A Guide to Lithium-Ion Battery Safety

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Battcon 2014

What is safety?

- Safety is not absolute!
- …or intrinsic (to batteries)

- Safety is relative and is expressed statistically

Definitions

- **safety** – 'freedom from unacceptable risk'
- **hazard** – 'a potential source of harm'
- **risk** – 'the combination of the probability of harm and the severity of that harm'
- **tolerable risk** – 'risk that is acceptable in a given context, based on the current values of society'

Safety statistics – IEC 61508

- "Functional safety of electrical/electronic/programmable electronic safety-related systems"
- Safety Integrity Levels:

SIL	High demand or continuous mode: probability of dangerous failure per hour
1	$\geq 10^{-6}$ to $< 10^{-5}$
2	$\geq 10^{-7}$ to $< 10^{-6}$
3	$\geq 10^{-8}$ to $< 10^{-7}$
4	$\geq 10^{-9}$ to $< 10^{-8}$

Good safety philosophy

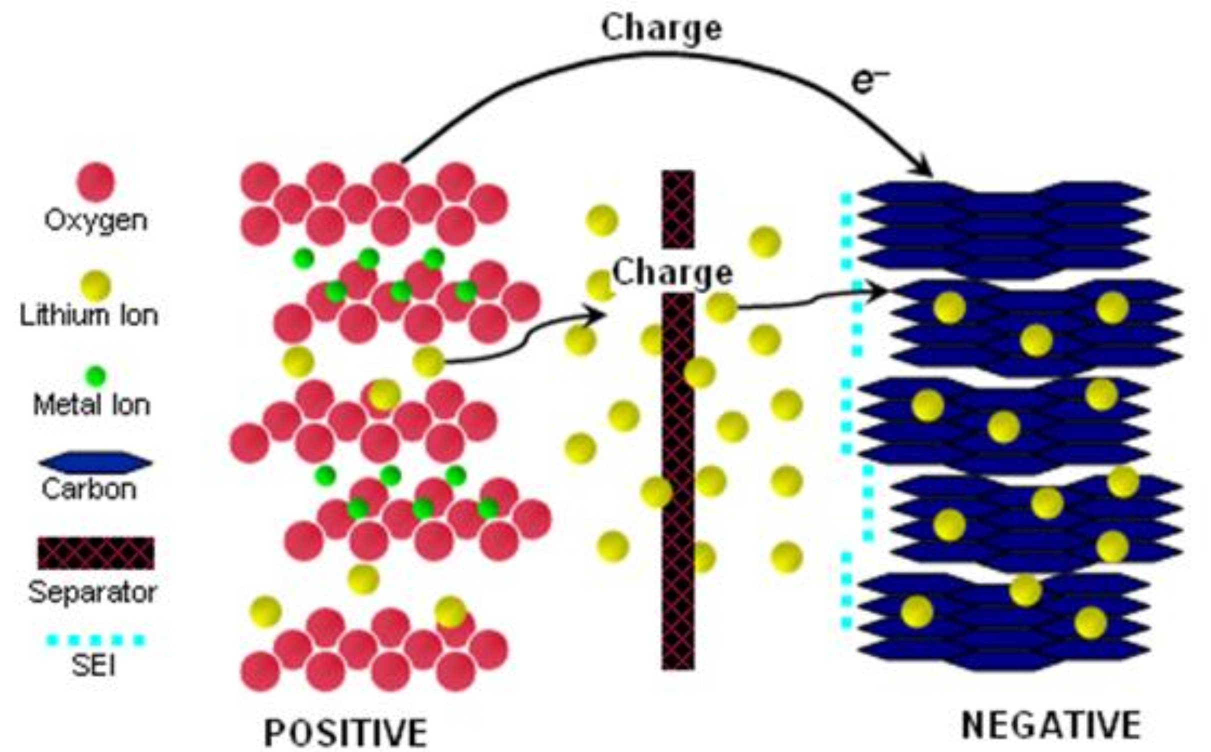
- Safety events cannot be entirely eliminated

- Reduce the probability of a safety event
- Minimize the level / severity of that event
- Limit the consequences of the event

Lithium-ion hazard categories

- Overcharging
- Overtemperature
- Mechanical abuse

Lithium-ion basics



Battcon 2008 –
"Understanding Lithium -Ion Technology"

