


New Internal Short Circuit Test Development for Battery Safety Standards

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PRODUCT SAFETY STANDARDS

A standard is a document that applies collectively to codes, specifications, recommended practices, classifications, test methods, and guides, which have been prepared by a standards developing organization or group, and published in accordance with established procedures.

Source: SES-1, “Recommended Practice for Standards Designation and Organization”

Focus on minimizing risk of electric shock, fire and injury

FIELD FAILURES

Since 2006, reports of failure but the not much detail

- Highly publicized failure of laptops powered by lithium ion batteries including fire and explosion
- Cargo airplane fires involving bulk transport of lithium ion cells
- In some cases, it has been noted that defects lead to internal short circuit (ISC) and thermal runaway
- Large number of recalls for single failure
- Electric vehicles are based on lithium ion cell chemistries utilizing sometimes several thousands of commercial, off the shelf (COTS) cells

BATTERY SAFETY STANDARDS

ORGANIZATIONS

- Underwriters Laboratories Inc (UL)
- International Electrotechnical Commission (IEC)
- National Electrical Manufacturer's Assoc. (NEMA)
- Society of Automotive Engineers (SAE)
- United Nations (UN)
- Institute of Electrical and Electronics Engineers (IEEE)
- Japanese Standards Association (JSA)
- International Organization for Standardization (ISO)
- Battery Safety Organization (BATSO)

BATTERY SAFETY TESTS

- Impact
- Shock
- Vibration
- Heating
- Temperature cycling
- Drop
- Molded case heating
- Open circuit voltage
- Insulation resistance
- External short circuit
- Abnormal discharge
- Forced discharge
- Crush
- Projectile
- Low rate/reverse charging
- Casing penetration
- Separator shutdown

	UL					IEC		NEMA	SAE	UN	IEEE		JIS	BATSO
TEST CRITERIA\STANDARD	UL1642	UL2054	SU 2271	SU 2580	SU 2575	IEC 62133	IEC 62281	C18.2M,Pt2	J2464	Pt.III,S 38.3	IEEE1625	IEEE1725	JIS C8714	BATSO 01
External short circuit	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Abnormal charge	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Forced discharge	x	x	x	x	x	x	x	x	x	x	x	x	x	
Crush	x	x	x	x	x	x		x	x		x	x	x	x
Impact	x	x	x	x			x	x		x	x	x		
Shock	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Vibration	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Heating	x	x	x	x	x	x		x	x		x	x	x	
Temperature cycling	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Low pressure (altitude)	x		x	x	x	x	x	x		x	x	x	x	x
Projectile	x	x	x	x							x	x		
Drop			x	x		x	x	x					x	x
Continuous low rate charging						x							x	
Molded casing heating test								x						
Open circuit voltage								x						
Insulation resistance				x				x						
Reverse charge			x	x										
Penetration			x	x					x					
Separator shutdown integrity									x					
Internal short circuit test	*			*									x	

BATTERY SAFETY RESEARCH

For safety of lithium-ion cells/modules/packs, *current focus* of key battery research organizations is ISC

UL is leading a task group reviewing possible ISC candidate tests:

- *NASA/UL*
- *Argonne National Laboratory*
- *Oak Ridge National Laboratory*
- *Sandia National Laboratories*
- *National Renewable Energy Laboratory*
- *Industrial Technology Research Institute*

Safety standards development organizations must help translate and transition this research into suitable tests based on best practices

ASPECTS OF CELL FAILURE

For products, such as batteries produced/consumed on very large scale (>10^6/yr), even with 6σ manufacturing processes, a relatively large number of failures are inevitable.

This is not easily addressed by tests in safety standards

For failure of a commercial product there are "reasonable and forseesable" abuse conditions that can be understood.

Developing comprehensive menu of abuse conditions is the main focus of tests in safety standards.

