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Role of testing in safe deployment of batteries

Andreas Hauser
Manager, A*STAR Battery Test Facility
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Introduction

Introduction – Why do we need to test batteries?

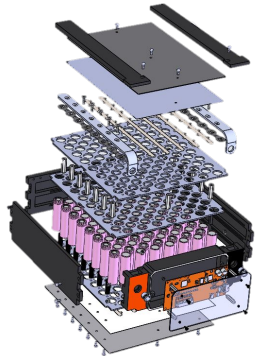
Battery testing is essential for safe & reliable products:

1. Safety behaviour
2. Battery performance validation
3. Reliability and battery lifetime
4. Regulatory compliance
5. Manufacturer quality control
6. End-user confidence
7. Failure analysis & forensics

Battery testing is conducted at different stages of product development by:

- Cell manufacturer
- Battery manufacturer
- Battery-powered product manufacturer
- Third-parties (regulators & authorities, TICs)

Introduction – Testing along the battery lifecycle I / II



Research & Material development

- manufacturing of coin cells
- Testing focused on material properties & performance (energy density, cycle life, etc.)

Cell development

Scale up from handmade prototypes to prototyping line

Cell A sample

- 100s of cells from prototyping line
- Testing focused on viability for mass production
- Performance (Capacity, OCV, max. C rates)
- Lifetime (CC-CV)
- Safety (Overcharge, short circuit, etc.)

B sample onwards

- 1000s of cells to mass production
- Testing focused on complete mapping & certification
- Performance & Lifetime (detailed testing for complete picture on behavior)
- Cell certification (IEC, UL, UN 38.3)

Battery pre-development

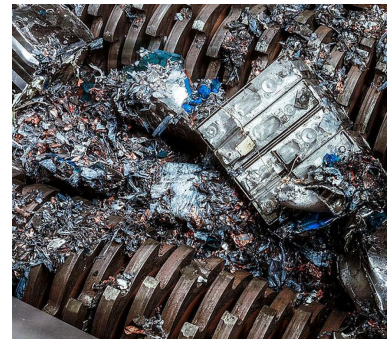
- Testing focused on cell selection
- Performance & Lifetime mapping of cell candidates (using application profiles)
- Application-relevant safety testing of candidates

Battery development

- Testing focused on understanding chosen cell
- Data generation for design [thermal] and modelling [simulation, BMS, digital twin] (thermal & electrical behavior of cell)

Sources (Image): V. Boulanger et. al. (2020)

Introduction – Testing along the battery lifecycle II / II



Prototype batteries

- Small number, produced for testing in application and for certification
- Inhouse application testing (performance)
- Certification (IEC, UL, UN 38.3)

Battery production

- End-of-line testing & QC
- Testing focuses on quality
- Quick checks at end of line (ACIR, optical scan, quick check methods [e.g. Li+])
- Sampling of products for inhouse QC testing
- Commissioning testing for stationary BESS

End of first life

- (Quick) Testing of batteries (or disassembled to module / cell level) for sorting & grading
  - Determination of SoH (capacity & IR)
  - Determination of safety state
- Reuse or recycling based on determination

Second life battery

- Depending on disassembly state, repeat of testing of various lifecycle stages (performance, safety evaluation)
- End-of-line testing & QC
- Commissioning testing

Recycling

- No testing as such, but typically (deep) discharge to minimize shredding risk

Sources (Images): Microvast, DSA, BMW, Librec

Introduction – Recap battery hazards

Batteries (especially those utilizing flammable organic electrolytes) present a number of hazards → the aim of safety testing is to understand the reaction of the sample under foreseeable misuse- and accident scenarios

Cell opening / leakage

Release of substances and decomposition products that are:

- An irritant / harmful
- Corrosive and flammable
- Toxic (or highly toxic) and carcinogenic