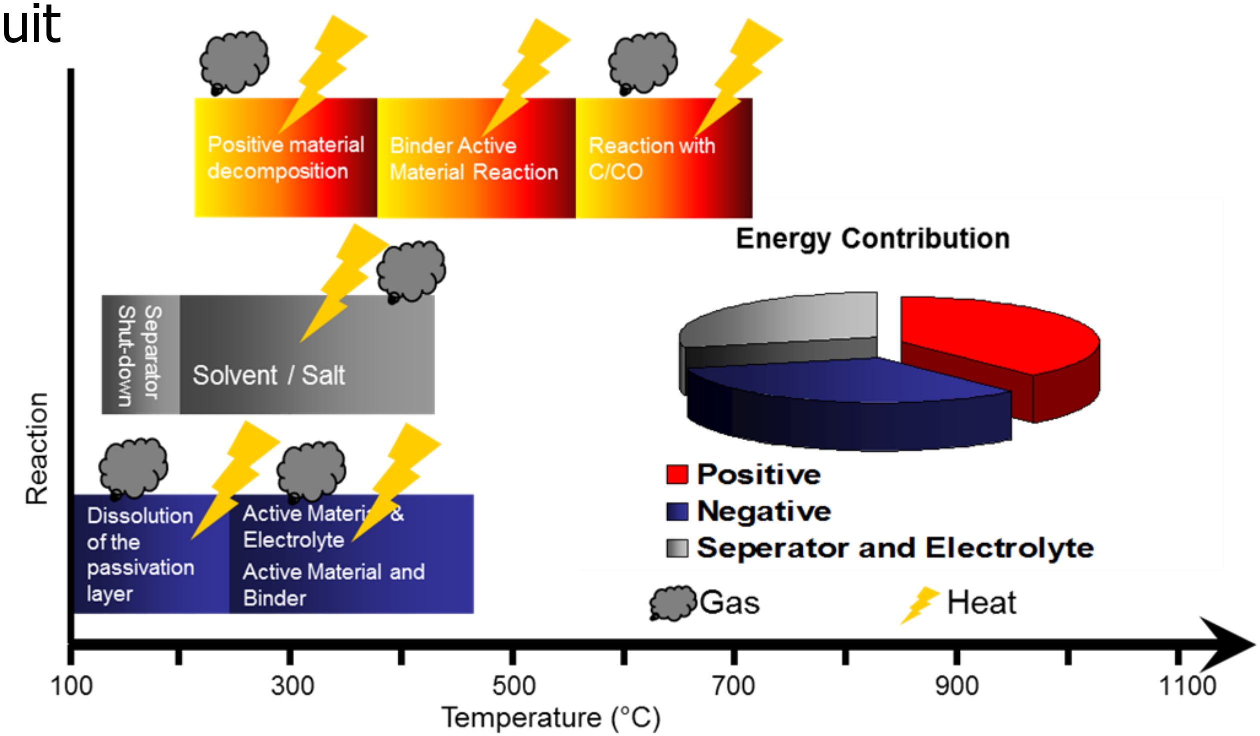
- Safety characteristics vary by Li-ion electrochemistry
- Overcharged (delithiated) positive can become unstable
- Passivation layer (SEI) can break down above 100°C

Overcharging

- The most serious of Li-ion safety events
- …but also the least likely
- Would require very high voltage
  - Around 65V for a 48V system
  - Around 160V for a 125V system
- Multiple layers of control
  - Reliable charging systems
  - Alarm management
  - Battery-level switches

Overtemperature

- Causes
  - High ambient temperature
  - I^2R heating from duty cycle
  - Internal short circuit



