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Evaluating Safety of Next Generation Battery Chemistries

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NASA Aerospace Battery Workshop 2025

January 22, 2026

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Agenda

- Intro to EVs4All Program
- Deeper Dive on a Chemistry
- Broader Accomplishments
- Conclusions

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Vehicle Engineering

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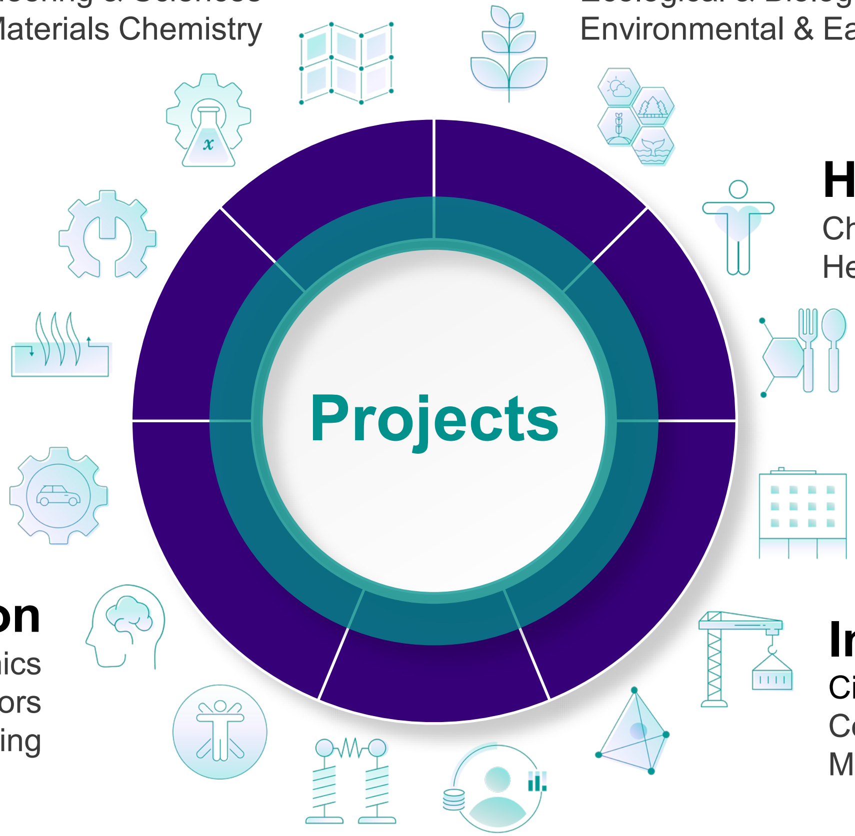
Our Bespoke Multidisciplinary Teams



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Intro to EVs4All

ARPA-e EVs4All at a Glance

- Goal: develop more affordable, convenient, efficient and resilient batteries (for transportation):
  - Achieving a charge rate equivalent to 5-15 minutes to restore 80% of cell capacity
  - Reducing low-temperature battery performance losses by at least 50%
  - Retaining a minimum of 90% capacity after the battery has delivered 200,000 miles of equivalent and cumulative range
  - Identifying a compelling pathway to a cost of < $75/kWh at commercial scale
  - Implementing new and existing protocols to verify safety of new battery chemistries and cell designs
- Program Director: Halle Cheeseman, Ph.D.

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Teams / Accepted Proposals ($42M total)

- Category 1 and 2 Teams (commentary by Dr. Cheeseman):
  - **OSU** – An eclectic anode aiming to be the spiritual successor to LTO, with twice the energy and similar power performance pedigree.
  - **Tyfast*** – The oxide-based anode rewriting the rules for EV-level energy and dazzling 5-minute charging.
  - **Virginia Tech** – A bold rethink: a cathode free of cobalt and nickel, paired with an anode enhanced by a sprinkle of coal dust.
  - **Project K*** – A Kalium-based anode (yes, potassium), bringing Kal-El-level power to Earth-bound batteries.
  - **University of Maryland** + **Ion Storage Systems** – Built like a tank, light on the bank. A 3D solid state anode that works pressure-free, and a cathode with zero diva metals.
  - **24M*** – Sodium-ion is nice, but protected sodium metal is where the real magic starts.
  - **Ampcera*** – A sulfide solid-state battery internally warmed by "Fast Lion Energy"—feline agility meets fierce conductivity.
  - **South 8** – Batteries that laugh in the face of cold. Performs even in dry ice territory.
  - **University of Maryland and Yale University** - Wood based battery, wild performance—lithium flies down nano cellulosic highways like it's late for work.
  - **Zeta Energy*** – A lush carpet of carbon nanotubes, partnered with a cathode engineered from fossil fuel by-product, delivering exceptional energy.
  - *WH Power**

- Category 3 Teams (Safety Evaluation)
  - Sandia National Labs (with Purdue, UMD & UL)
  - NREL (with UT Austin & Exponent)

What can go wrong?