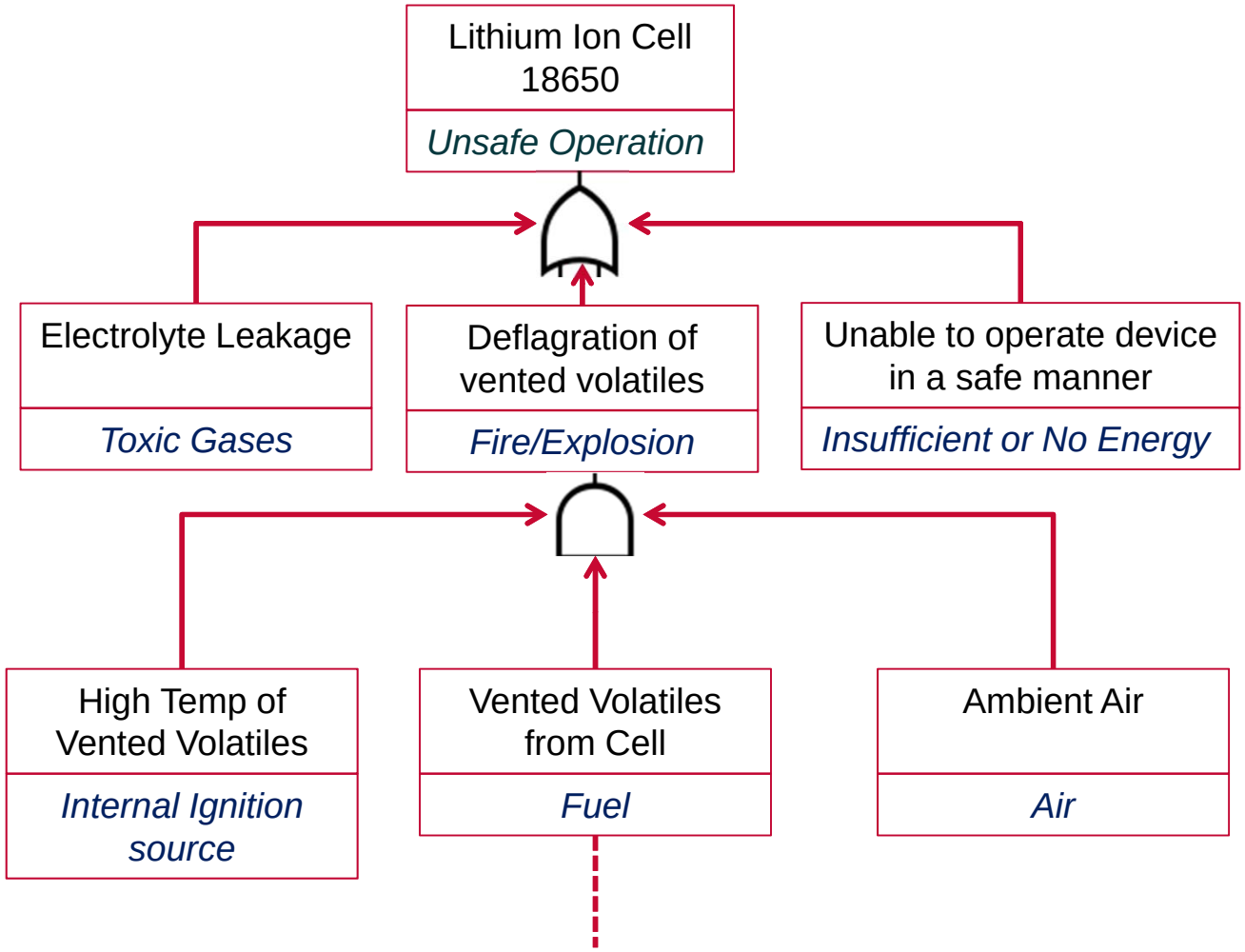
HAZARD ANALYSIS

- Standards safety tests need to be developed in the context of a *hazard analysis:*
  - ✓ Comprehensive
  - ✓ Based on multiple methodologies (FTA, FMEA, ETA, etc.)
  - ✓ Quantitative vs. Qualitative
  - ✓ Living document