Mechanical abuse

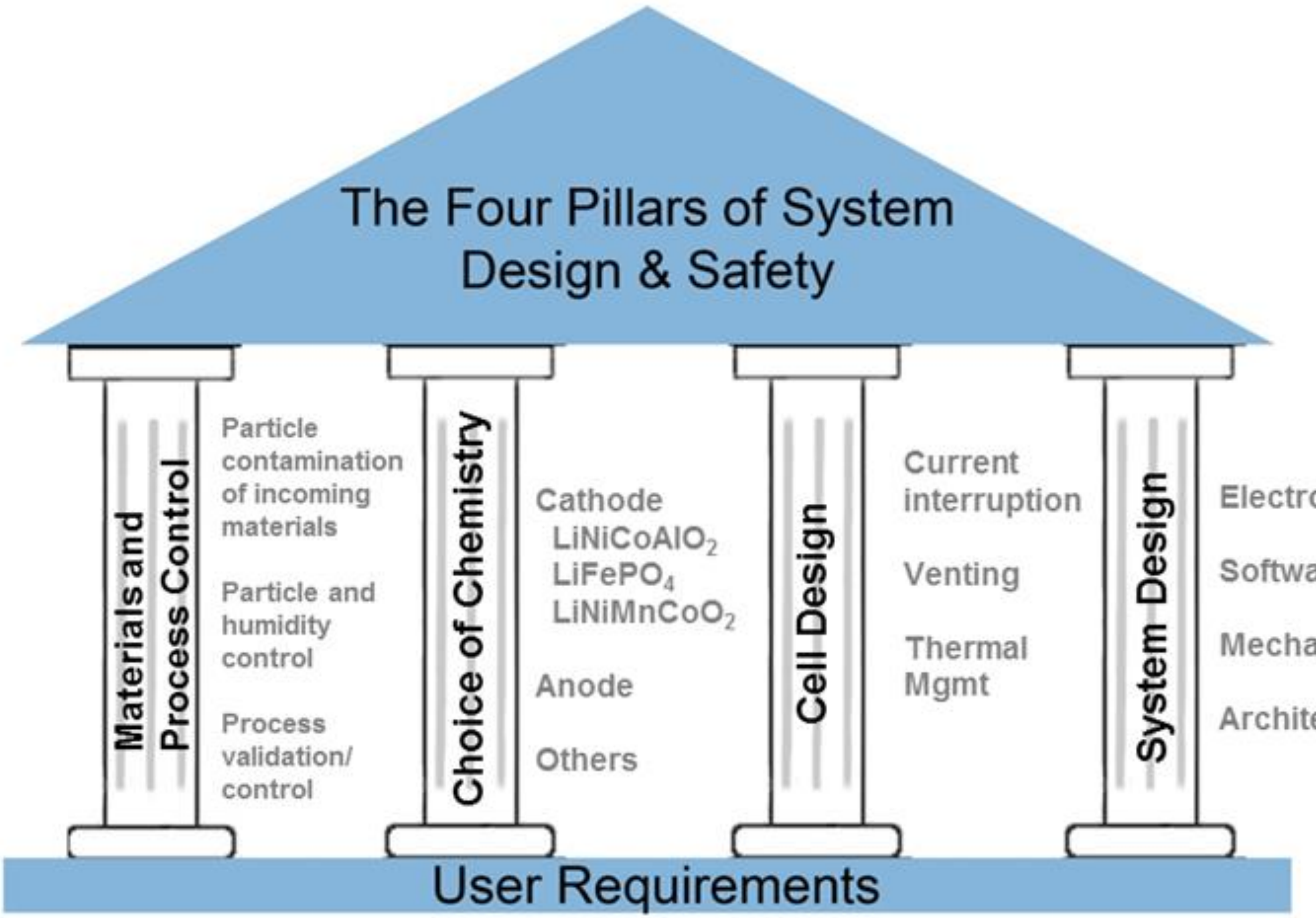
- Crushing or penetration of cells
- Can cause short-circuiting and overtemperature
- Most likely during transportation and installation
  - Shipment in partially charged state
- Roadside cabinets could be hit by a vehicle
  - Partial protection from cabinet structure

Selling safety

- Frequent promotion of 'single-shot' safety solutions
  - Electrochemistry
  - Ceramic-coated separators
  - Thermal-management devices
- Electrochemistry
  - Lithium iron phosphate
  - Lithium titanate
  - Each has pros and cons
  - No intrinsic safety!