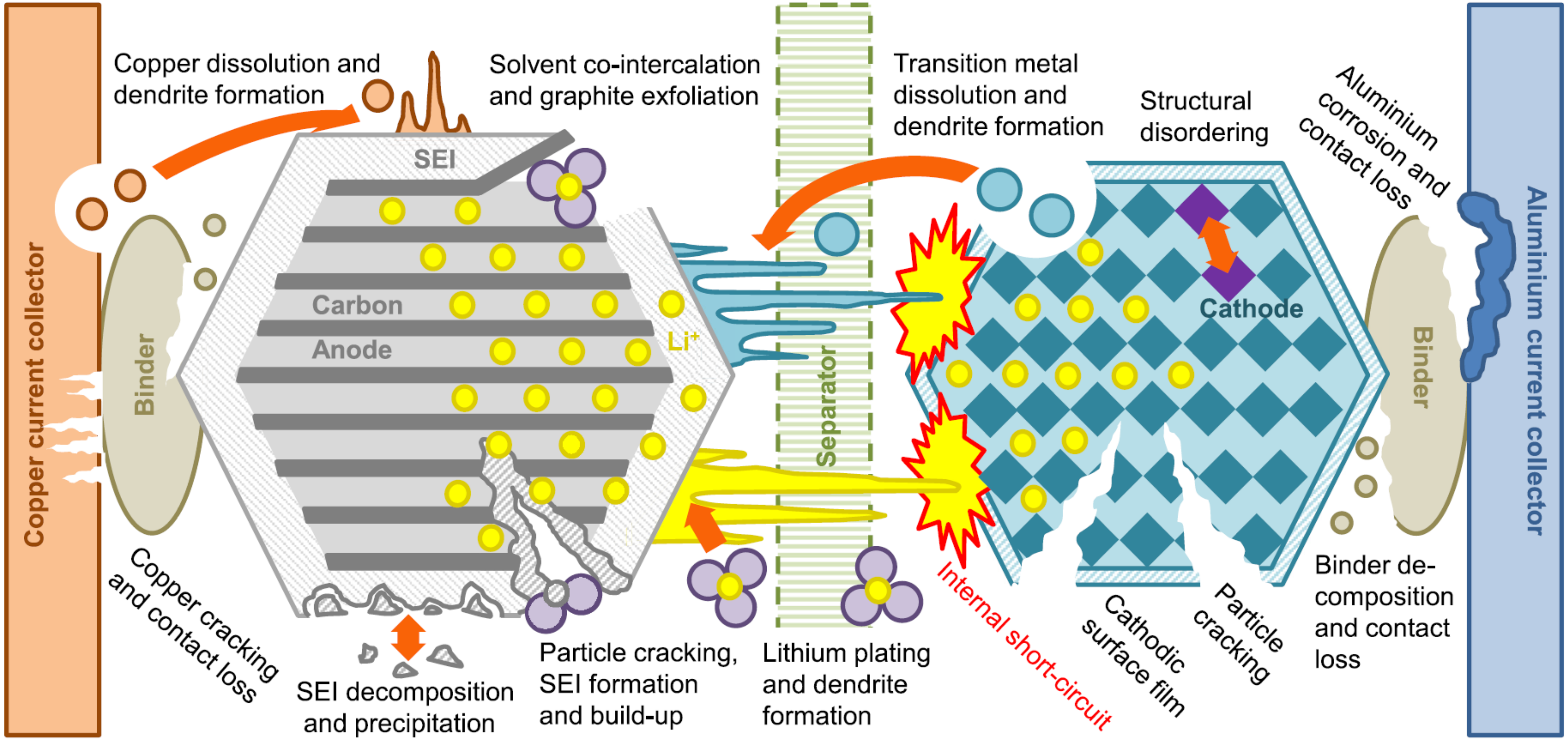
Operational
- Operating conditions
- Human Factors
- Environment
- External fire
- “Surprise” performance

Integration, Assembly
- Systems
- HVAC
- Cooling
- Interventions
- Wiring

Manufacturing
- Cell-level defects
- Contamination
- Incorrect tolerances
- Incorrect / Insufficient parts

Design
- Insufficient for UX
- Foreseeable Misuse
- Non-compliance

What can go wrong? (Chemistry Edition)



Birkl et. Al., *Journal of Power Sources*, Volume 341, 15 February 2017, Pages 373-386.

Is it Safe?

Total gas generated

Total heat generated

Changes in
behavior with
cycle history

First responder practices

Changes in
behavior with
state of charge

Benchmark risks against Li-ion

Rate of heat generated

Rate of gas generated

Properties of particulates
and solids from thermal
runaway

Abuse tolerance,
mechanical,
thermal,
electrical

Composition of gases
(flammability and toxicity)

Our Team

- **Project vision:** We aim to determine the hazards and abuse tolerance of next-generation batteries, provide guidance on standard testing methods for evaluating the safety of next-gen cells, and to identify opportunities to manufacturing safer battery systems.
- **Institutions / Leads:**
  - NLR (NREL) / Donal Finegan *(Principal Investigator)*
    - Avtar Singh, Anudeep Mallarapu, Chuanbo Yang
  - University of Texas-Austin
    - Ofodike Ezekoye
      - Hadi Khani, Lingmin Lin, Ayrton Yanyachi, Doosoo Kim, Sidharta Nanda
  - Exponent
    - Ryan Spray