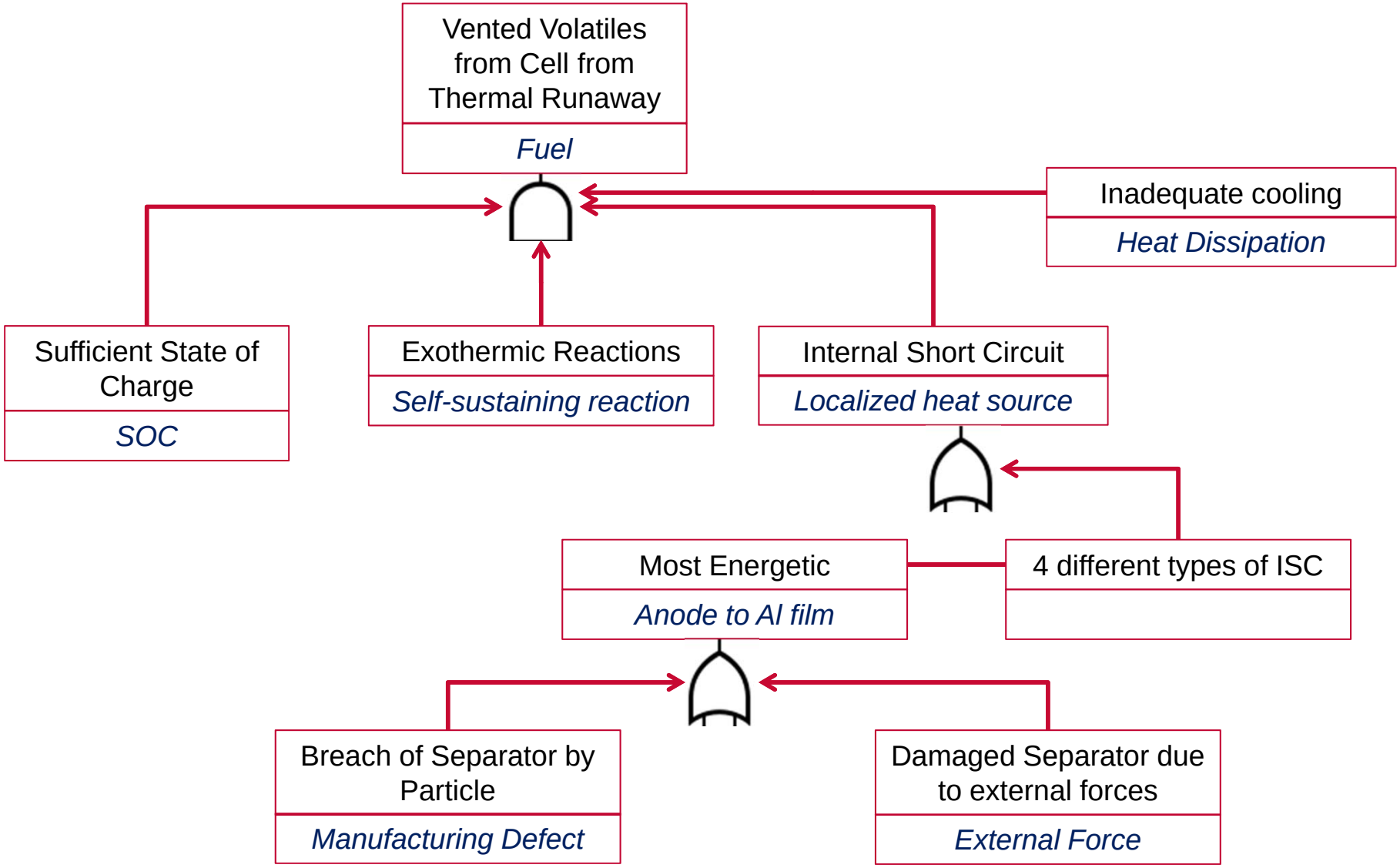
- Each safety test should address a root cause for a particular failure mode

