CHARGED VIRTUAL CONFERENCE
EV ENGINEERING

Navigating the Challenges in Battery Safety Testing For Materials Development and the Parallels With the Catalytic Converter

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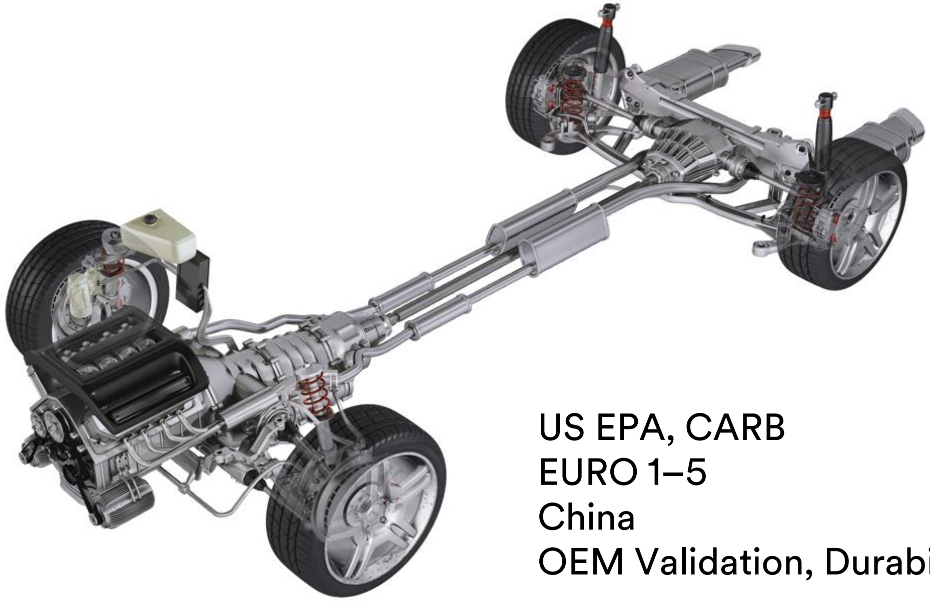
Brandon Bartling and Mark Fairbanks

Parallels Between Emission Device Testing and Battery Pack Testing

Regulated global standards and validation protocols are based on complete systems

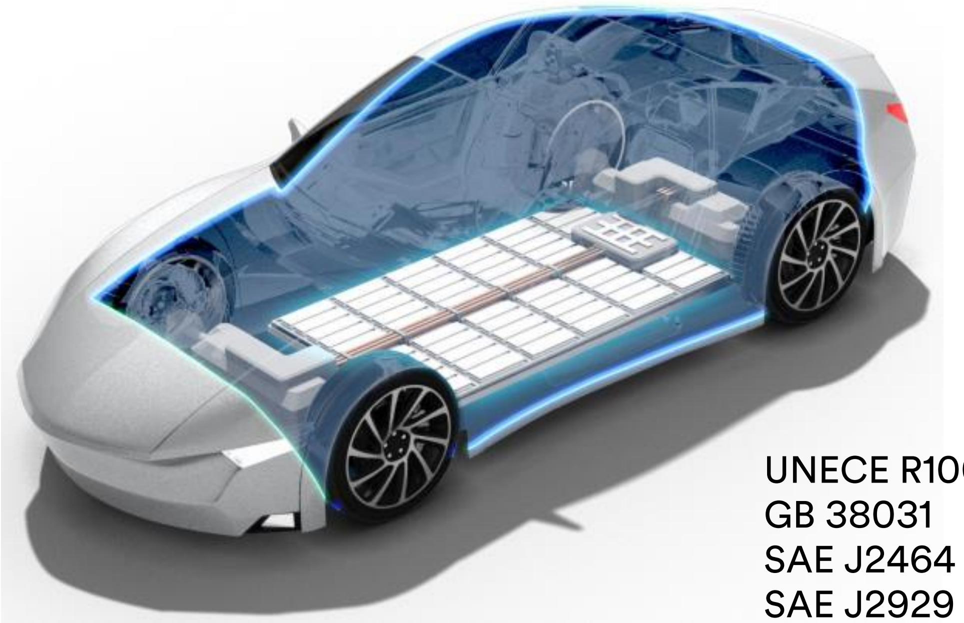
- Slow
- Costly
- Unrealistic for materials development use

ICE/Emission System



US EPA, CARB
EURO 1–5
China
OEM Validation, Durability

EV/Battery System

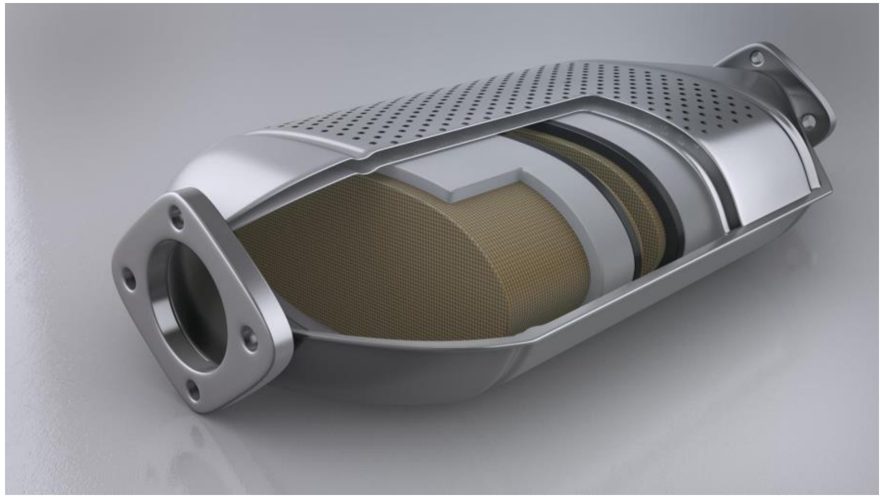


UNECE R100
GB 38031
SAE J2464
SAE J2929

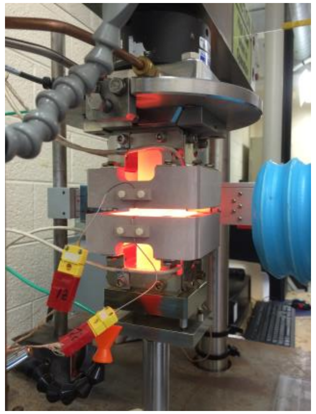
Parallels Between Emission Device Testing and Battery Pack Testing

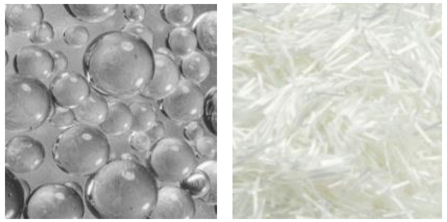
Early emission component durability challenges...

