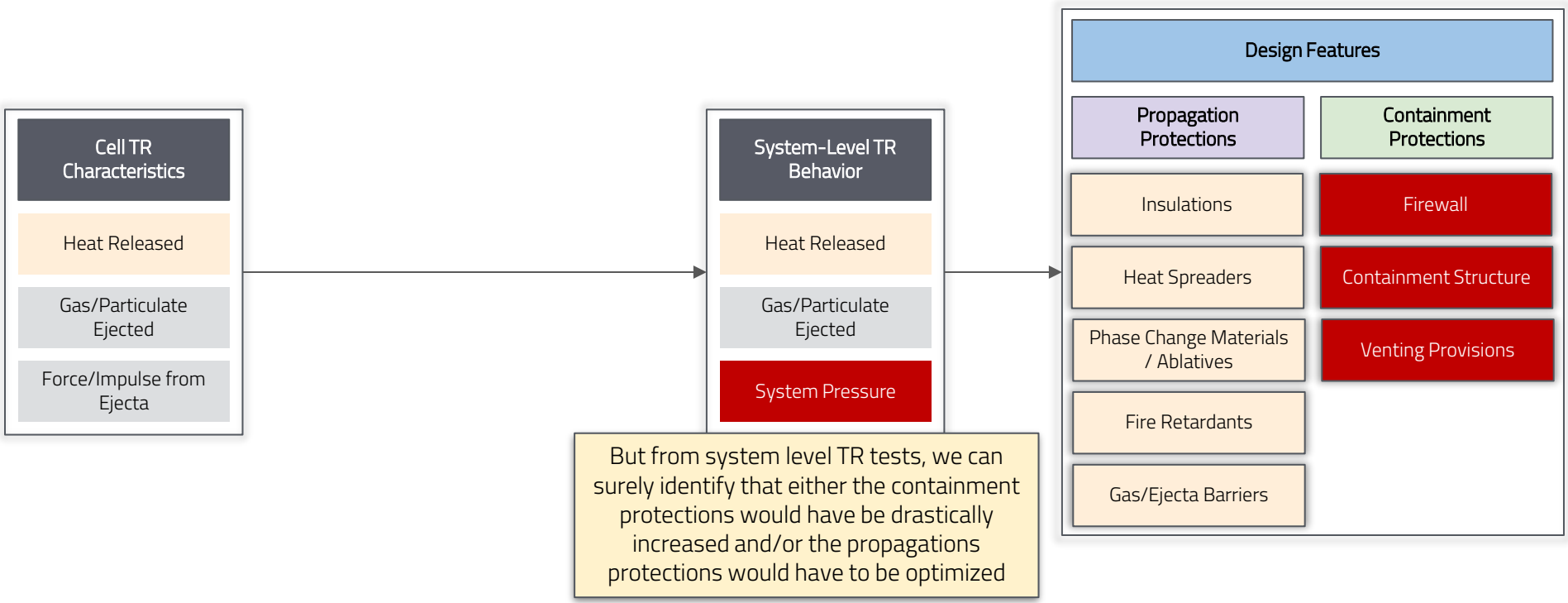

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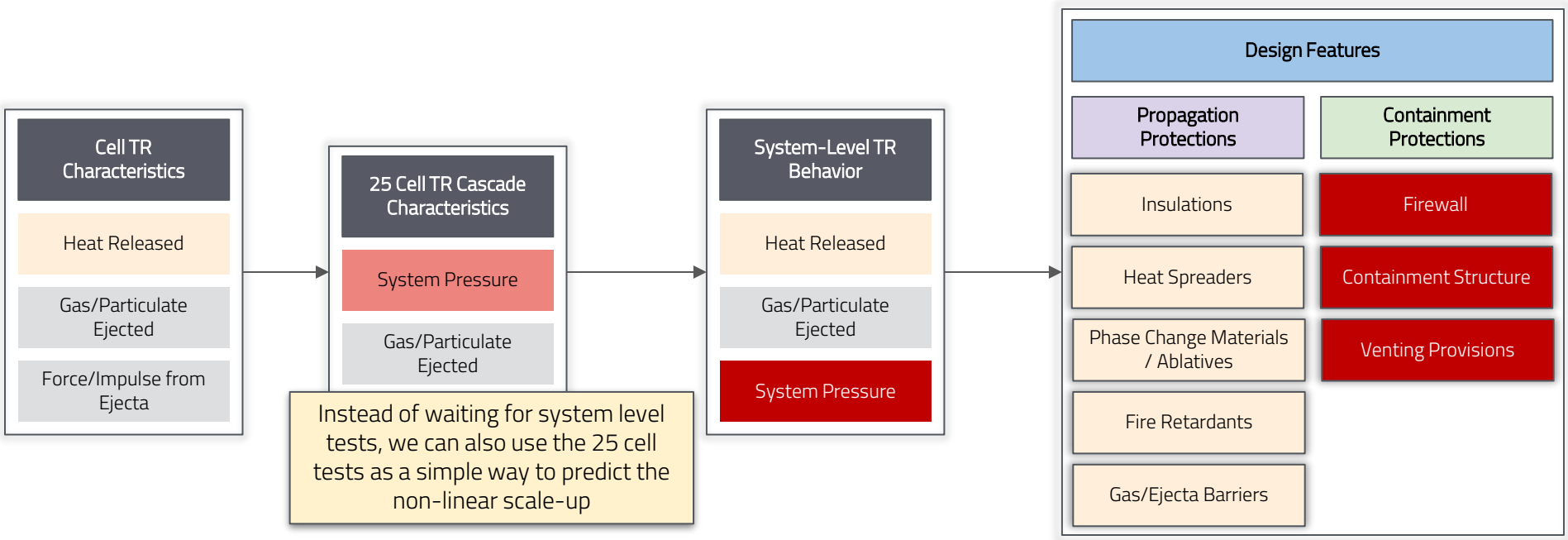
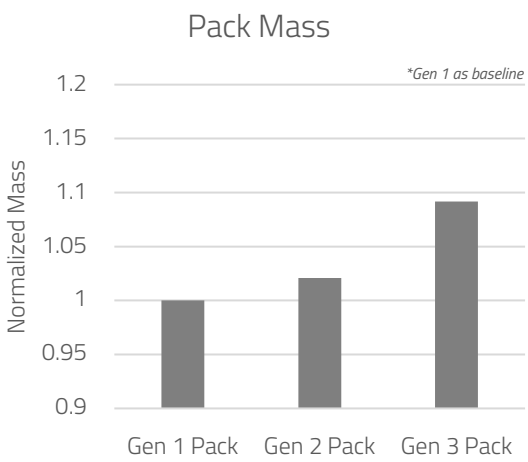
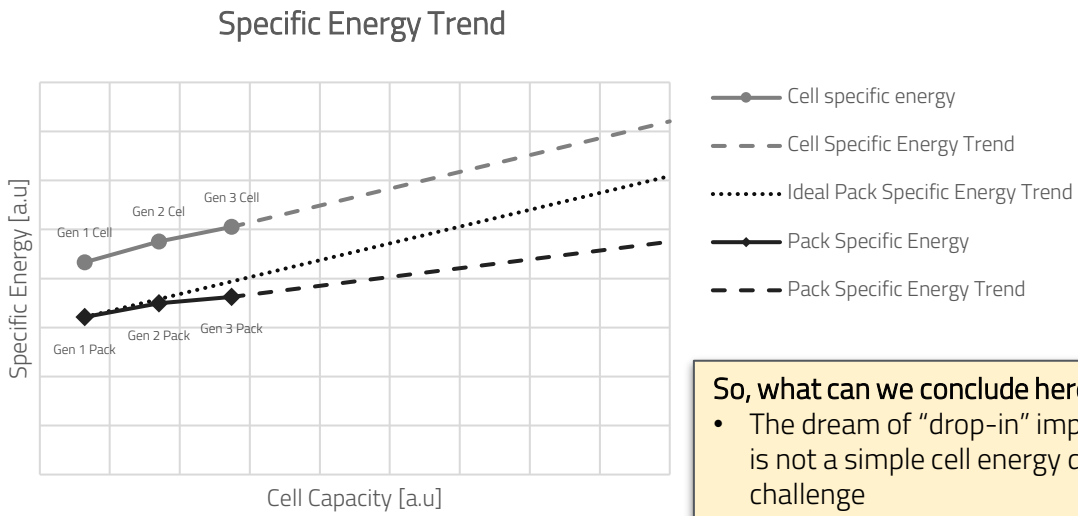


Can we truly tap into cell energy density improvements?





Because of an increased TR intensity with each cell, we see an increase in pack mass

Ideally pack Specific Energy trend should increase at the same rate as Cell Specific Energy

But the gap between Cell and pack specific energy could increasing over generations

So, what can we conclude here?

- The dream of "drop-in" improvements is not a simple cell energy density challenge
- The scale-up from cell to system is highly non-linear, so rigorous testing is essential early in the design development process
- But as we gain a better understanding of the scale-up, we can truly improve the system level metrics on par with cell level metrics

Questions?

Yesaswi Chilamkurti, PhD | ychilamkurti@beta.team | beta.team/careers