- For a failure mode that occurs at very low levels, a pass-fail test may not be suitable. Instead a test that induces failure and evaluates the subsequent performance may provide a more **risk-informed approach.**

SIMPLIFIED FAULT TREE ANALYSIS

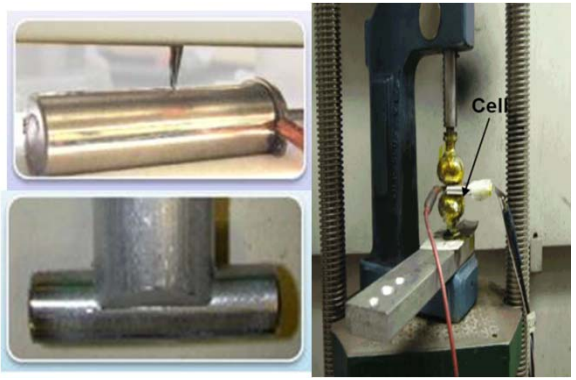


More FTA



PARTIAL HAZARD ANALYSIS FOR ISC

EXTERNAL FORCE
- ***Crush***
- ***Penetration***
- ***Indentation***
- ***Vibration***



INTERNAL DEFECT
- ***Manufacturing***
- ***Aging (overcharging, etc.)***

ISC

Localized Temperature Increase

Heat Dissipation

Exothermic Reactions

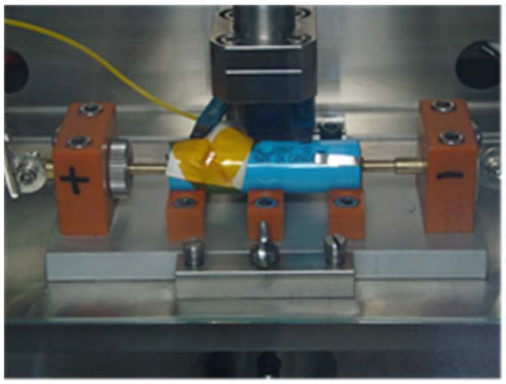
Thermal Runaway

- Fire
- Explosive release of gases
- Leakage

- ‘Safe Failure’

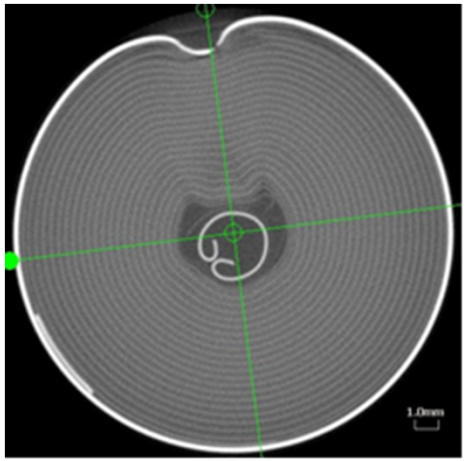
INDENTATION INDUCED ISC TEST

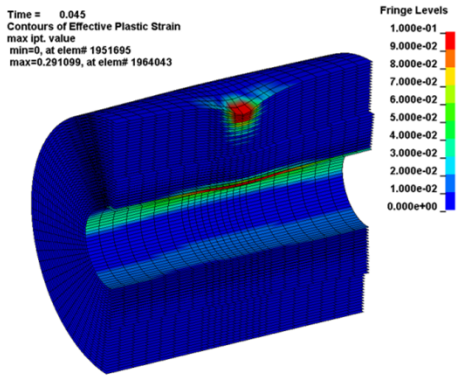
- **Features of New Test Method**
  - Localized indentation of cell without penetration
  - Controlled speed and temperature conditions
  - Specified state of charge (SOC) and cycle life of cell
  - Measure cell surface temperature, open circuit voltage (OCV), displacement and force of indenter along with visual observations
  - Induce failure to assess performance of cell