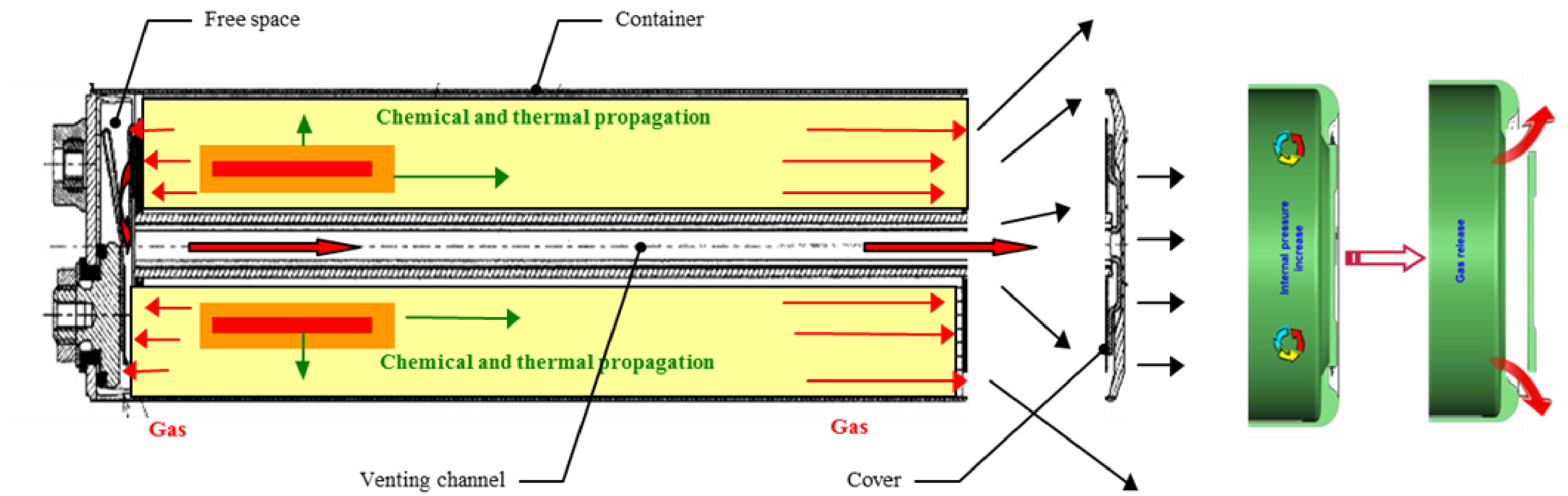
"Prius fire forensics" report

Holistic safety – the four pillars



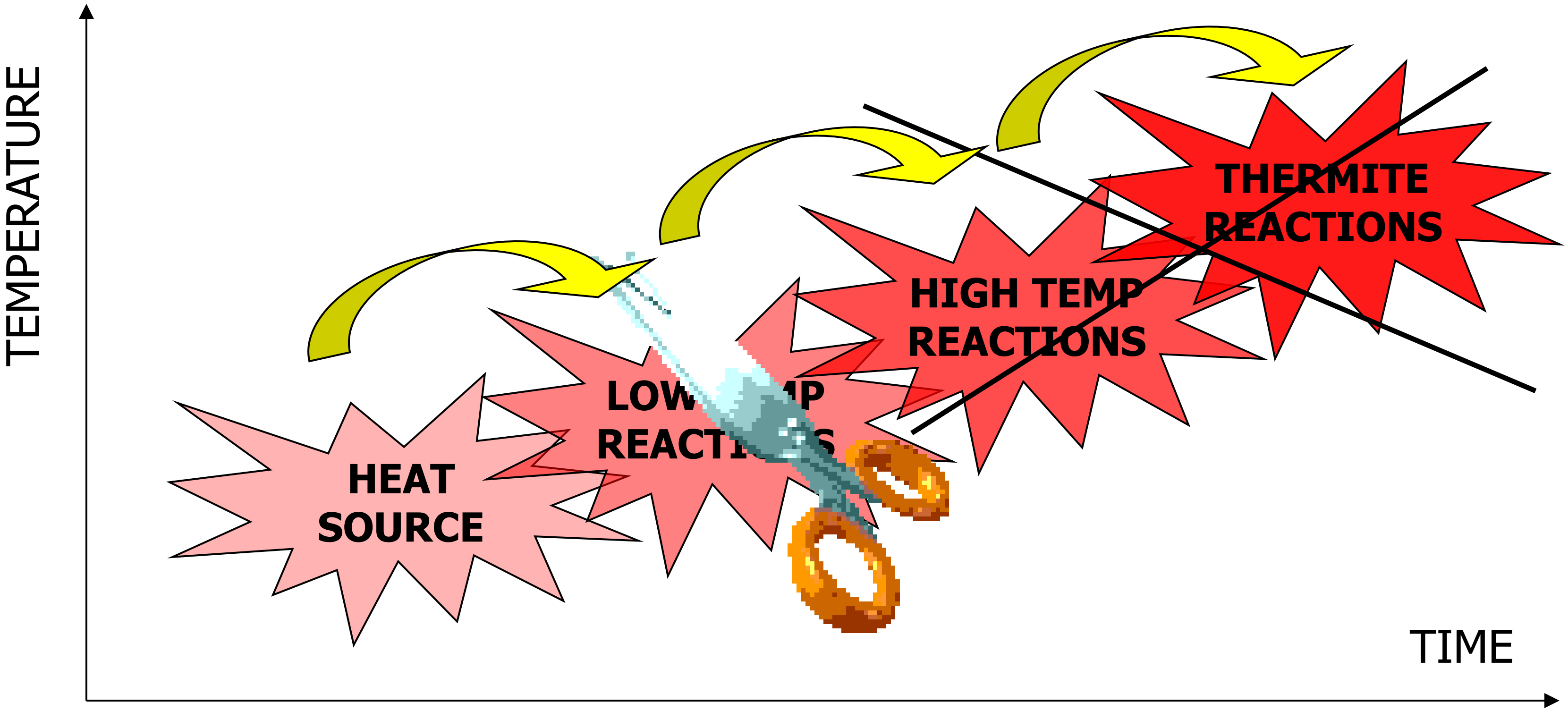
Cell design – venting

- Relies on gas pressure buildup within cell
- May also have a circuit-interrupt function



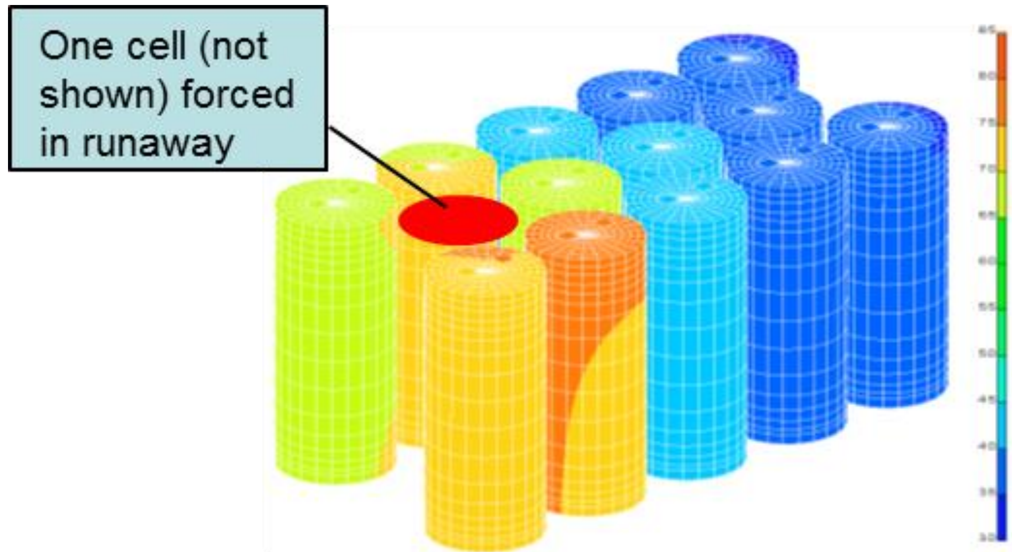
Effects of cell venting