NATIONAL
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~~NREL~~
NATIONAL RENEWABLE ENERGY LABORATORY

TEXAS
The University of Texas at Austin

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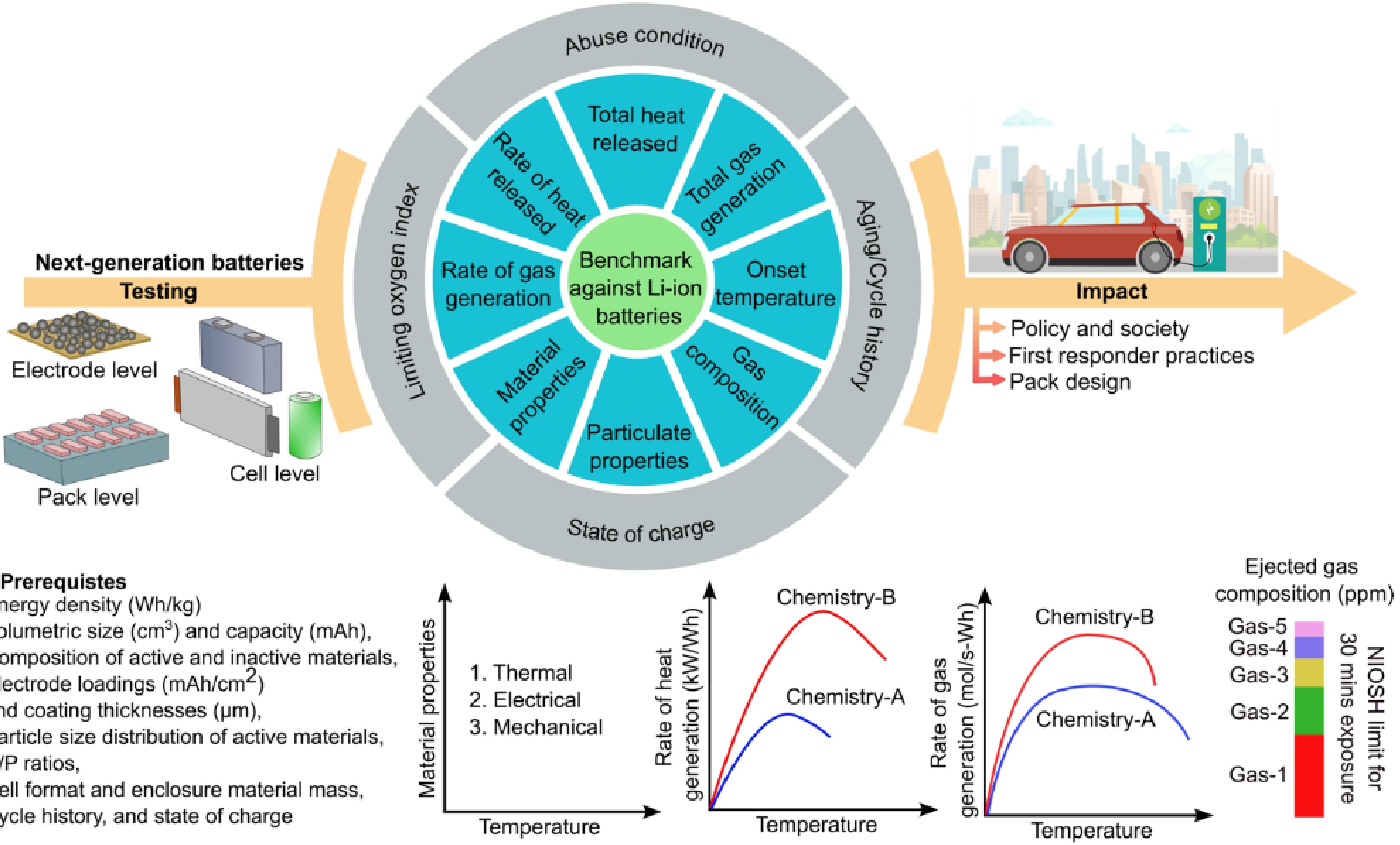
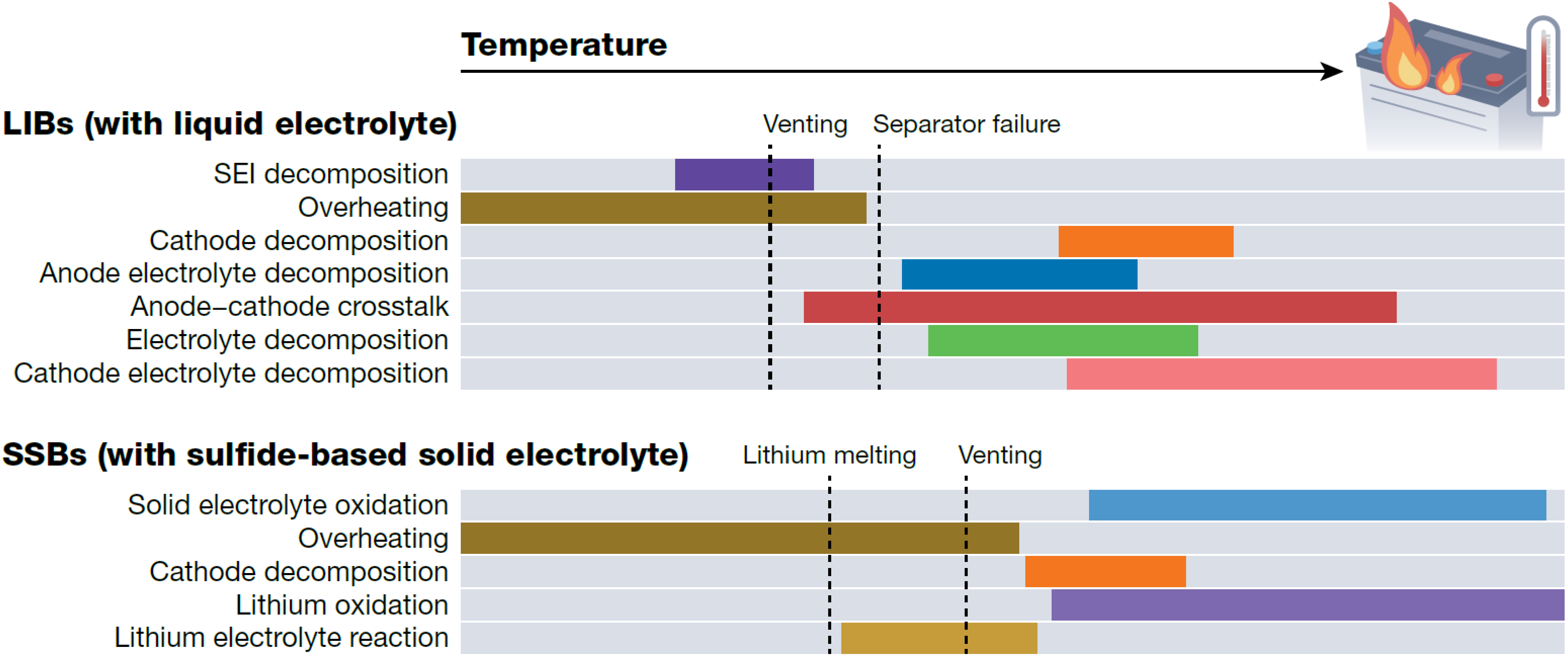
Goal: Comprehensive Review of Cell Safety