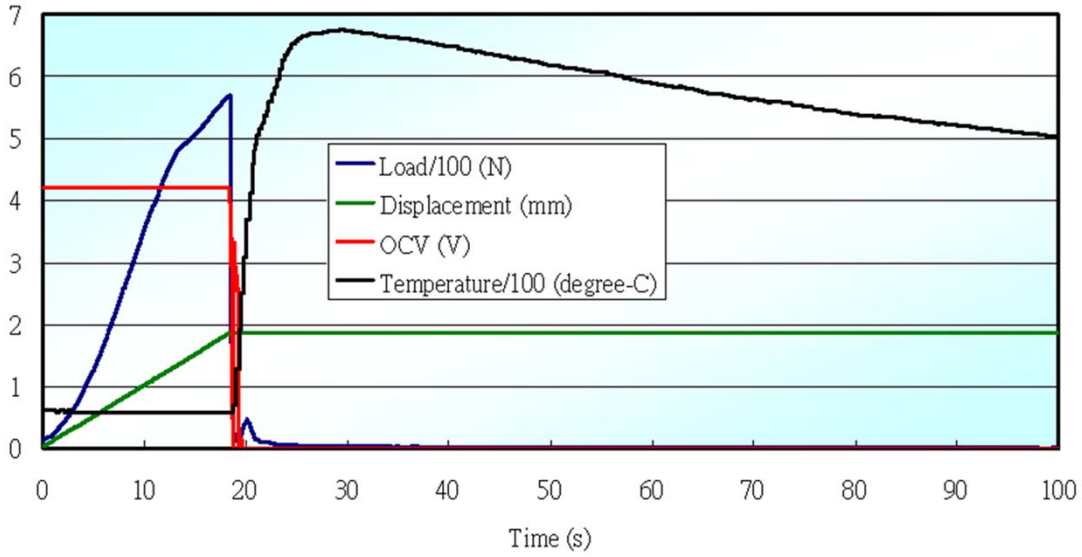


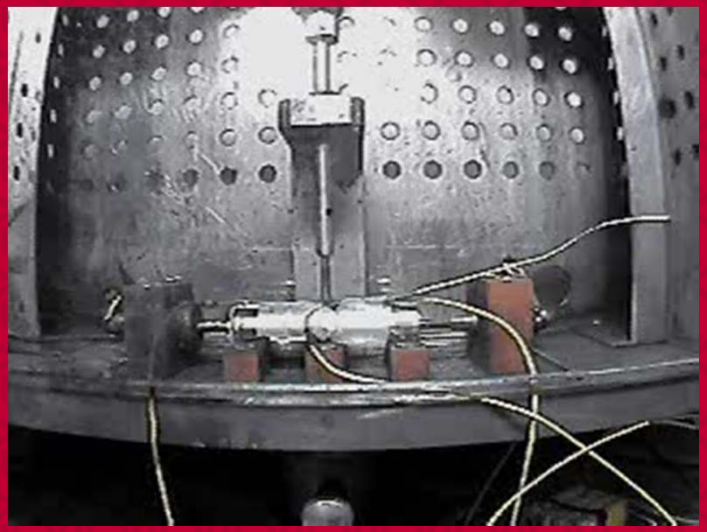
SAMPLE RESULTS

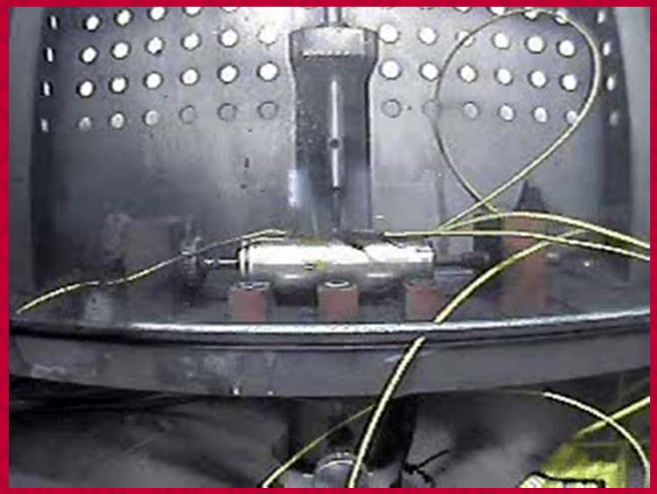
- **Induce ISC within a few layers from the indentation surface**