- The severity of a thermal runaway event can be limited if the chain is interrupted



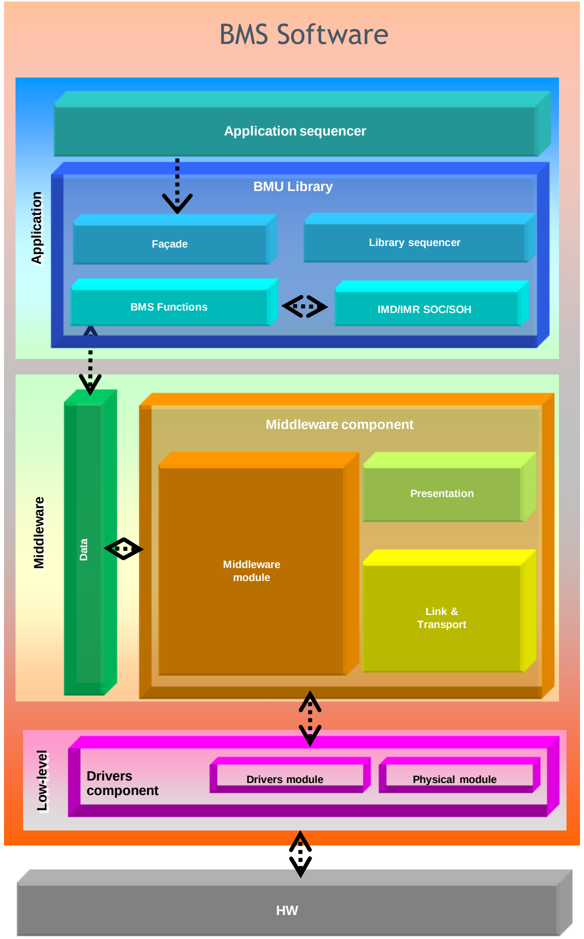
System design – module

- Avoid heat propagation from a cell in thermal runaway
  - Air gap
  - Thermal insulation
  - Phase-change material
- Module mounting must allow for management of vented gas



