Trends, Challenges & Emerging Solutions for Lithium Battery Logistics

An Industry Overview for the 2017 Labelmaster Dangerous Goods Symposium

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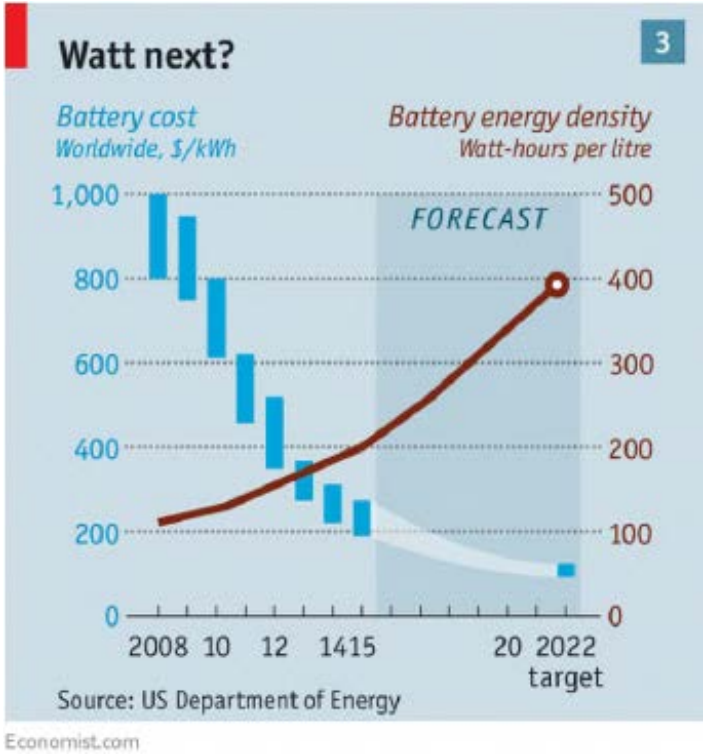
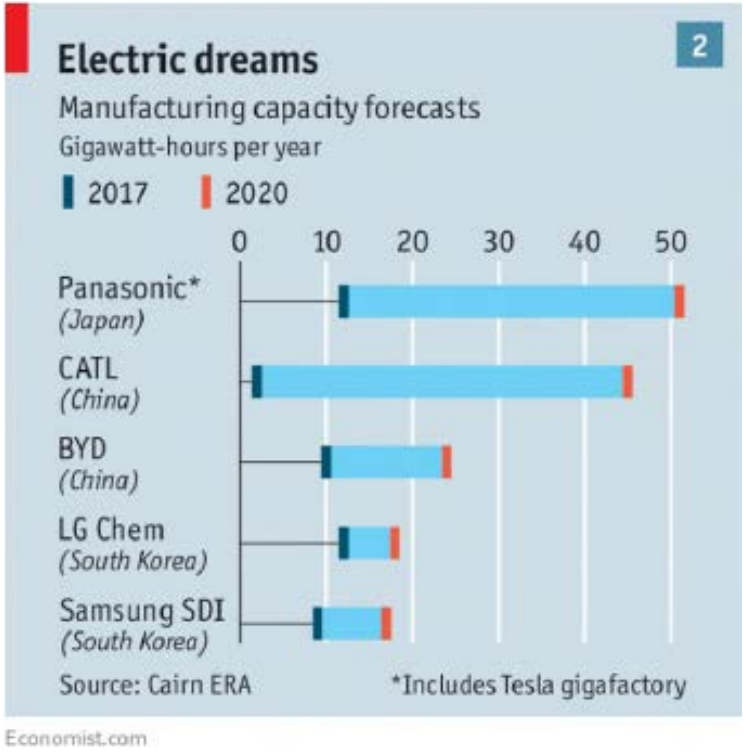
James Jones
Director
Product & Quality Management
PA^2