Prerequistes

1. Energy density (Wh/kg)
2. Volumetric size (cm^3) and capacity (mAh),
3. Composition of active and inactive materials,
4. Electrode loadings (mAh/cm^2) and coating thicknesses (µm),
5. Particle size distribution of active materials,
6. N/P ratios,
7. Cell format and enclosure material mass,
8. Cycle history, and state of charge

Benchmarking Safety to Lithium-ion



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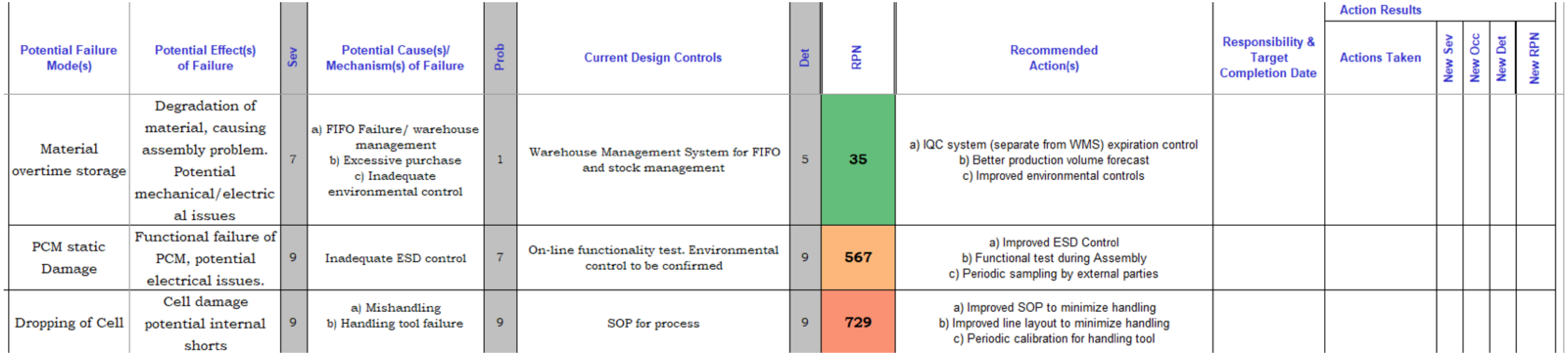
Failure Mode and Effects Analysis (FMEA)



										Action Results				
Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	New Sev	New Occ	New Det	New RPN
Material overtime storage	Degradation of material, causing assembly problem. Potential mechanical/electrical issues	7	a) FIFO Failure/ warehouse management b) Excessive purchase c) Inadequate environmental control	1	Warehouse Management System for FIFO and stock management	5	35	a) IQC system (separate from WMS) expiration control b) Better production volume forecast c) Improved environmental controls						
PCM static Damage	Functional failure of PCM, potential electrical issues.	9	Inadequate ESD control	7	On-line functionality test. Environmental control to be confirmed	9	567	a) Improved ESD Control b) Functional test during Assembly c) Periodic sampling by external parties						
Dropping of Cell	Cell damage potential internal shorts	9	a) Mishandling b) Handling tool failure	9	SOP for process	9	729	a) Improved SOP to minimize handling b) Improved line layout to minimize handling c) Periodic calibration for handling tool						

Severity (S)

1 2 3 4 5 6 7 8 9 10

Insignificant … Catastrophic

Probability of Occurrence (O)

1 2 3 4 5 6 7 8 9 10

Very Unlikely … Very Likely

Detectability (D)

1 2 3 4 5 6 7 8 9 10

Almost Certain … Completely Uncertain

x

Deeper Dive: Ampcera

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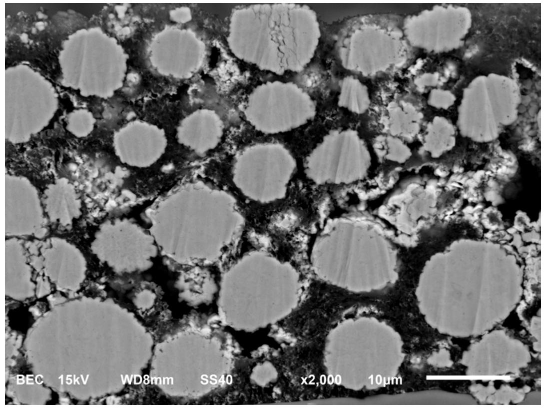
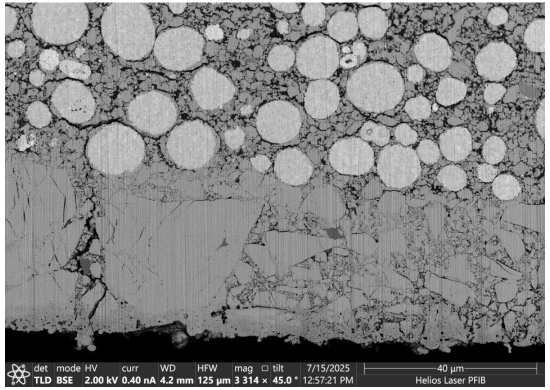
Overview: Ampcera