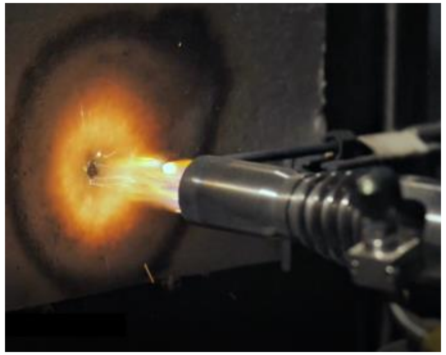
- Industry recognized gap in testing validation rigor
- Recognition that current tests weren't effective – not reproducing field failure modes
- Recognition the industry didn't understand material failure modes
- Collection of field data showed real-life conditions
- Equipment that made alternate testing possible
- Application specific test samples (availability)
- Need to produce tests results in shorter amount of time



Parallels Between Emission Device Testing and Battery Pack Testing

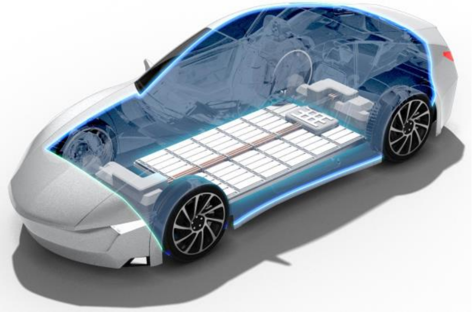






Materials and component development

- Screening of materials
- Test methods that mimic real life situations
- Unspecific to individual OEM/Tier requirements
- Correlate test data to real life applications



Parallels Between Emission Device Testing and Battery Pack Testing

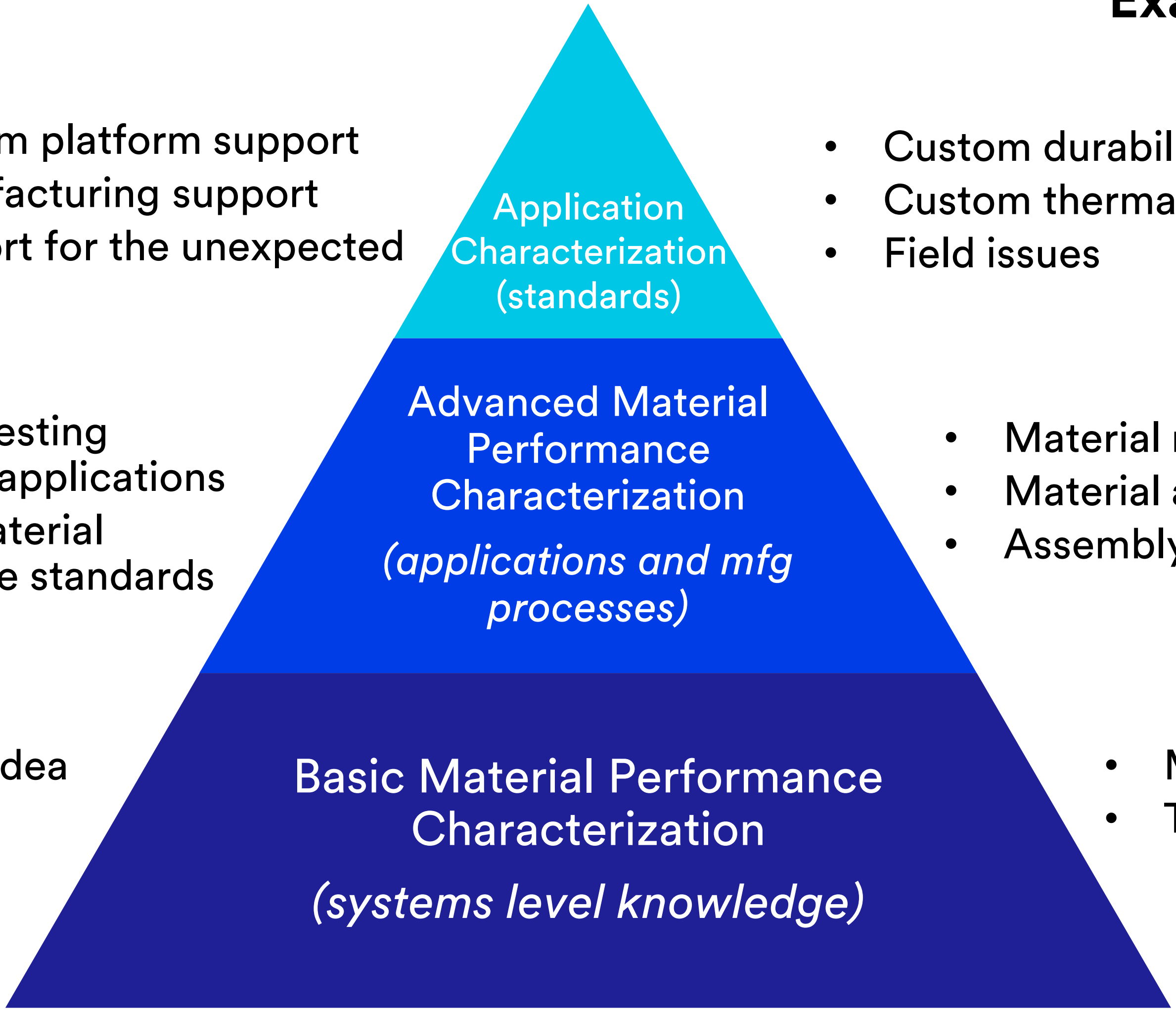
Testing Philosophy

Process

- Custom platform support
- Manufacturing support
- Support for the unexpected

- Advanced testing focused on applications
- Quantify material performance standards