Thermal runaway

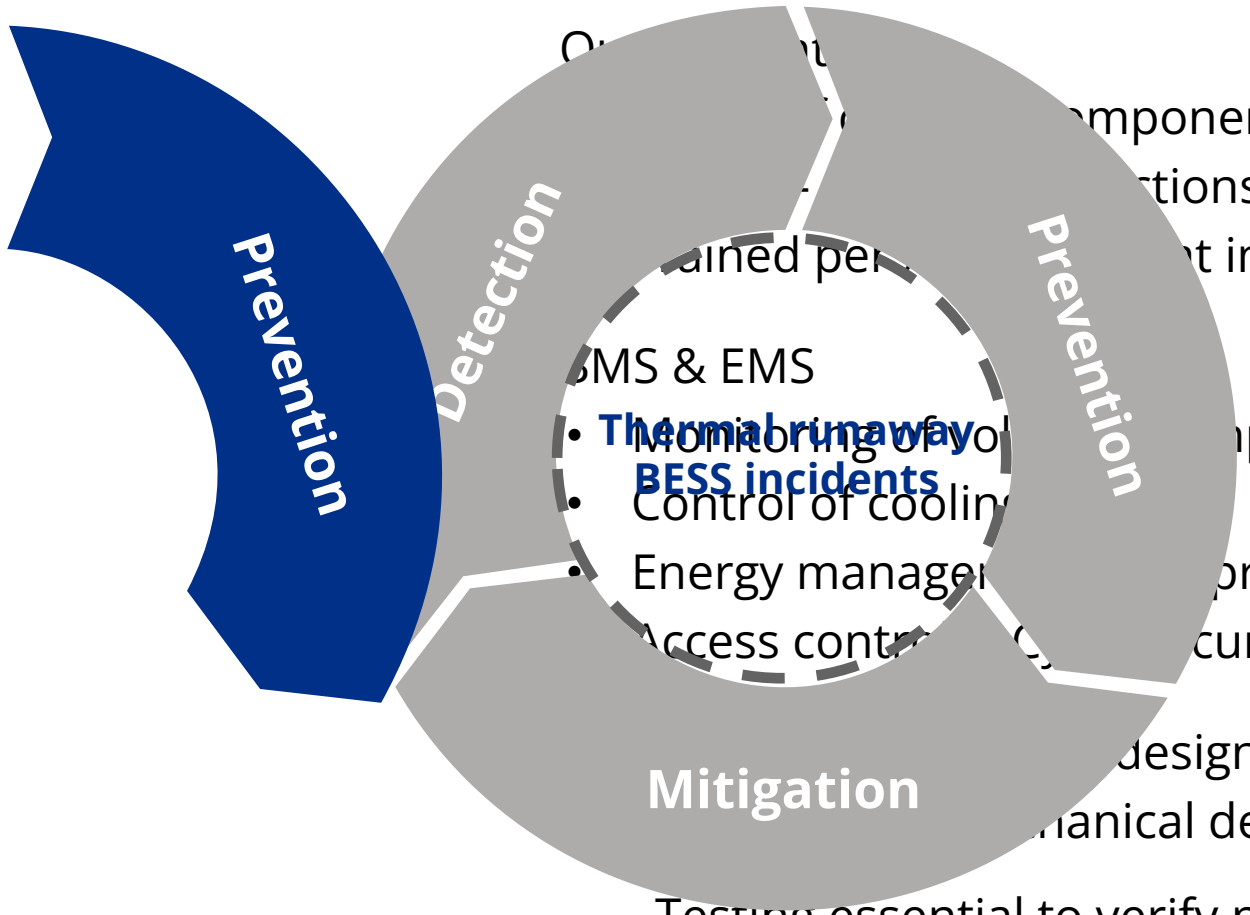
Self-accelerating, exothermal chemical reaction, leading to fast increase in temperature:

- “Containment“ very difficult
- Rapid pressure increase
- Release of smoke, possible rupture of cell
- Possible Fire / Explosion

Battery safety testing

Battery safety testing – ensuring safe deployments of BESS

Prevention by Design, QC, BMS & EMS



mponents

tions & assessments

t installer)