- Technology provided for EVs4All:
  - Catholyte: NMC811 + Li_6PS_5Cl (LPSC)
- NLR-made LPSC solid-state cells
  - *Electrolyte / Separator (solid): LPSC*
  - *Anode: Silicon*
  - Akin to technology from Ampcera, Solid Power, and CATL

Traditional NMC Cathode (SEM)



Ampcera Catholyte (SEM)



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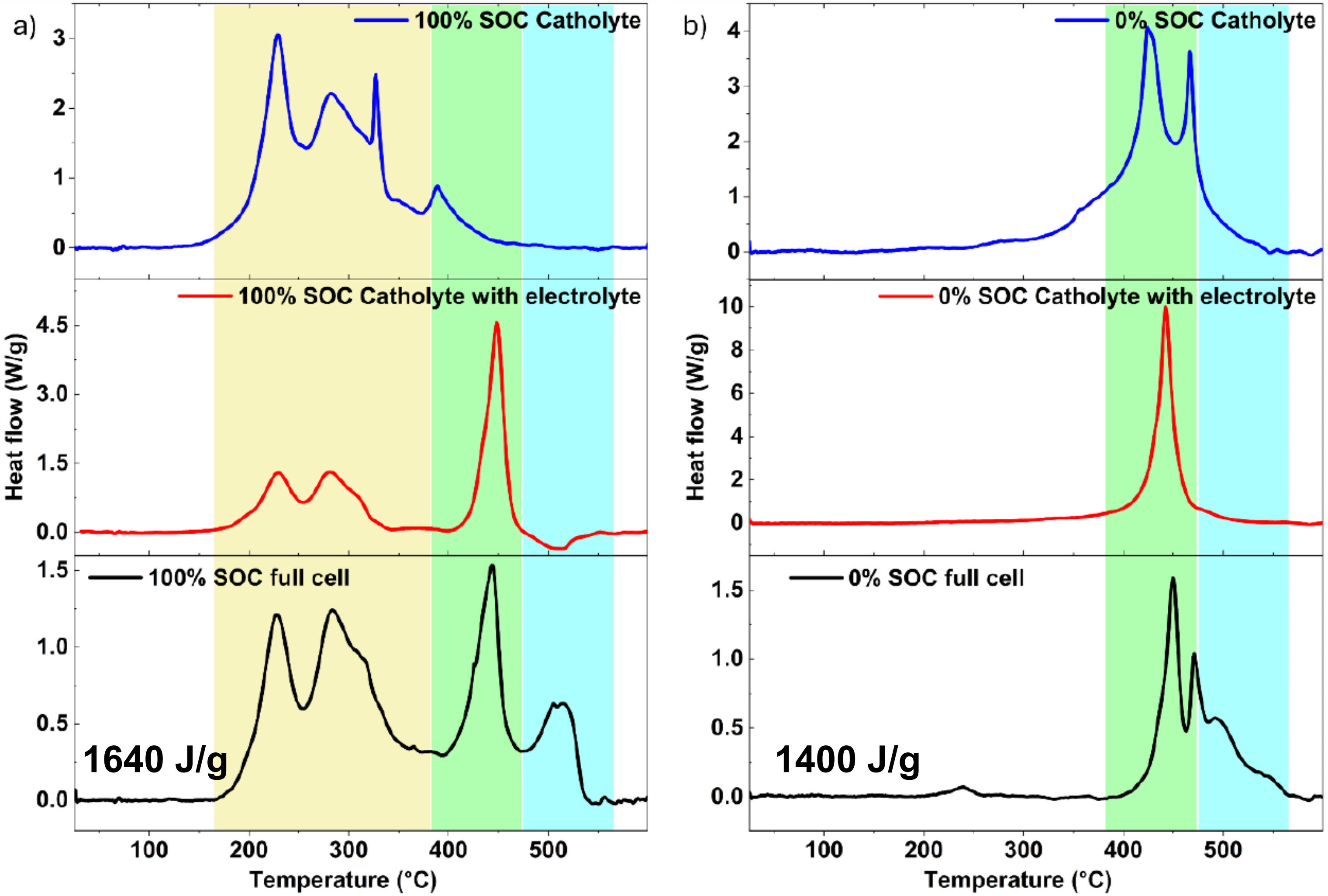
Cell Materials Thermal Analysis (DSC)

- Low-temp exotherms missing for 0% SoC
- Exotherm at ~400°C, consistent with LPSC decomposition
- Smaller exotherm at ~500 °C in full cells, indicating a possible contribution from the Si anode
- The total heat release from full cells in DSC testing was more than 2x the baseline cell on a J/g basis (1300 J/g vs 662 J/g)
  - Thermal management will be challenging for runaway
  - The reaction mechanisms that contribute to this are still under investigation



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FMEA: Ampcera

- Root causes of top RPN Scores:
  1. Failure of the solid separator, either from dendrites and/or chemical degradation of its mechanical integrity or electrical insulative properties.
  2. Li plating and side reactions that can occur during fast charge or cold charge conditions.
  3. Heterogeneous ionic conductivity within electrolyte that leads to regional overuse or under use.
  4. Chemical degradation of electrolyte where the electrolyte loses its ionic or electronic conductivity
  5. Heterogeneous material activity that leads to overuse of some regions of the electrode and accelerates capacity fade and dendrites.
  6. Uneven compression within the cell, either by external or internal operational forces.