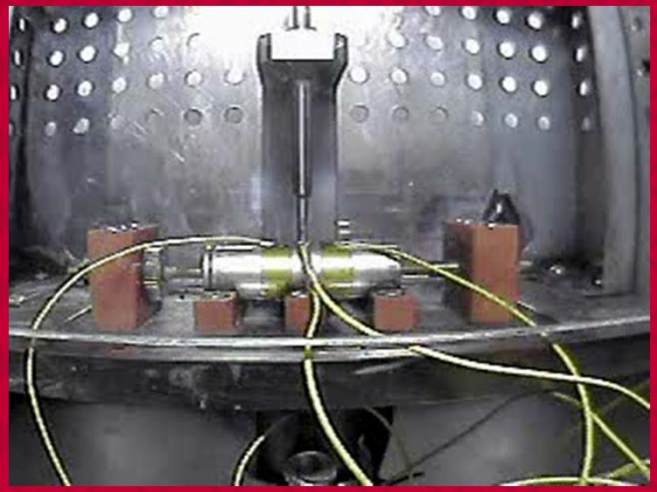






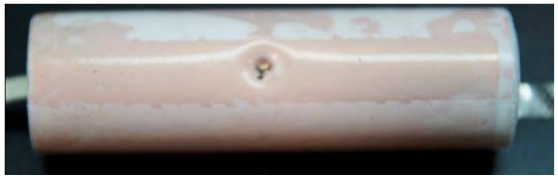






CHARACTERIZING ISC

0% SOC

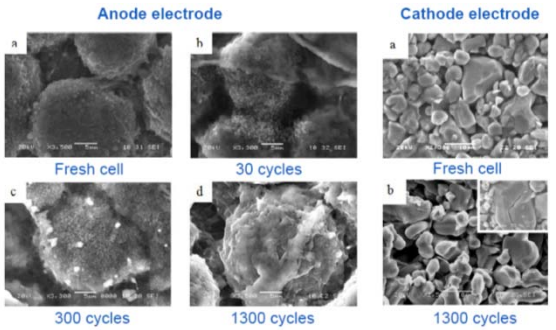


50% SOC

LIFECYCLE HAZARDS

New vs. aged cell samples

Are aged cells more susceptible to a particular failure mode?