peratures and currents

predictive load reduction

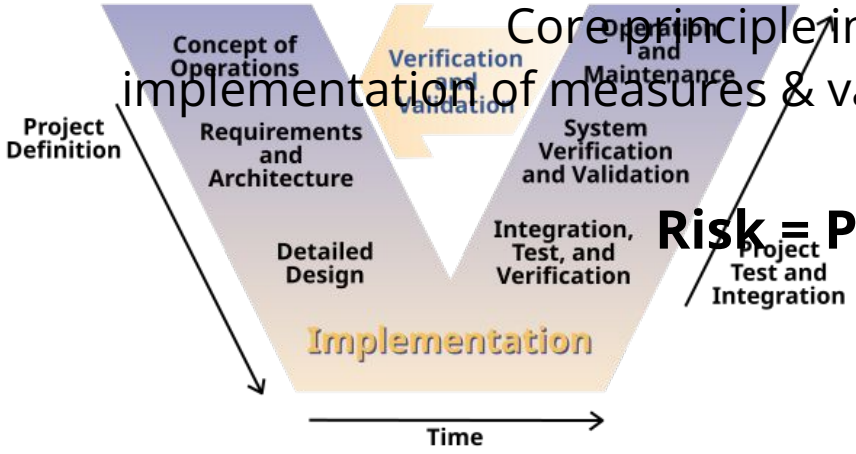
curity

design

hanical design

Testing essential to verify product design, effectiveness of measures and high-quality production

Battery safety testing – ensuring safe deployments of BESS



Core principle in safe technology is risk assessment, implementation of measures & validation

Risk = Probability x Severity

→ lower only due to fundamental technology change

Implementation of measures to lower probability
→ need to be verified to be effective

Testing essential to:

- Identify systematic failures that occurred in design phase before such failures become costly (recalls & legal cases)
- Uncover system response to unexpected & worst-case scenarios in application
- Understand & characterize system behaviour (thermal runaway & fire simulations challenging) to develop emergency procedures & fire fighting response

"You've got to be very careful if you don't know where you are going, because you might not get there."
- Yogi Berra

Source (Image): US Federal Highway Administration

Battery safety testing – landscape of safety standards

ISO 12405-4: Test specifications for li-ion traction battery packs
IEC 62660: Secondary li-ion cells used for propulsion of electric vehicles
UN ECE R100: Safety requirements on electric powertrain
UL 2580: Batteries for use in EV

ISO 18243: Safety requirements & tests for electric mopeds / motorcycles
EN 50604-1: Secondary li-ion batteries for light electric vehicles (LEV)
UN ECE R136: Safety requirements on electric powertrain for motorcycles
UL 22271, 2272, 2849: Batteries for use in LEV, PMD, Ebikes

IEC 62841-1: Electric hand-held tools
IEC 62133-2: Secondary li-ion cells & batteries for portable applications
UL 2054: Household and commercial batteries
IEC 60335-1: Safety of electric household appliances

IEC 62619: Secondary li-ion cells & batteries for industrial applications
IEC 62485, 62933-5: Safety of (grid-integrated) battery installations
UL 1973, 9540 & 9540A / 9540B: Stationary (battery) energy storage systems
CSA TS-800: Large-scale fire test procedure for stationary ESS

UN 38.3: Transportation testing
IEC 62281: Transportation testing

Sources (Icons): Freepik, berkahicon and monkik

Battery safety testing – Singapore context

Cell / battery level

- Adoption of IEC 62619 and UL 1973 for secondary cells, cell blocks and batteries with national foreword
- Adoption of IEC 62932 2-2, UL 1973 for flow batteries
- Code of Practice for Transport and Storage of New and Spent Batteries in planning, likely to include harmonized transportation test requirements

System level

Technical Reference (TR) 77 - Electrical Energy Storage (EES) System

- Part 1: Modified adoption of IEC TS 62933-3-1 (Planning and performance assessment of ESS)
- Part 2: Modified adoption of IEC TS 62933-5-1 (Safety considerations for grid-integrated EES system)
- Maximum 600 kWh, cluster of battery rack max. 250 kWh, spacing 1m from other clusters
- Additions for flood protection, thermal runway handling, dust / moisture / corrosion protection

UL 9540, UL 9540A for ESS at system level (inclusive propagation testing)

Battery safety testing – Singapore context

ESS requirements in the Singapore Fire Code (Section 10.3)

- In general max. 600kWh per fire compartment, 2h rated compartment, doors, automatic sprinkler (or mist) is required, same level as fire engine accessway, mechanically ventilated to be ≥6 air changes per hour
- Special requirements for temporary ESS on construction sites, Battery swap stations and Basement ESS installations
    - Basement ESS classified as small underground ESS (up to 250 kWh per compartment & 500 kWh in aggregate) and large underground ESS (up to 600 kWh per compartment)
    - Requirements on separation distances, compartment size, fire protection system, monitoring & alarm system, smoke purging & pressure relief, fire fighting access, etc.
    - For large underground ESS & small underground ESS not fulfilling spacing / requirements subject to UL 9540A testing and NFPA 855 Hazard Mitigation Analysis