Top RPN scores

Function	Potential Failure Modes	Mechanism	Occurrence	Mode	Effect	Severity	Current Method of Detection/ Control	Detection	RPN (Risk priority number)	Comments
Cycling	1	Break-up of separator and electrolyte via interfacial reactions, dendrites, cyclic mechanical stresses	8	increase in electrolyte resistance, higher risk of dendrites	Internal short circuit, thermal runaway, reduced abuse tolerance	9	None	8	576	Unique to SSBs
Fast charge	1	Li Plating / Dendrite growth. Additional SEI growth on plated lithium.	6	Loss of lithium inventory	Internal short circuit, thermal runaway, capacity fade	9	None	10	540	
Fast charge	2	Uneven ionic conductivity within separator and cathode	8	Over or underutilization of regional active material	Capacity fade, resistance rise, self heating	6	None	10	480	Unique to SSBs
Cycling	2	Chemical degradation of electrolyte	10	Loss of ionic conductivity	Power fade	6	None	8	480	
Cycling	2	Increasingly heterogeneous utilization	10	Formation of hot spots, over- and under-utilization	Capacity fade, power fade, self heating	6	None	8	480	Unique to SSBs
Charge	2	Uneven compression from anode expansion during lithiation	6	Heterogeneous lithium content, lithiation gradients, overused cathode particles	Capacity fade, self heating	6	None	10	360	Unique to SSBs

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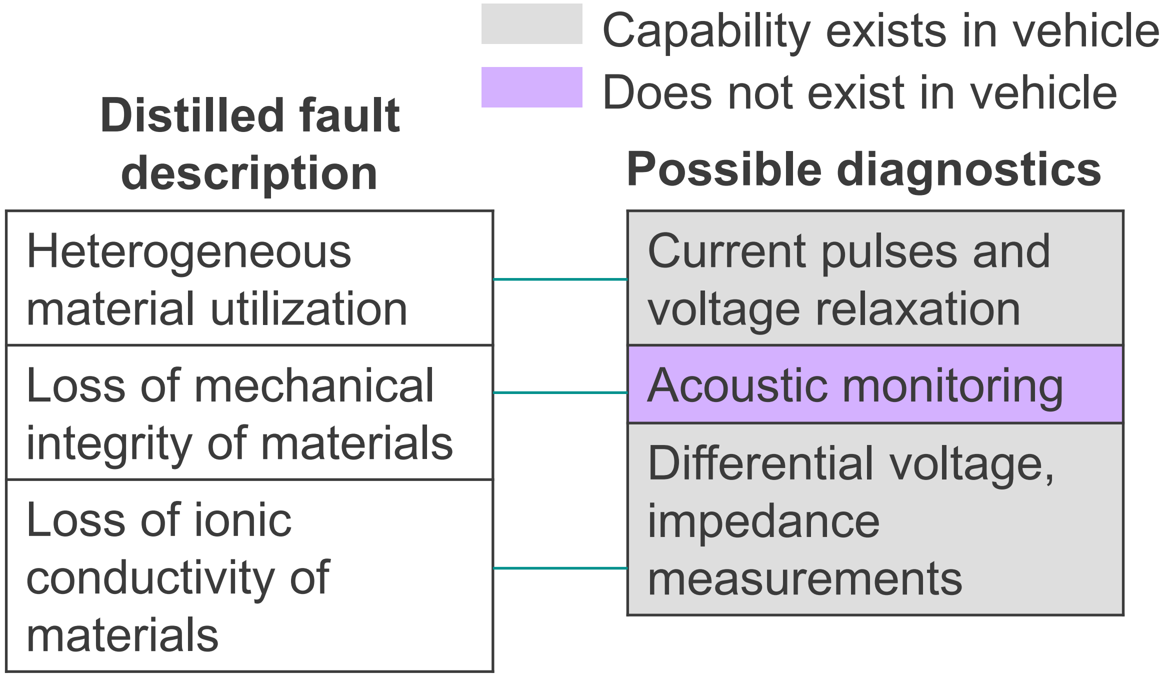
Insights & Mitigation

- Key insights unique from Li-ion:
  1. Manufacturing process is different from conventional Li-ion, and therefore a manufacturing focused FMEA should be conducted.
  2. Heterogeneous material properties are a concern, such as uneven ionic conductivity from uneven pressure in the electrode microstructure.
  3. Related to heterogeneous properties is heterogeneous utilization of materials such as over-use of some regions and under-use of others.
  4. Mechanical weakening of solid separator materials over time and cycling is an unknown but likely greater in magnitude that polymer separators.
  5. Changing ionic conductivity properties of electrolyte over time and cycling is currently unknown.
  6. Uneven internal forces accruing due to heterogeneous lithiation of Si or heterogeneous microstructures from manufacturing. These will likely get worse over time and cycling.