- Concept / Idea
- Feasibility



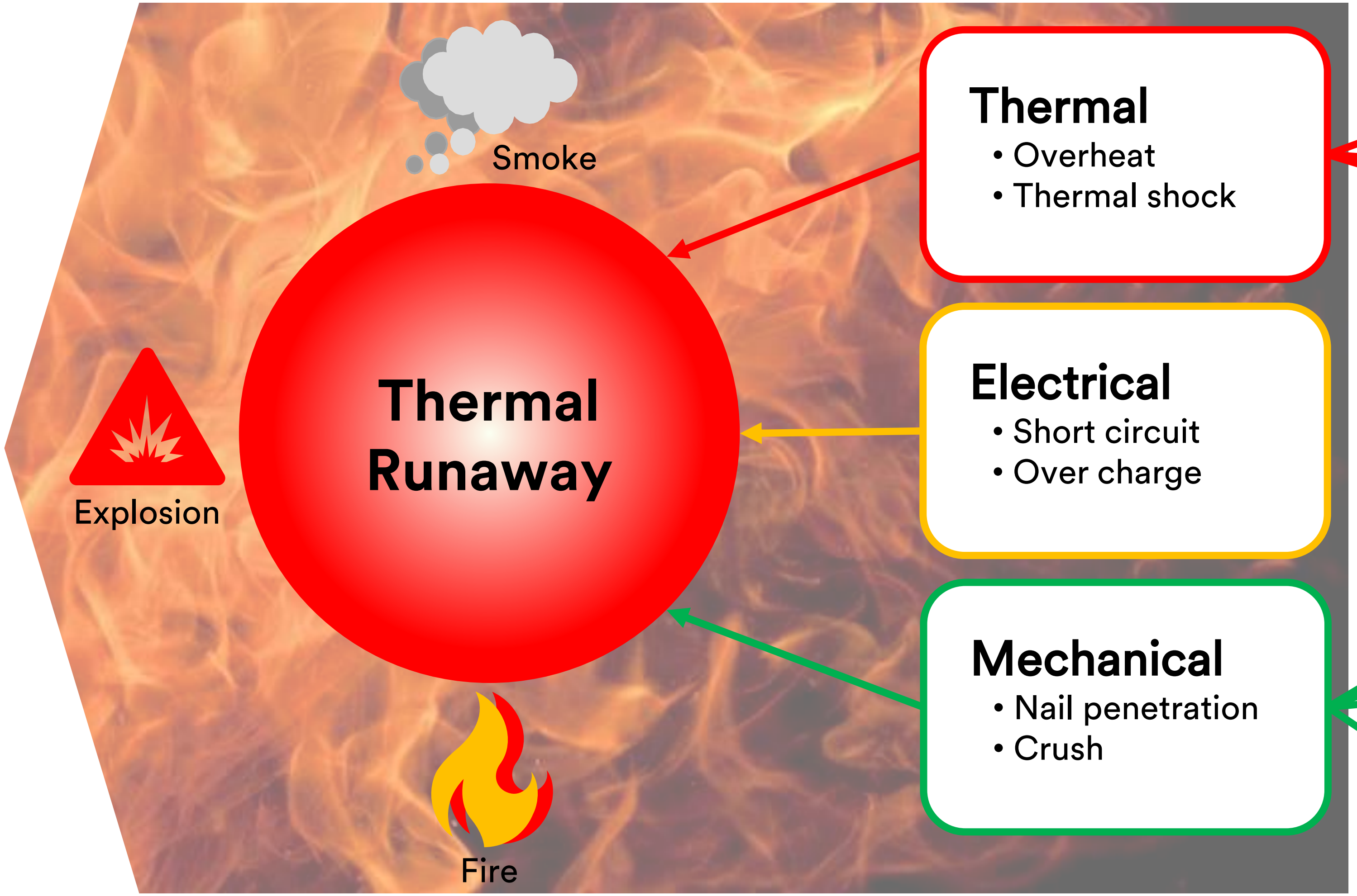
Examples

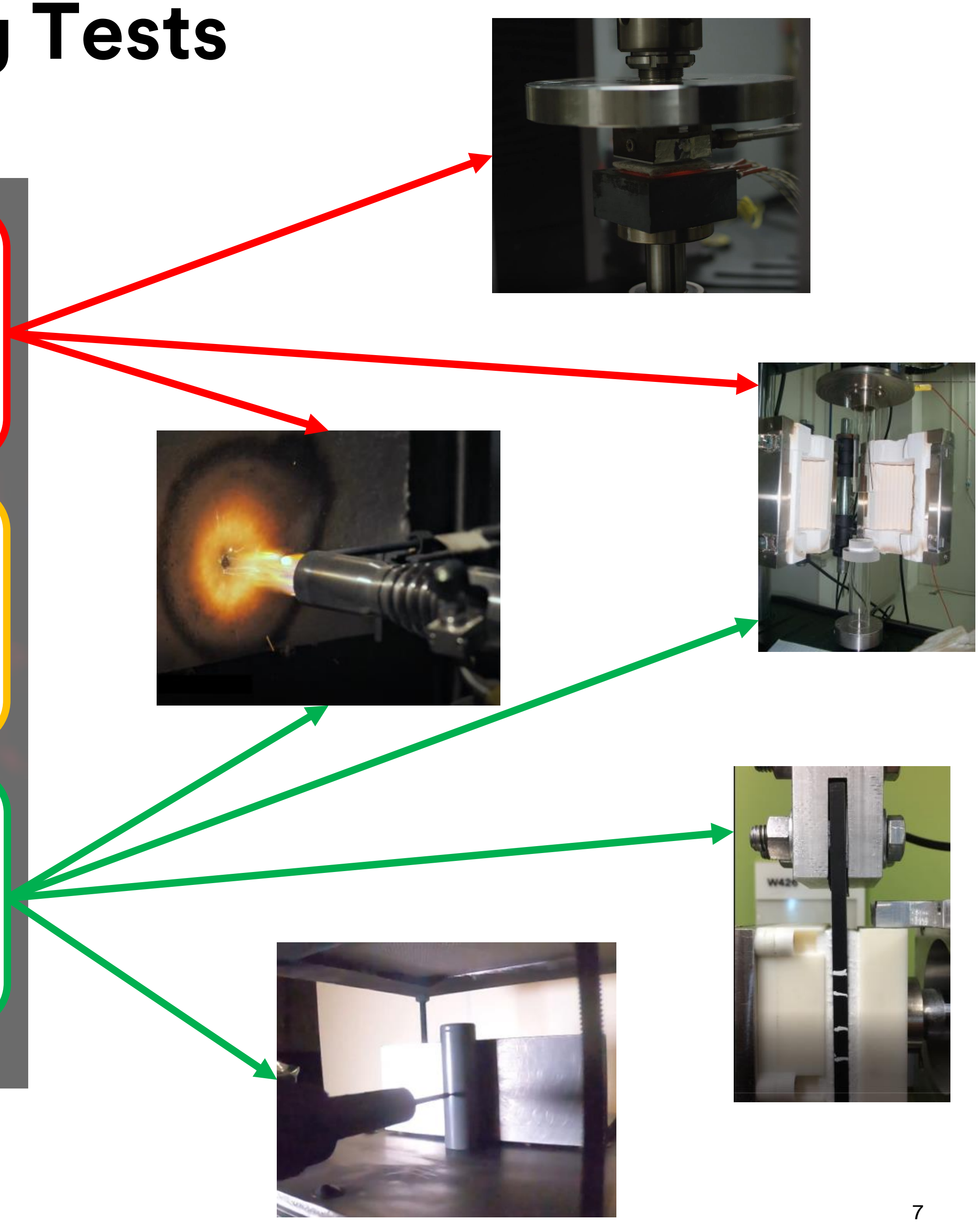
- Custom durability testing
- Custom thermal profiling
- Field issues

- Material recommendations
- Material aging
- Assembly performance

- Mechanical properties