Battery safety testing – Common tests from standards

Electrical tests

- Abnormal charge, continuous charge, overcharge
- Forced discharge (polarity reversal) / deep discharge
- External short circuit
- Insulation resistance & HV test
- Internal short circuit (*)

Thermal tests

- Thermal cycling (e.g. -40 °C to +70 °C)
- Thermal stress (up to +130 °C)
- Molded case stress test
- Projectile- & external fire test

Mechanical tests

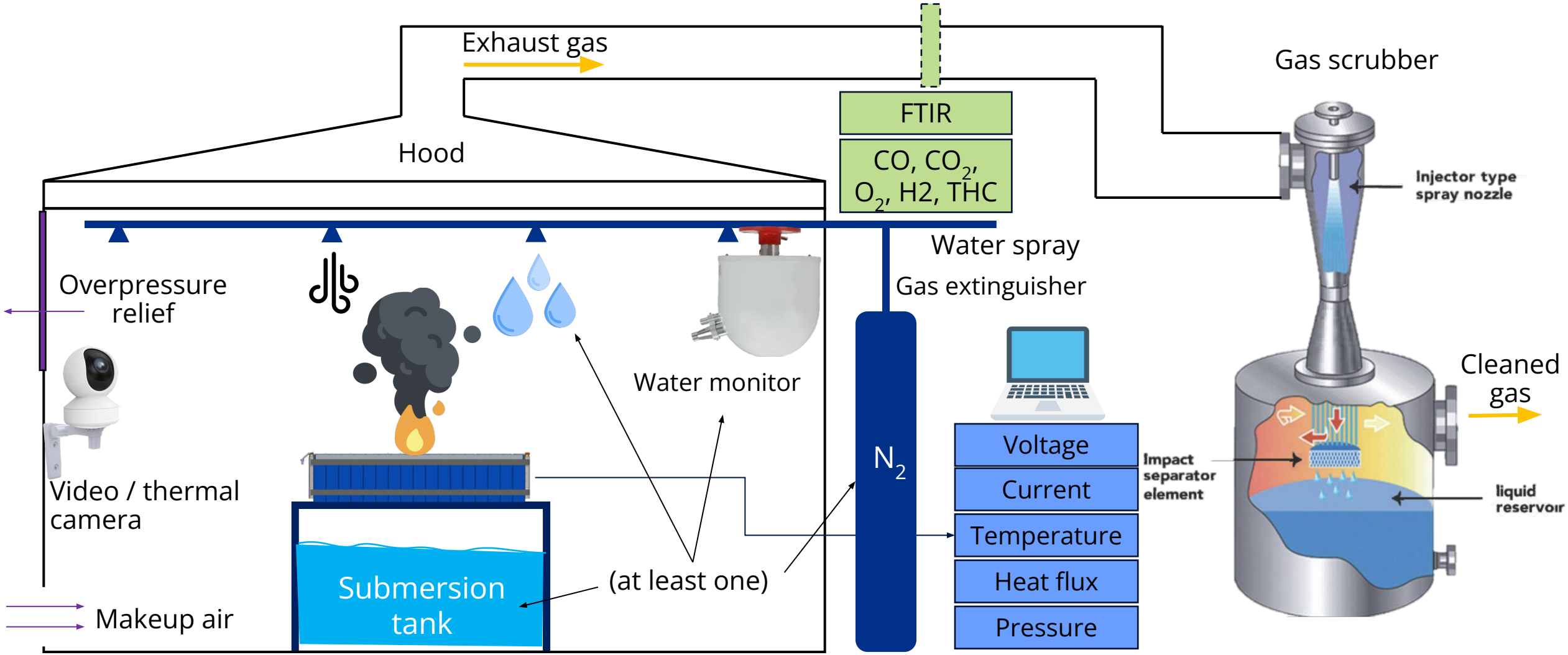
- Crush
- Vibration
- Shock
- (Blunt) Nail penetration – ceramic & steel nail
- Impact & drop (free fall)