State of Lithium Battery Industry

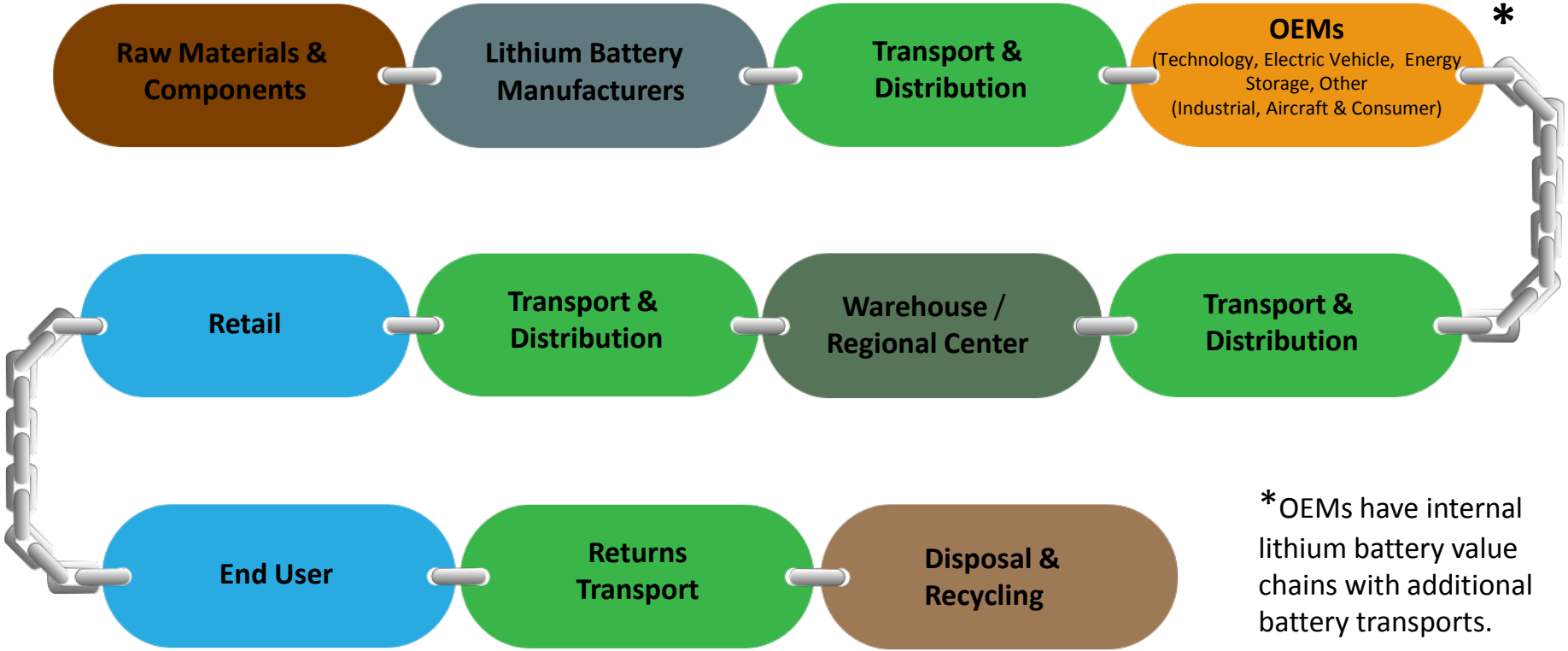
- Continued double-digit growth in Li-ion cell/battery production
  - 2006-2016 – 22% CAGR
  - 2017-2025 – 13-17%% CAGR
    - Reflects maturation of some markets
- Ever cheaper cost per unit
  - 2015-2020 – 50% decrease in cost per unit
- Continued increase in power storage (energy density) per unit
  - 5-7% CAGR
- Mix of Li-ion battery production is changing
  - 2016 – 48 Gigawatts – non-automotive – 25 Gigawatts automotive
  - By 2020 – Electric vehicle battery output will surpass all others

Lower Costs, More Power Per Unit & Many More Factories





Batteries Are Transported 4-6 Times Throughout The Lithium Battery Value Chain



*OEMs have internal lithium battery value chains with additional battery transports.

Critical Issue – Air Transport Safety

- Catastrophic fires/explosions on at least 3 cargo aircraft traced to lithium battery cargo
- Many other non-catastrophic lithium battery fires in cargo hold & in passenger compartment

Five Deadly Sins

ICAO SAE G-27 Preliminary Draft Standards
Pressure Management*
Fire Containment
Flame Arrestment
Blast & Ballistic Projectile Containment
Flammable Gas Containment/Control
Prevent Auto-ignition of Adjacent Packages
*Implied for ascent, descent & flammable gas pressure pulse

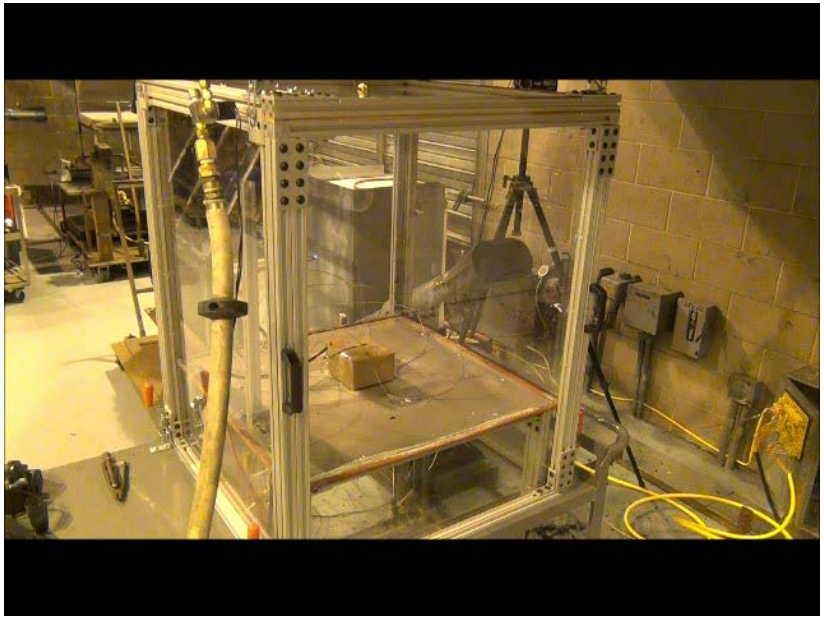
- Recommended to ICAO DG – late 2017?
- ICAO approval & implementation – 2018-2019?
- These standards will flow to other transport modes