- Thermal properties

Development of Material Screening Tests





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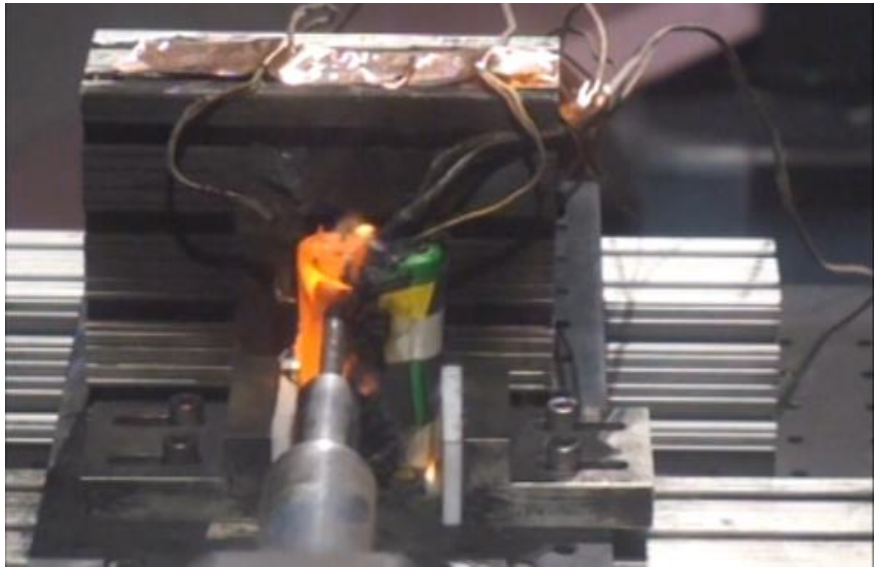
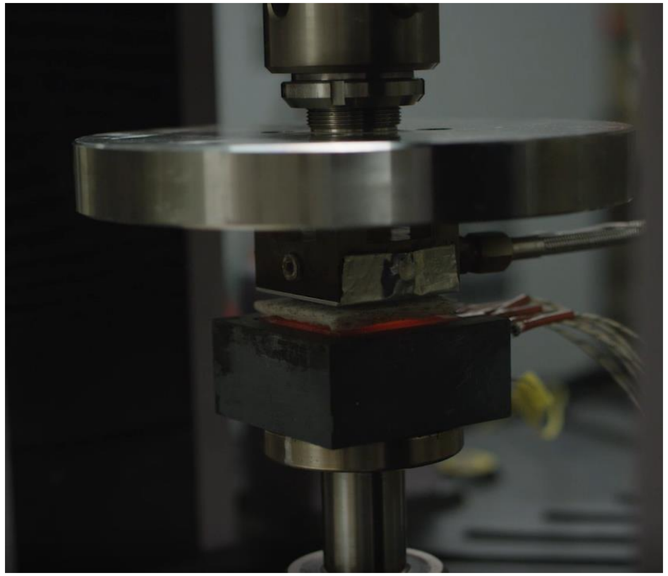
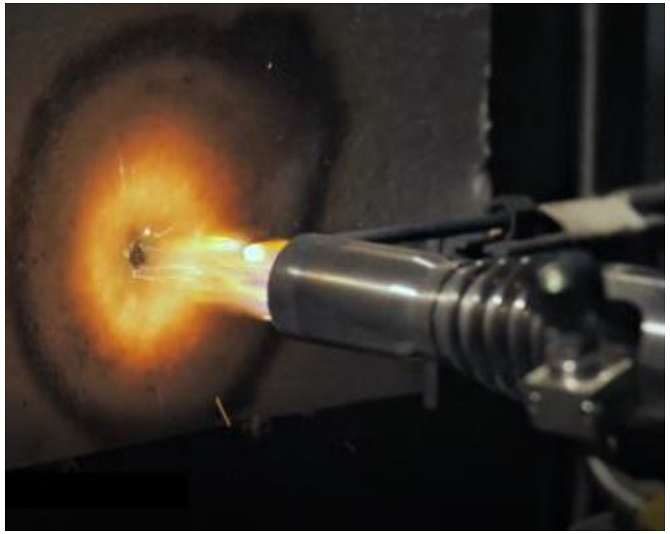
Development of Material Screening Tests