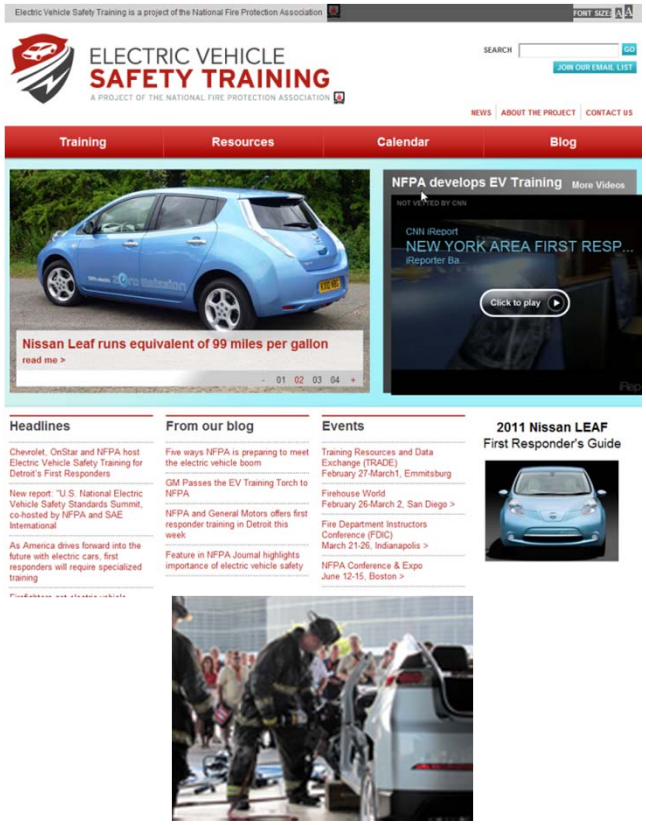
Bulk transport and storage

- Concerns by insurance companies
- Fire incidents on board freight airlines involving bulk transport of lithium-ion cells (FAA)

Disposal/Reuse/Recycling

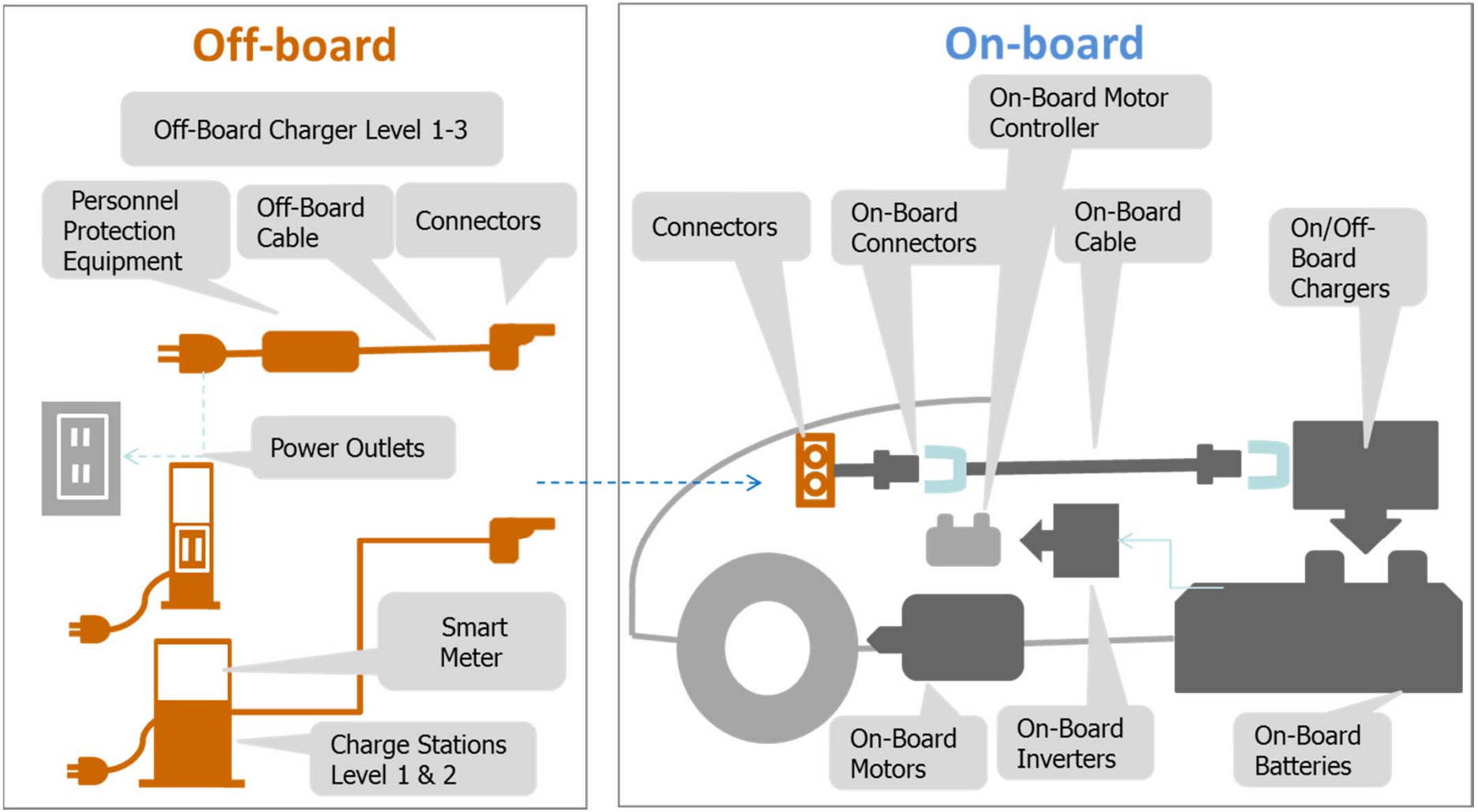
2nd life/secondary market for EV batteries as energy storage devices for utility