Others

- High altitude (low pressure)
- Propagation testing
- Heat release rate & heat flux, vent gas composition
- Saltwater submersion
- (Functional) safety testing of BMS
  - Over / under voltage & current, overtemperature
  - Insulation resistance, Dielectric strength

(*) Requires cell preparation during cell manufacturing

Battery safety testing – Safety testing facility



Sources (Images): CR Clean Air, Winan, Tekcam

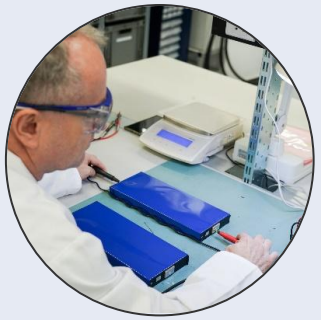
A*STAR Battery Test Facility

A*STAR Battery Test Facility

Test Services, Consulting and Research Projects

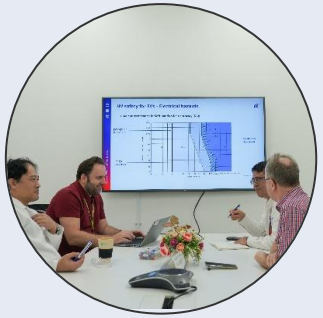
- Battery testing (performance, lifetime and safety) to support industry in Singapore and the region
- Testing based on (international) standards (IEC, UL, UN) or based on customer requirements to support product development, safety assessments or regulatory compliance / certification (with TIC partners)
- Consulting and development support on technology and (international) standards
- Support of research initiatives of A*STAR & Singapore IHLs (BRICE, SGBP2 and others)

Battery Forensics & Failure Analysis



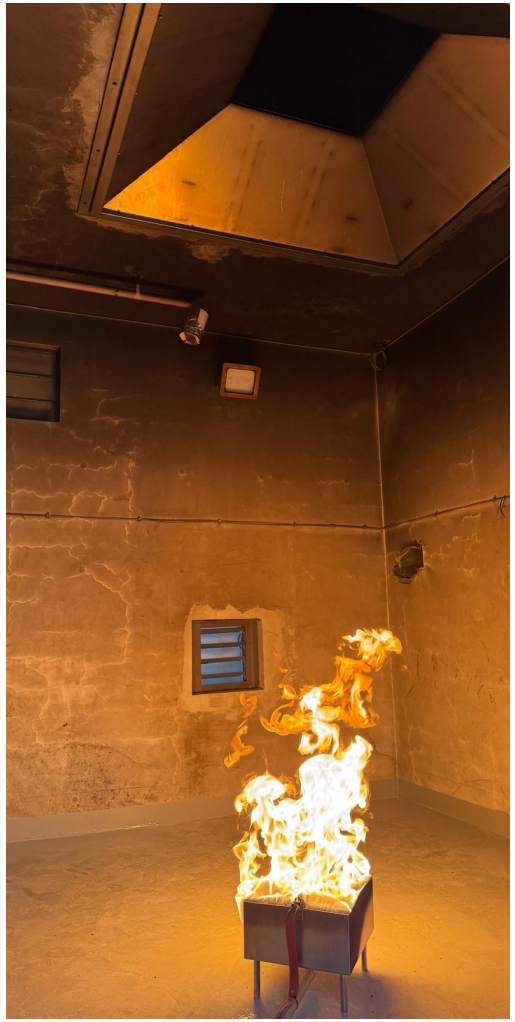
- Leveraging A*STAR's experts and scientists
- Reconstruction of accidents, electrical (re-) testing, (chemical) analysis of cells and materials
- Onsite inspections
- Providing expert opinions for possible causes of incidents
- Planned potential collaborations with Singapore public agencies (AHJs)

Training and Workshops



- Courses and Workshops with ARTC's Knowledge Transfer Office and IHL partners on lithium-ion technology
- Possible topics:
  - Lithium-ion technology introduction – cell chemistry and behaviour, system design, BMS
  - Safe handling and storage of batteries and dealing with High-Voltage battery systems
  - Masterclasses on battery technologies (technology, market, lifecycle, end of life)
  - Transport regulations and battery standards