Understanding heat flux and insulation properties



Understanding heat, pressure and media blast resistance



Safety Challenges in Li-ion Battery Packs

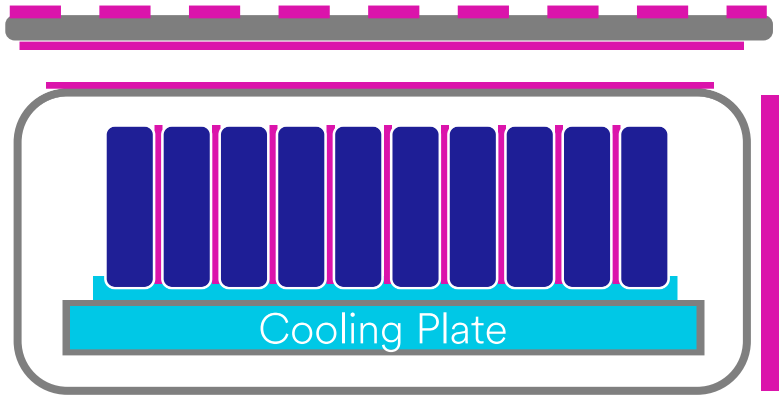
- Cell and pack energy densities have continued to increase with the introduction of new chemistries
- New regulations are highlighting the need for a more focused understanding of battery safety
- Without a deep understanding of the pain points the solution may cause greater damage than good
- Battery safety must be thought of on the system level with different elements working to achieve the goal

Model S
3.2Ah

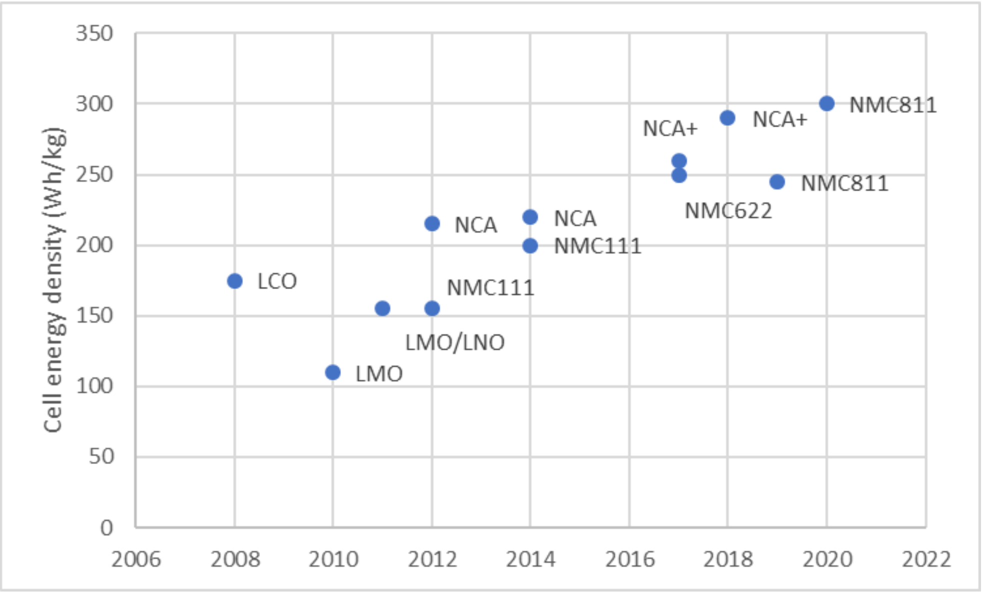
~5000 cells
60kWh

I-PACE
60Ah

~400 cells
90kWh



Module Level



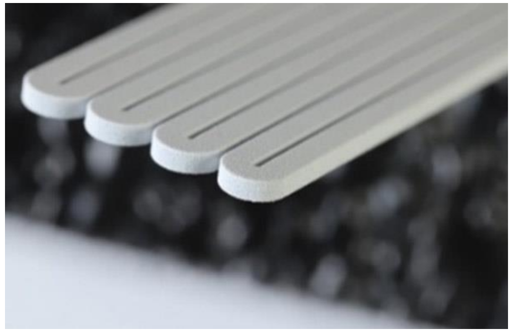
3X energy density increase in ~10yrs

Methods of Thermal Runaway Initiation

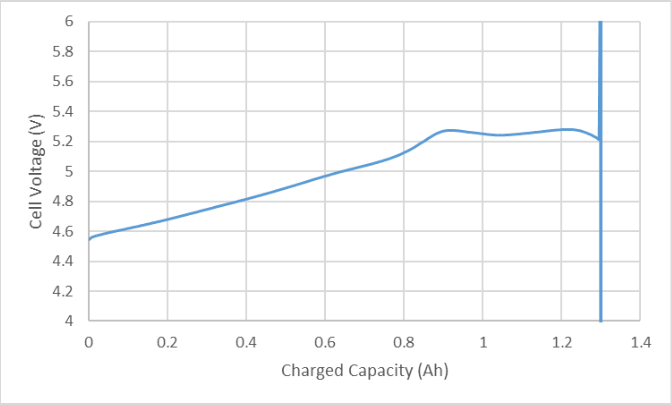
The method of initiation can result in substantial differences in behavior. Defined methods of initiation include:

- **Nail penetration**
  - Steel 3-8mm diameter with 20-60° tip
  - Inserted from 1-10 mm/s in triggerable location
- **Thermal Initiation**
  - Heated coil or platen matched to cell energy
  - Energy provided by external source or the cell
  - Some standards include two separate tests
- **Overcharge**
  - A given amount of energy is inputted into the system
  - Electrical behavior of the cell is monitored vs. time

Nail used in thermal runaway testing



TRIM heater pioneered by NRC



Example of overcharge cell behavior

Tradeoffs in Methods of Initiation

Nail Penetration

- Method shows good repeatability and can be applied to all cell formats
- Accessibility, new failure modes and applicability can be a challenge

Thermal

- Flexible form factor – emulates adjacent cell or external heat source
- Need to balance heat input – can be limiting to some cell formats

Overcharge

- Emulates conditions where SOC has slipped
- Complicated by CID and other safety measures

Nail inducted side wall eruption

Thermal initiated runway resulting in melted containers

Potential Pain Points Experienced During Thermal Runaway

There are several potential issues that can occur when a cell goes into thermal runaway.