▨ Capability exists in vehicle

🟪 Does not exist in vehicle

Distilled fault description

Heterogeneous material utilization

Loss of mechanical integrity of materials

Loss of ionic conductivity of materials

Possible diagnostics

Current pulses and voltage relaxation

Acoustic monitoring

Differential voltage, impedance measurements

Required research

- Better understand spatially heterogeneous degradation rates in SSBs
- Better understand the changing material properties of solid electrolytes with time and cycling
- Heterogeneity of internal forces with time and cycling
- Prevalence and consequences of manufacturing defects for specific manufacturing processes, e.g. Slurry casting, dry-process lamination, compaction

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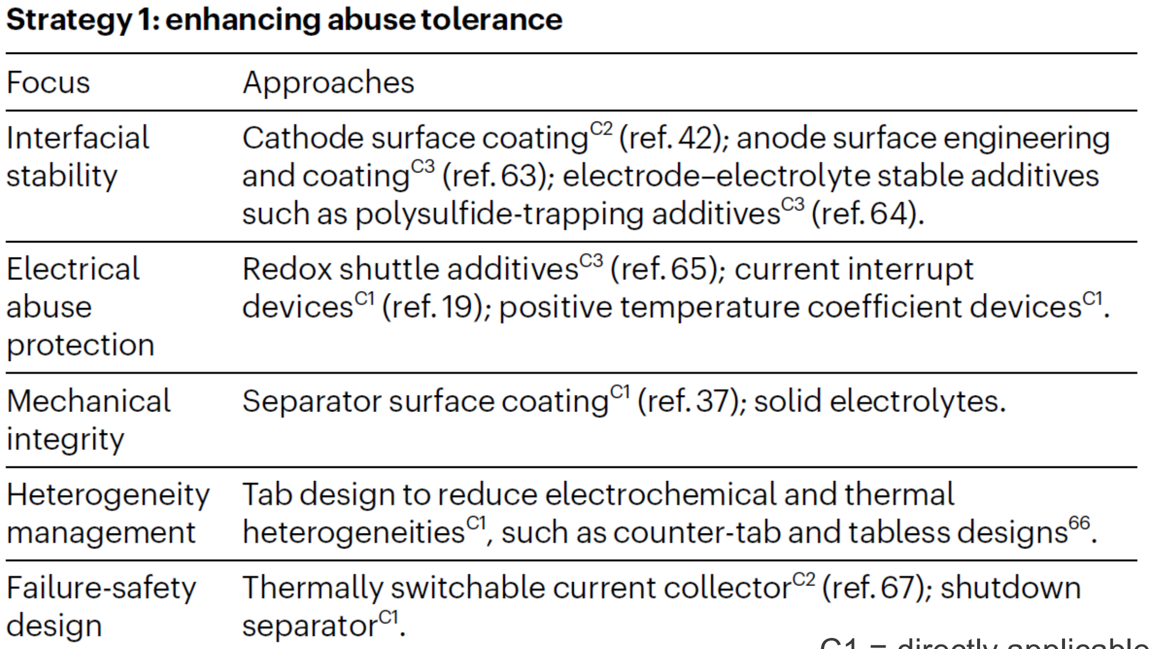
Broader Accomplishments

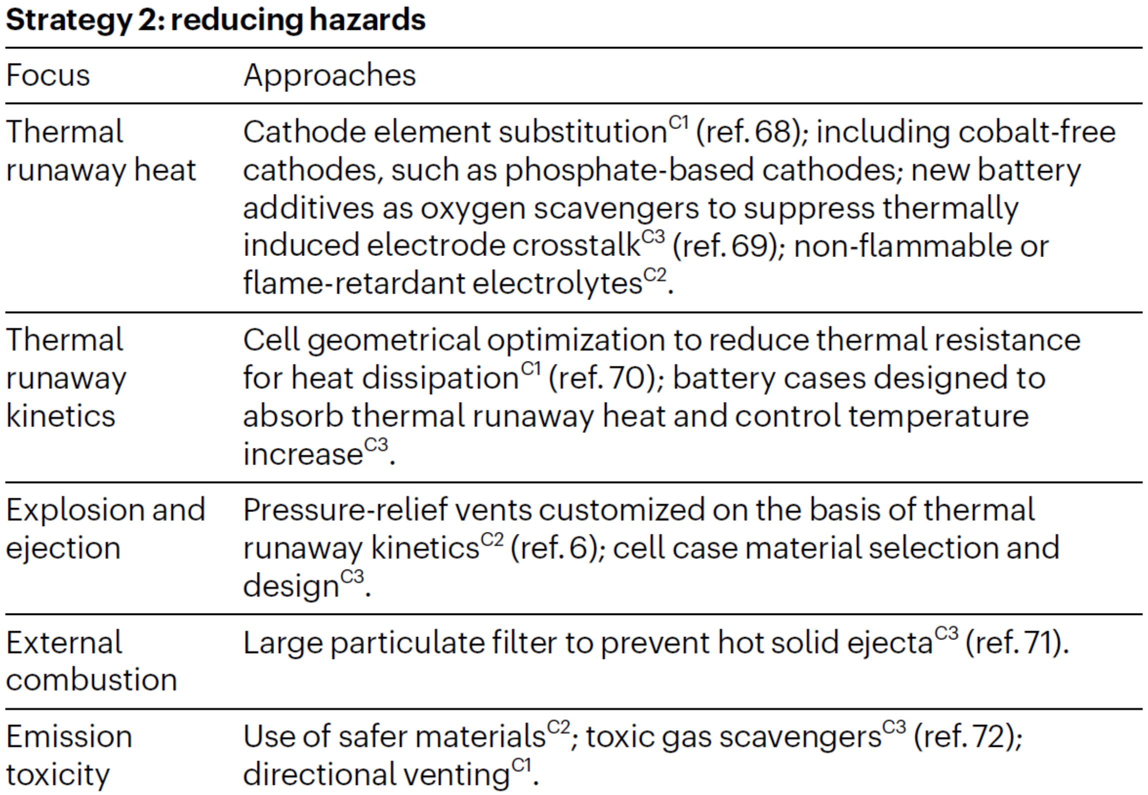
Key thermal runaway mitigation strategies and corresponding examples in cell design