System design – battery management

- Layered approach to safety management
  - Measurement and detection
  - Cell balancing
  - Switches (contactors; MOSFETs)
  - Algorithms
  - Alarm management



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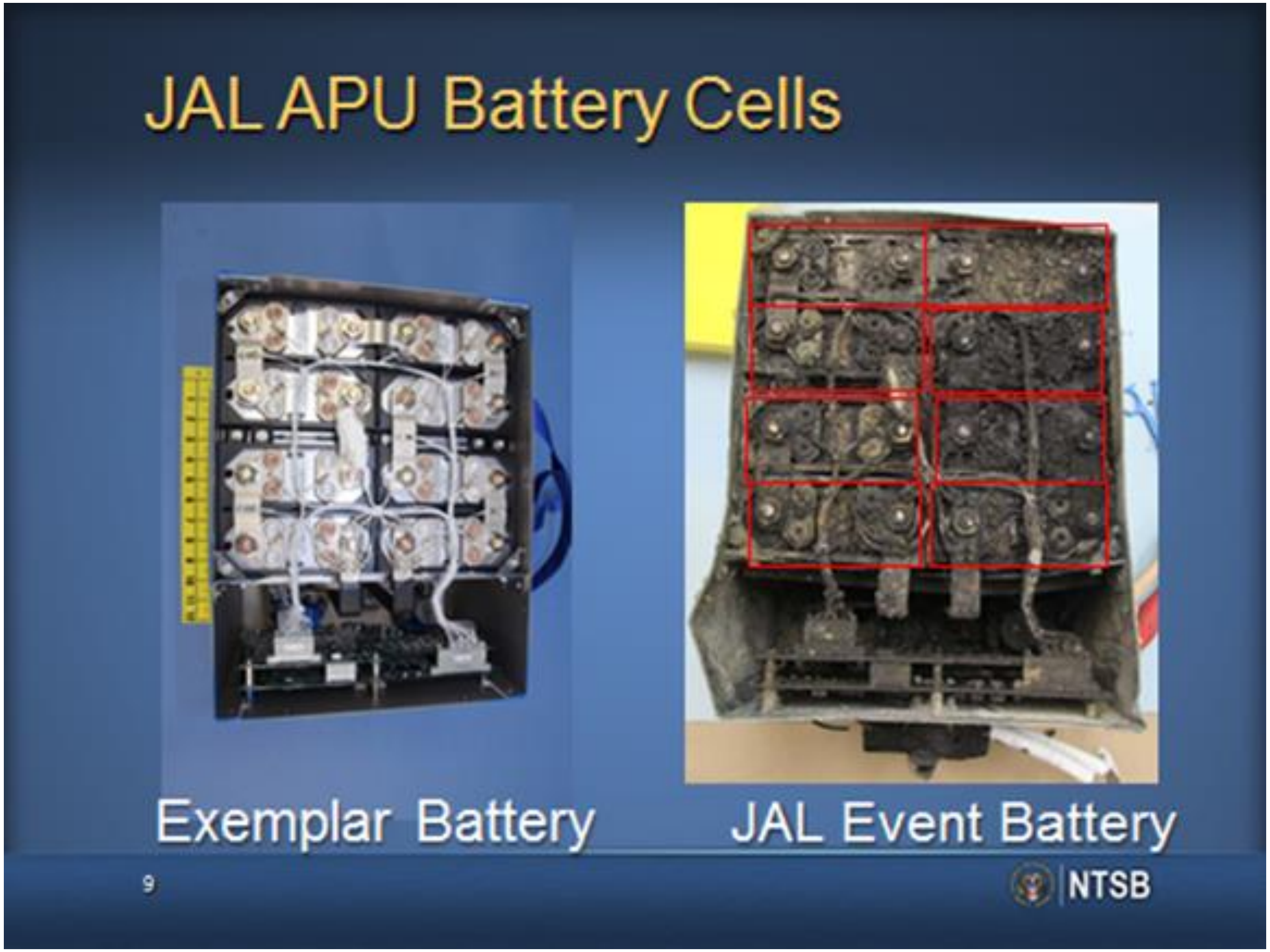
Case study – Boeing Dreamliner