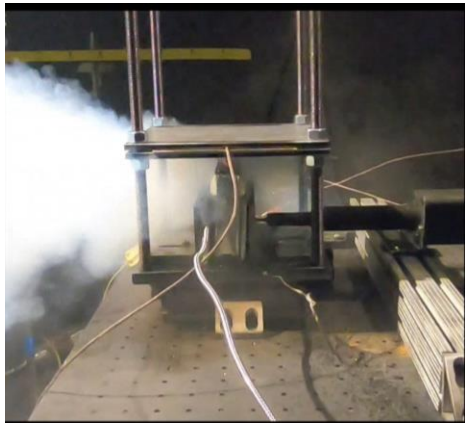
Understanding the **what** will significantly help in addressing the **how**.

Large directed flames

Rapid high temperatures

Vent direction

Hot conductive particles

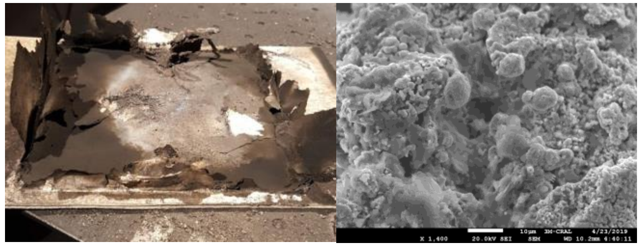


Smoke & particulate generation

Expansion

Mechanically Related Challenges During an Event

Volume expansion



Emitted particle-based erosion

Deflagration & pressurization

Component expansion

- Large format cells can experience non-symmetric expansion that can exceed >200% original volumes
- Forces >2MPa can be developed within the stack, which can lead to substantial damage to internal components

Erosion

- 10-100µm particles are ejected from the cell during runaway
- The particles – in combination with the heat – result in mechanical abrasion of protective coatings and layers

Gas pressure

- Greater than 8L per cell can be released during an event over seconds of release.
- Rapid release can fail seals, over-pressurize the pack and destroy mechanical systems

Thermally Related Challenges During an Event

Rapid heating of cells

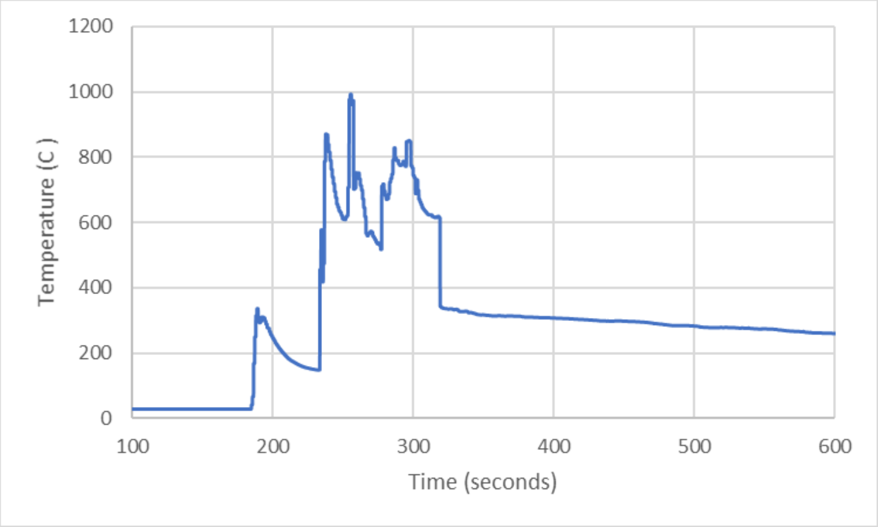
- Once initiated cell temperatures can rise at rates >40°C/sec to over 1000°C
- Measured heat fluxes of >40kW/m^2 peak released energy

Thermal propagation (cascade thermal runaway)

- 10-100µm particles are ejected from the cell during runaway
- The particles – in combination with the heat – result in mechanical abrasion of protective coatings and layers

Venting location

- Prismatic and cylindrical cells contain integrated vents to help guide the direction of failure
- Due to potential issues cells can vent in non-standard direction which expose adjacent cells to a direct blast



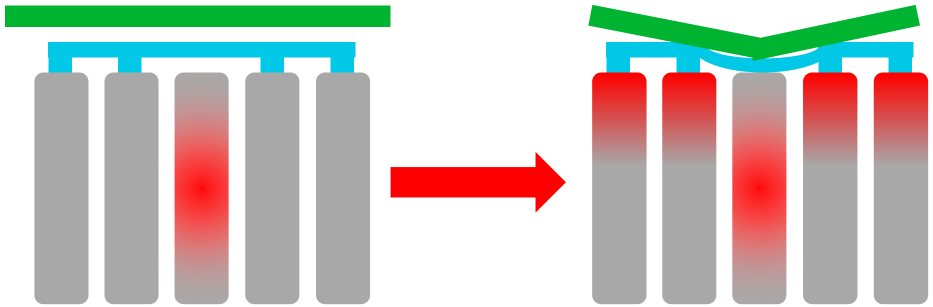
Successive cell failures

Non-optimum flame release

Electrically Related Challenges During an Event

Short-circuits due to component sag

- Aluminum – with a melting point of 660°C – is used in several pack components, including lids and busbars
- In the exposed temperatures energized component can warp and sag leading to shorting and electrically induced runaway



Electric components sag under heat

Loss of component isolation

- Polymeric films (PET) are typically used to electrically isolate cells
- These films are unable to maintain isolation at these high temperature and allow for cell to cell shorting