Safety – It's Not Just An Air Transport Problem

- Ground transport has a Li-ion battery safety problem, too.
- Li-ion battery fires on trucks and rail cars
  - Seven (+) fires on major carrier trucks in last 12 months
  - Union Pacific rail car fire in Houston, TX in April 23, 2017
    - Blast flung projectiles hundreds of feet & damaged nearby homes & businesses
- Why?
  - Unit Volume Increase - More batteries shipped every year
  - Energy density - More powerful batteries every year
    - Increases blast & ballistic fragments
    - Increases flame & **flammable gas output**

It’s All About The Gas

- A single 8.88 Wh 18650 cell at 100% SOC generates 8 liters of gas
  - 30% hydrogen
  - 15-20% flammable hydrocarbons – methane, ethane, acetylene, others
  - 4 liters of flammable/explosive gas (2.4 hydrogen, 1.6 hydrocarbons)
- **One** 9-cell laptop battery can produce 36 liters of flammable gas (21.6 hydrogen, 14.4 hydrocarbons)
- “Bonus” – hazardous gases include hydro chlorine, hydro fluorine & carbon monoxide
- No problem in <u>open air</u>
- **Big problem** in <u>a contained space</u> with no/limited ventilation



How Long Until Safer Batteries?

- 5 – 20 years; 10-15 years is probable for commercially viable entrant
  - It takes 10 – 20 years to move from lab to manufacturing, AND
- All Li-ion battery replacements are chasing a moving target
  - Cheaper every year
  - More energy density every year
  - Huge manufacturing investment
- Replacement cycle after commercial viability will require 5-10 years(+)
  - Li-ion battery market momentum
  - Huge installed base of Li-ion powered equipment

Emerging Lithium Battery Packaging Solutions: Two Design Approaches

- **Worst case containment**
- Design packaging that can contain a thermal runaway cascade that propagates to **all** cells/batteries in the package
- Burning all batteries is accepted
- Focus on containing thermal runaway hazards of flames, blast & ballistic projectiles inside the package

- **Control thermal runaway spread**
- Design packaging that limits the spread of thermal runaway cascade from the initiating cell/battery to adjacent cells/batteries
- Only burning of the initiating battery & 1 or 2 adjacent batteries is accepted
- Focus on reducing **all** hazards inside & outside the package by limiting thermal runaway propagation

Worst Case Containment

Advantages

- Blast control
- Ballistic projectile control
- Flame arrestment
- Fire containment
- May prevent auto-ignition of adjacent packages

Disadvantages

- No control of flammable gases
- No control of hazardous gases
- No control of particulates in battery smoke
- Greater HAZMAT clean-up requirements

Control Thermal Runaway Spread

Advantages

- Blast control
- Ballistic projectile control
- Flame arrestment
- Flammable gas control*
- Hazardous gas control*
- Smoke filtering*
- Prevents auto-ignition of adjacent packages
- Reduced HAZMAT clean-up requirements
- *Direct effect in some – In-direct effect in most

Disadvantages

- All hazard controls dependent on effectiveness & speed of thermal runaway limitation method
  - Packaging may not be robust enough to withstand full thermal runaway cascade if limitation fails
  - Dangerous amounts of flammable & hazardous gases may be vented into cargo hold if limitation is slow or fails

Examples

Worst case containment

- Various metal containers
- Various flame resistant or flame retardant materials reinforced with ceramic plates or other material with high ballistic resistance such as Kevlar or carbon fiber
- Ceramic coatings on corrugation
- Combinations of metal, Kevlar, carbon fiber or ceramic coated corrugation with Vermiculite pellets

Control thermal runaway spread

- Intumescent coatings on corrugation
- Intumescent plastic
- Gel packs (some with flame retardant corrugation)
- Flame retardant & gas adsorbing silicone beads
- Thermal panels with flame retardant corrugation & gas adsorption

Thank You!

James Jones

Director
Product & Quality
Management

PA^2

E: jjones@pa-2.com