Strategy 1: enhancing abuse tolerance

Focus	Approaches
Interfacial stability	Cathode surface coating[C2] (ref. 42); anode surface engineering and coating[C3] (ref. 63); electrode–electrolyte stable additives such as polysulfide-trapping additives[C3] (ref. 64).
Electrical abuse protection	Redox shuttle additives[C3] (ref. 65); current interrupt devices[C1] (ref. 19); positive temperature coefficient devices[C1].
Mechanical integrity	Separator surface coating[C1] (ref. 37); solid electrolytes.
Heterogeneity management	Tab design to reduce electrochemical and thermal heterogeneities[C1], such as counter-tab and tabless designs[66].
Failure-safety design	Thermally switchable current collector[C2] (ref. 67); shutdown separator[C1].

C1 = directly applicable
C2 = adaptable with modifications
C3 = requiring fundamental research and development



Strategy 2: reducing hazards

Focus	Approaches
Thermal runaway heat	Cathode element substitution[C1] (ref. 68); including cobalt-free cathodes, such as phosphate-based cathodes; new battery additives as oxygen scavengers to suppress thermally induced electrode crosstalk[C3] (ref. 69); non-flammable or flame-retardant electrolytes[C2].
Thermal runaway kinetics	Cell geometrical optimization to reduce thermal resistance for heat dissipation[C1] (ref. 70); battery cases designed to absorb thermal runaway heat and control temperature increase[C3].
Explosion and ejection	Pressure-relief vents customized on the basis of thermal runaway kinetics[C2] (ref. 6); cell case material selection and design[C3].
External combustion	Large particulate filter to prevent hot solid ejecta[C3] (ref. 71).
Emission toxicity	Use of safer materials[C2]; toxic gas scavengers[C3] (ref. 72); directional venting[C1].

Gaps and Industry Analysis

- Equipping OEMs for design of “safe” batteries
- Standards Gap Analysis
  - Toxic emissions
  - Age-dependent behavior
  - Dendrite Hazards
  - Managing different reactivities and reaction kinetics
- Informing First Responders
  - Guiding personal protective equipment choices used at the scene of EV fires
  - Development of strategies for managing battery fires as they occur
  - Informing protocols for addressing contamination following a fire

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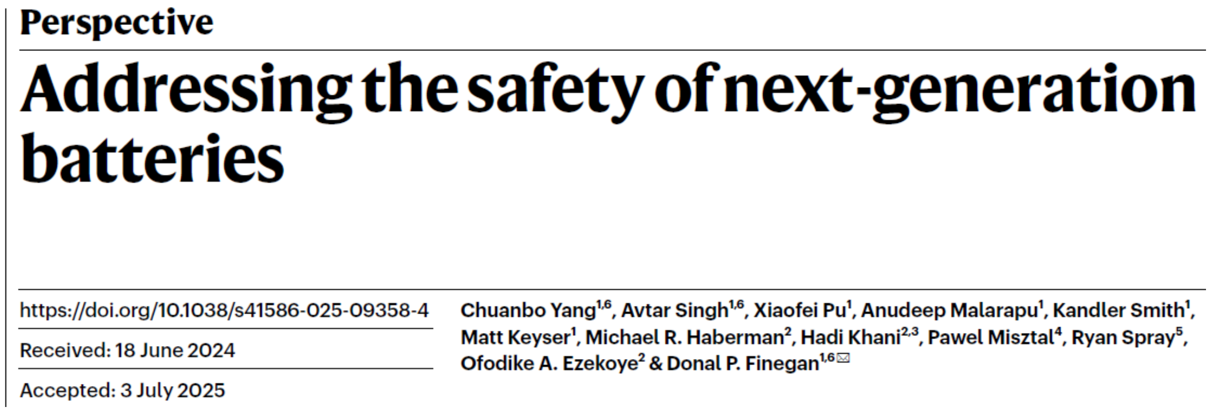
Conclusions / Take-aways



Perspective

Addressing the safety of next-generation batteries

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Chuanbo Yang[1,6], Avtar Singh[1,6], Xiaofei Pu[1], Anudeep Malarapu[1], Kandler Smith[1], Matt Keyser[1], Michael R. Haberman[2], Hadi Khani[2,3], Pawel Misztal[4], Ryan Spray[5], Ofodike A. Ezekoye[2] & Donal P. Finegan[1,6]✉

- The behavior of many next-generation cell types will diverge considerably from present understanding of the safety and abuse tolerance of LIBs.
- Some modern methods for safety evaluation are still valuable for next-gen chemistries, especially in benchmarking to existing LIBs.
- For next-gen chemistries, some materials, thermal runaway reactions, failure mechanisms, and inherent safety risks are not well understood, including how they can change with operational history
- It would help accelerate the comprehension and response of the community to the differences in cell responses if hazards are benchmarked against LIBs using open-access, normalized metrics

Questions?

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Let’s Discuss.

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