Conductive debris

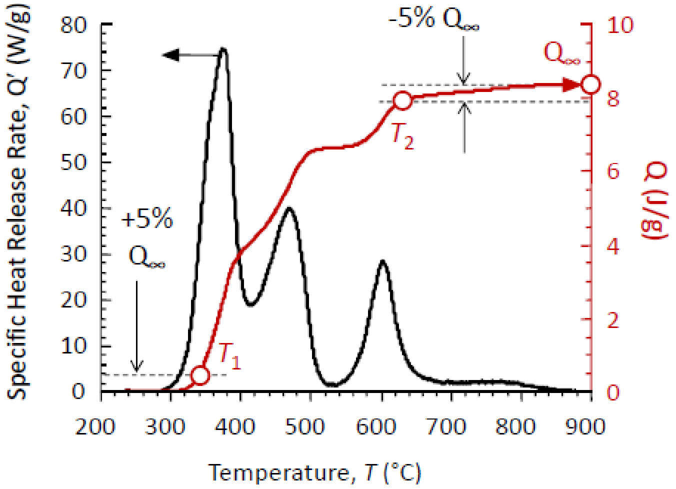
Molten cell containers allow for cell to cell shorting

Electrically conductive hot debris

- Particles with temperatures >1200°C can be ejected from the cell onto the surrounding components.
- The electrically conductive particles can burn through insulation and initiate electrical failure

Chemical Related Challenges During an Event


Smoke formation prior to combustion



Micro-combustion calorimetry (Safronova 2019)

Chemical Release

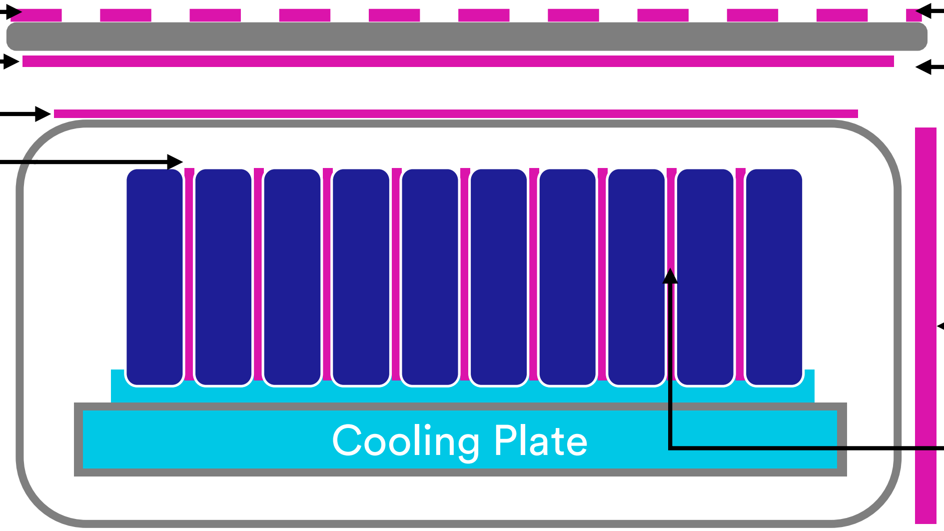
- Gas released from a cell during runaway can contain a mixture of CO, CO_2, H_2, HF and C_xH_y in cell dependent ratios
- Improper venting that inhibits the release of these gases in the pack can lead to gas levels above allowable limits
- Understanding of the relationship between gas composition, SOC and cathode types still continues

Smoke and particles

- Materials used in the construction of the battery pack can serve as fuel during thermal propagation
- Release of harmful species and incompletely combusted materials need to be considered
- Methods can be used to assess the rate of heat release of material and their contribution to smoke generation

Tackling the Battery Safety Problem

Lid & Enclosure
- Electrical
- Chemical
- Thermal
- Mechanical

Module Level

Outer enclosure
- Electrical
- Thermal

Busbar/connections
- Electrical
- Thermal
- Mechanical

Around cells
- Electrical
- Thermal
- Mechanical


Mechanical Material Properties to Address the Need

Higher Strength-Focused Features

- High thermal runaway durability (blast)
- High temperature resistant (> 1200°C)
- Flexible
- Material thickness: 1.0 mm – 2.0 mm
- Basis weight: 1.5 to 2 kg / sqm

Before

After (front)

After (back)

Condition after 12th blast

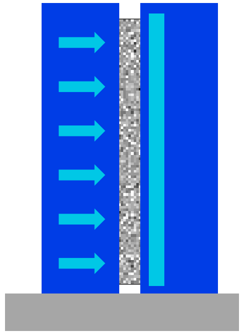
Electrical-and-Flexibility-Focused Features

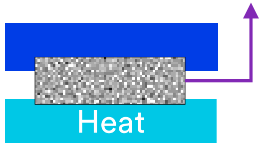
- High temperature resistant up to 2000°C
- Dielectric strength > 5.8 kV
- 3D-formable
- Material thickness: 1.0 mm – 2.0 mm
- Basis weight: 1 to 1.5 kg / sqm

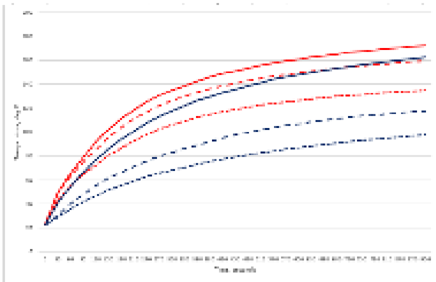
Materials can be highly conformable with tradeoffs

