

A Study of the SOC of Lithium-ion Batteries in Transportation

Presented to: International Aircraft Materials Fire Test Forum

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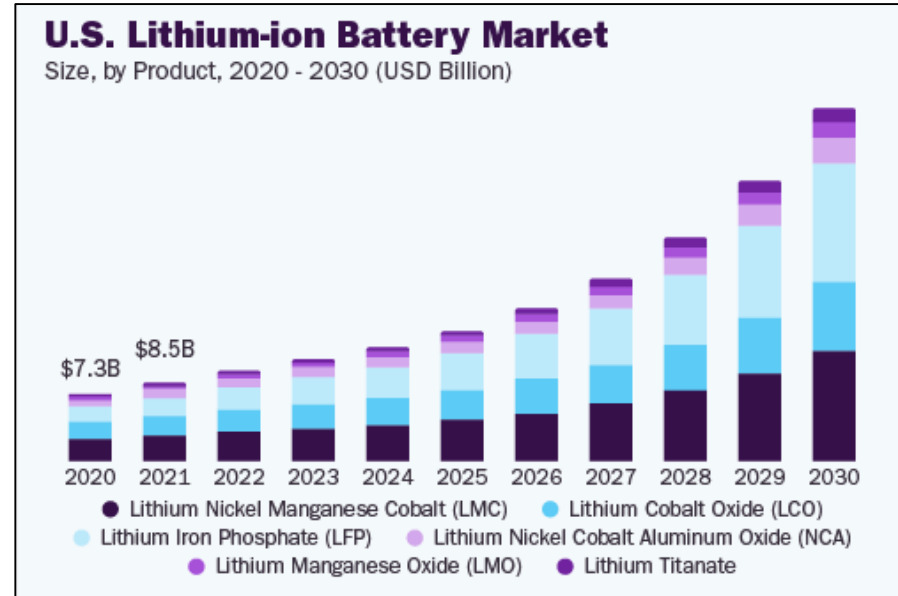
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**Federal Aviation
Administration**

Introduction

- Lithium-ion batteries are a common power source in many different electronic devices
 - Phones, tablets, laptops, EVs, etc.
- Worldwide market valued at \$48.2 billion in 2023
 - Estimated compound annual growth rate (CAGR) of 18.9% from 2023 to 2030
 - Forecasted total market revenue of \$182.5 billion by 2030
- As a result of forecasted growth, safe transportation has become more important than ever