A*STAR Battery Test Facility – Safety testing

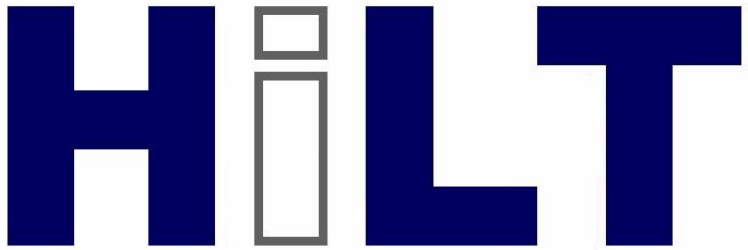


Destructive safety testing of (cell) materials, cells and batteries:

- Electrical testing *(overcharge, deep discharge, overcurrent, short circuit)*
- Mechanical testing *(crush, vibration, drop & impact, nail penetration [blunt & sharp nail, conductive & non-conductive nail])*
- Thermal testing *(overheating, temperature swing)*
- Thermal runaway propagation testing *(triggered by overheating, overcharge or nail penetration)*

- Bunker recently upgraded for heat release rate & heat flux measurements, as well as gas analysis (flammable & toxic)
- Enables conducting UL 9540A module- & unit level testing

Partnership on battery safety testing based on UL 9540A



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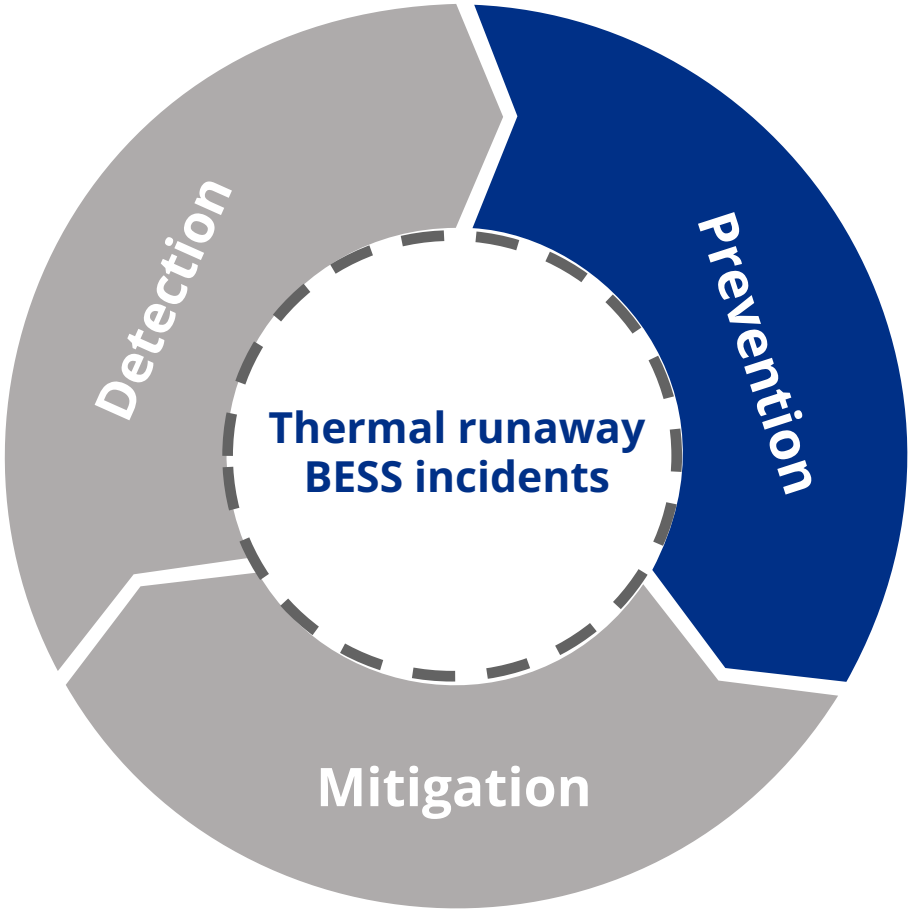

Prevention by Design, QC, BMS & EMS

Quality control

- Usage of certified components
- Factory- / facility inspections & assessments
- Trained personnel (also at installer)

BMS & EMS

- Monitoring of voltages, temperatures and currents
- Control of cooling strategy
- Energy management, e.g. predictive load reduction
- Access control & Cybersecurity

Constructive measures / design

- Thermal- and mechanical design

→ Testing essential to verify product design, effectiveness of measures and high-quality production