Thermal Material Properties to Address the Need

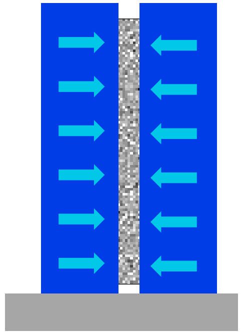
Thermal Exposure

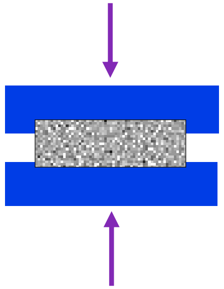


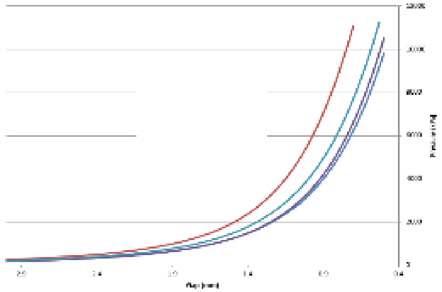




Compression

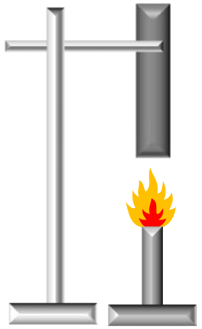


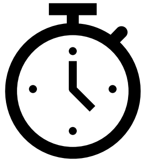




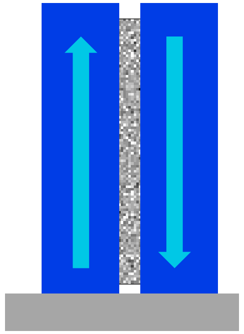
e.g. 3M™ TRB600 & TRB1000

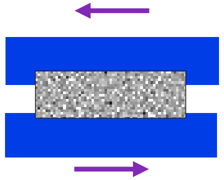
UL 94 V-0

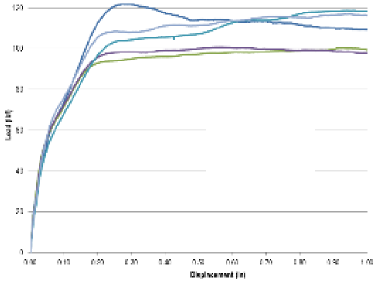




Shear



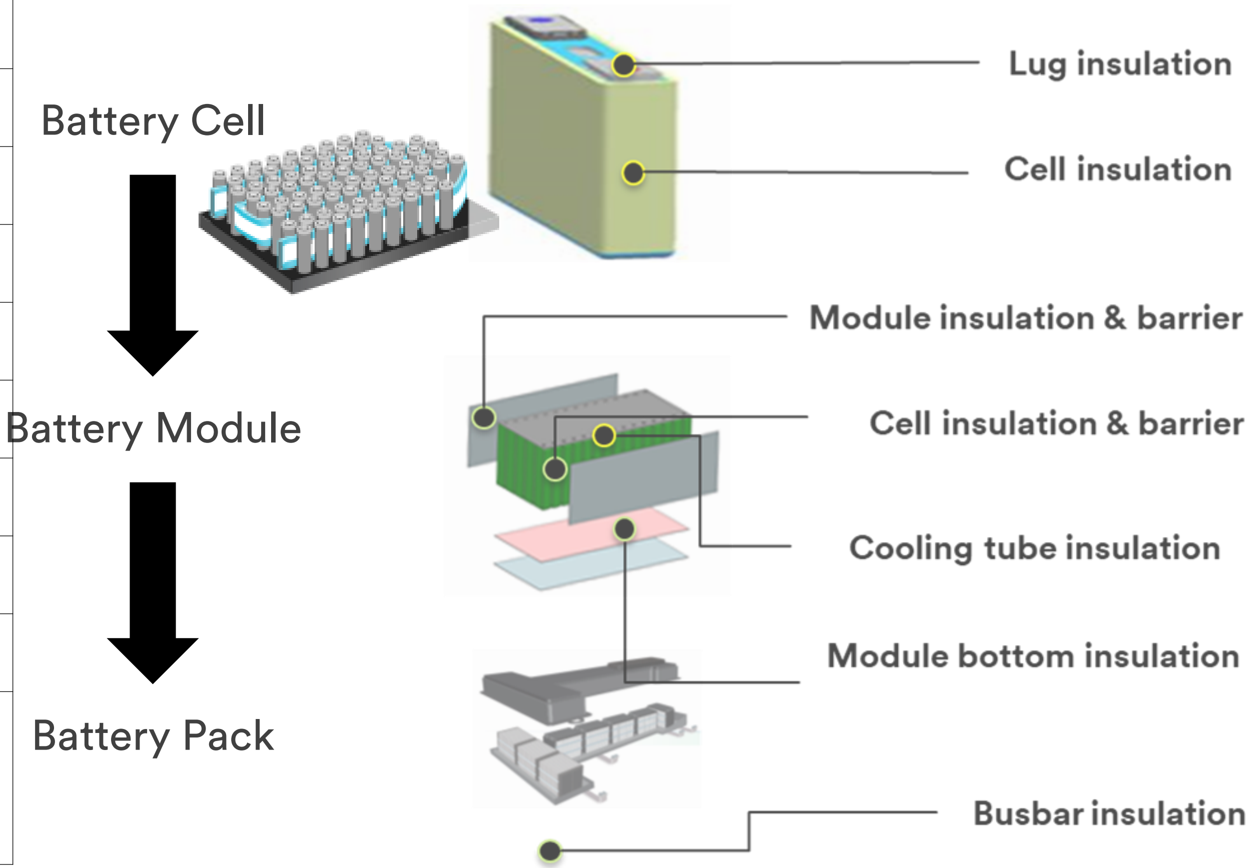




Electrical Properties to Address the Need

Property	3M FRB-NT254
Dielectric strength	5.0 kV
UL 94 flame rating	V-0 and 5VA
High voltage arc tracking rate (HVTR)	PLC = 0
Comparative Tracking Index (CTI)	PLC = 0
High current arc to ignition (HAI)	PLC = 2
Hot wire ignition	PLC = 4
Glow wire ignition temperature (GWIT)	990°C
Glow wire flammability index (GWFI)	960°C
High volt, low current arc resistance	PLC = 4
Relative thermal index, component • Electrical • Mechanical	 140°C 130°C

Application



Learning From the Past to Help With the Future

- The automotive industry is going through a tremendous change, but change is not new
- To meet these challenges it is important that to gain a deep understanding of the fundamental material properties and how those translate to the application
- Representative, application specific test development can help the industry move at the speed needed to meet this challenge
- Battery safety is a complex challenge that requires addressing thermal, mechanical, electrical and chemical needs
- **By thinking of battery safety at a system level innovative solutions that help address safety challenges while still balancing cost and complexity can be developed.**

Thank you!

Join us for a follow-up roundtable:
Wednesday, September 9th at 11:30am PST / 1:30pm CST / 2:30pm EST

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Follow the link to register:
https://attendee.gotowebinar.com/register/888280421695871335

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