- First large commercial jet with Li-ion batteries
- Two incidents of battery fires grounded the fleet for months
- Extensive NTSB investigation

Dreamliner battery design



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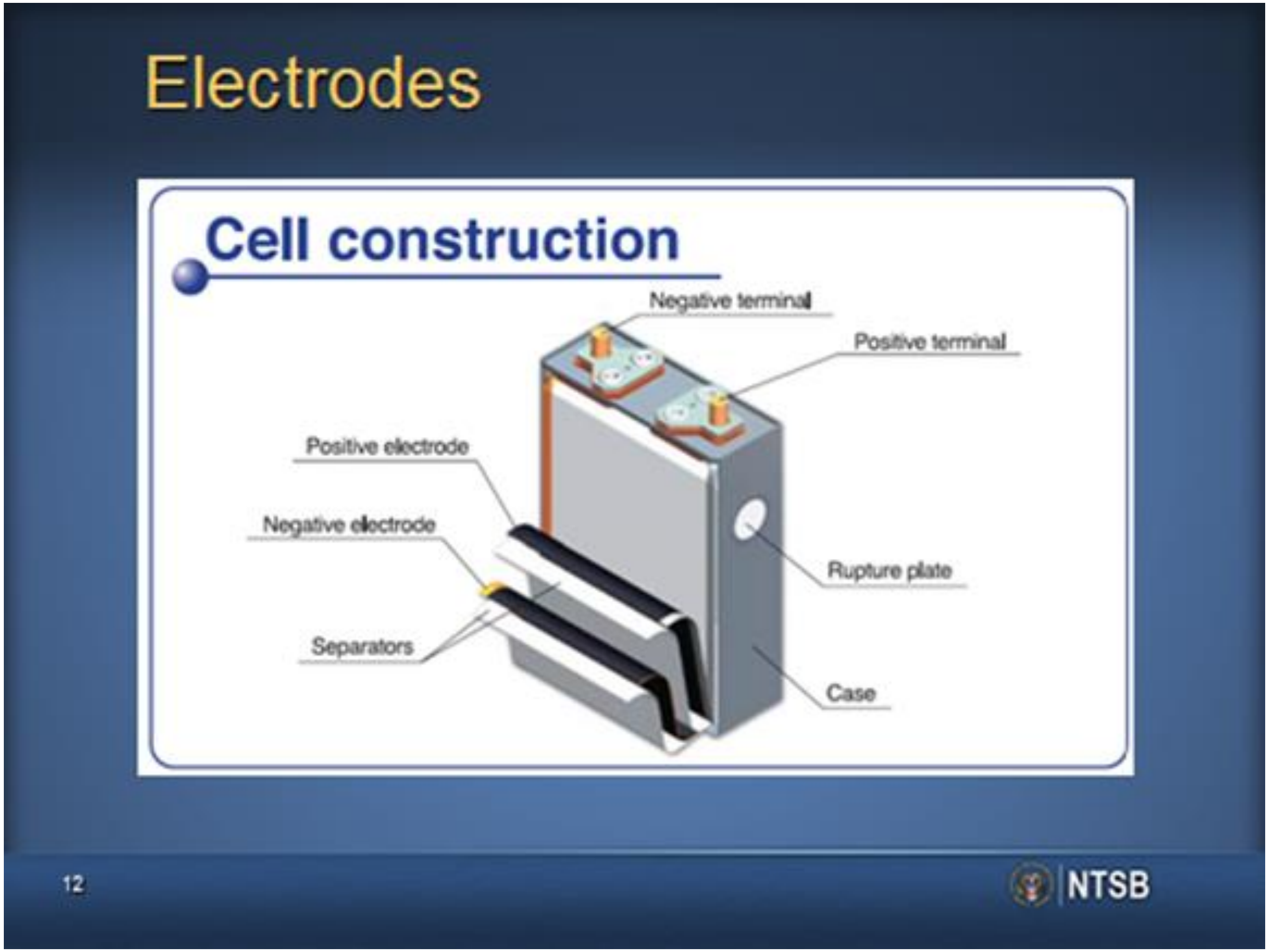
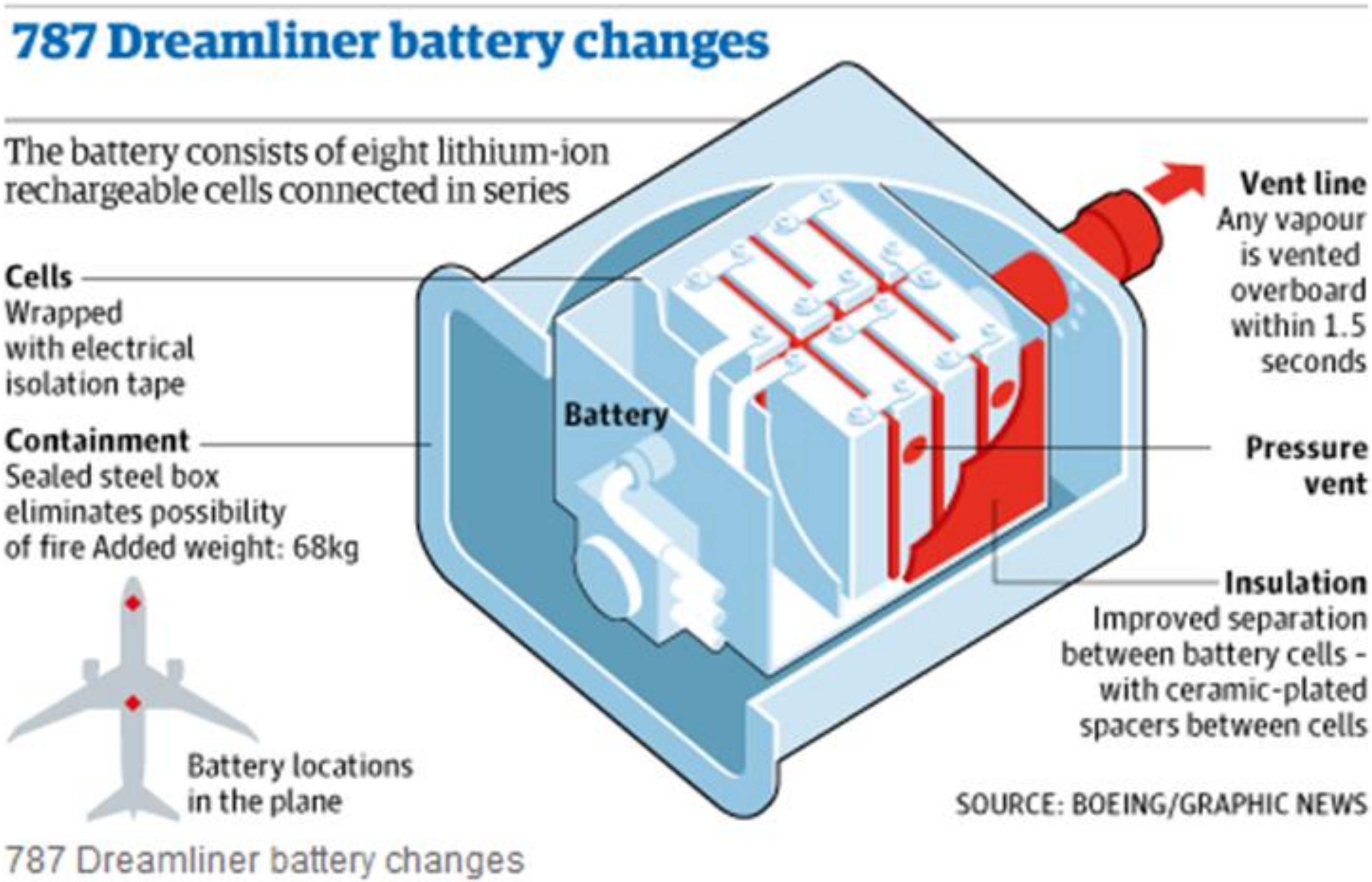
Dreamliner cell construction



Dreamliner battery fix



Standards and specifications

- Two approaches
  - Specify safety design features
  - Specify functional safety under application conditions
- Specifying functional safety is far better
  - Allows use of standards
  - IEC 61508 – SIL level
  - Telcordia GR-3150
- IEEE Std 1679 provides framework for evaluating safety and other functionality of new technologies

Summary

- Recognize that safety is never absolute
- Holistic approach through “four pillars” concept
- Safety maxim: “Do everything possible to eliminate a safety event, and then assume it will happen”
- Properly designed Li-ion batteries can be operated confidently with a high degree of safety

Thanks for listening…

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