ELECTRIC VEHICLES



*Tesla Roadster uses about **6800** of 18650 cylindrical lithium-ion cells with a mass of 450 kg*

STANDARDS FOR EV COMPONENTS



UL Product Safety Process

simplified for Electric & Electronic products

legal framework

standards

pre-market testing & certification
- components pre-qualification
- end-product verification
- re-evaluation of modified products or components

post-market factory surveillance
- factory pre-qualification
- ongoing product inspection at factory

post-market trade surveillance
- 'blind-shopping' & verification
- customs control & anti-counterfeiting
- regulatory cooperation

technical competence
(of the parties involved)

simplified version of the process

CHALLENGES

Difficult challenges ahead for developing new ISC tests (lithium-ion cells) suitable for safety standards

- Standards are consensus based
- Product development is still cutting edge research
- Practical difficulties in procuring samples (and field failure data) especially as testing moves from cell to module to pack

Transition of research laboratory safety test into suitable format for standards

- Based on best practices template
- Suite of ISC tests may be necessary
- Induce failure vs. measure against a threshold
- Extend research into fire suppression

MAKING BATTERIES SAFE

Collaborations and partnerships are vital to help move battery (and EV) safety standards forward

- *Standards harmonization can help reduce regulatory complexity*

Strong safety standards and market surveillance covering cells to EV to infrastructure:

- *Enable safe product commercialization*
- *Move from component to system safety*
- *Help manage risks of complex global supply chain*
- *Build and maintain public confidence*

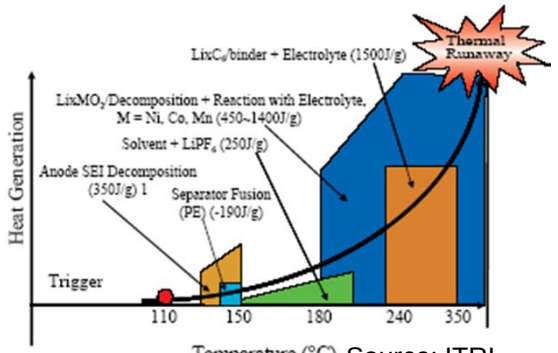
THANK YOU.

谢谢你

POSSIBLE FAILURE MODES

Thermal runaway → fire and explosion

- Abuse condition leads to thermal instability
  - Heating of active materials may initiate self-sustaining exothermic reactions within cell
    - Internal short circuit
    - High temperature environment
    - Overcharging/overdischarging
- Reaction time of passive safety mechanisms may be longer than rate of internal heat/pressure generation resulting in explosive failure of cell housing possibly leading to combustion as hot volatiles are released into atmosphere
- Transfer of heat from one cell to adjoining cell(s) or other nearby flammable objects



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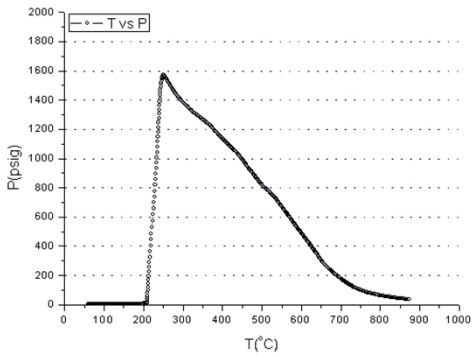

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