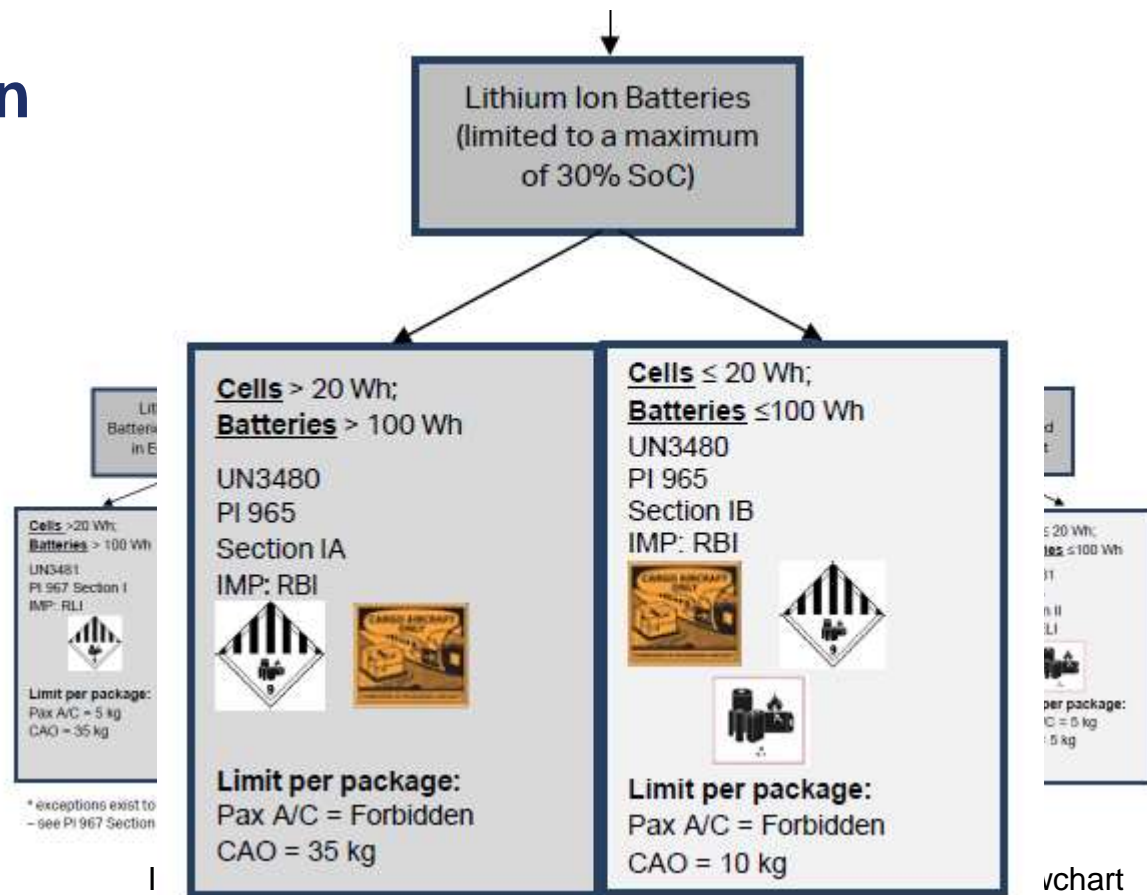
U.S Projected Market - Source: Grand View Research (2022)

Li-ion Battery Transport Hazards

- Lithium-ion batteries can undergo a process called “thermal runaway”
 - Thermal runaway is an uncontrollable and self sustaining process which causes the temperature within the battery to increase exponentially, releasing smoke and flames
 - Can cause cell to reach temperatures exceeding 1,000°F (538°C)
 - Occurs when cells are overheated, overcharged, mishandled, or have a manufacturing defect leading toward an internal short circuit
- Required to be shipped as a Class 9 (Miscellaneous) Dangerous Good

Battery Classification

- Li-ion batteries categorized based on how they are packaged
- Li-ion cells/batteries shipped in bulk are classified as UN 3480
 - Limited to 30% state of charge (SOC) when transported on aircraft
 - SOC is an electrical cell's charge level compared to its total capacity



Why is SOC important?

- Cells with a higher SOC are more likely to produce higher heat release rates, maximum temperatures and toxic gases during a thermal runaway event
- Cells are more likely to propagate to nearby cells/packaging at higher SOC



30%

70%

100%

Peak reactions of batteries at various SOC from past FAA testing

SOC Testing

- Despite SOC restrictions, thermal runaway incidents involving UN3480 packages have continued to occur at airports and all-cargo sort facilities
 - FAA analyses of cells from some of these incidents have found that they were shipped at >30% SOC
- Additional testing was conducted to determine if UN3480 cells were being shipped like this on a wider scale or if these were isolated incidents

UN3480 package undergoing thermal runaway in all-cargo sort facility after previously being shipped on aircraft



Cells from the same shipment were found to have been shipped at ~70% SOC

SOC Testing (Continued)

- Lithium-ion cells were ordered from different e-commerce platforms and tested at the FAA William J. Hughes Technical Center
- Each cell's SOC was measured using battery analysis equipment
- A total of 107 lithium-ion cells were tested
 - Types
 - Cylindrical Cells (26650s, 18650s, 14500s, 10440s etc.)
 - Pouch Cells
 - Chemistries
 - Lithium Cobalt Oxide (LiCoO₂) - LCO
 - Lithium Nickel Manganese Cobalt Oxide (LiMnCoO₂) – NMC
 - Lithium Iron Phosphate (LiFePO₄) - LFP



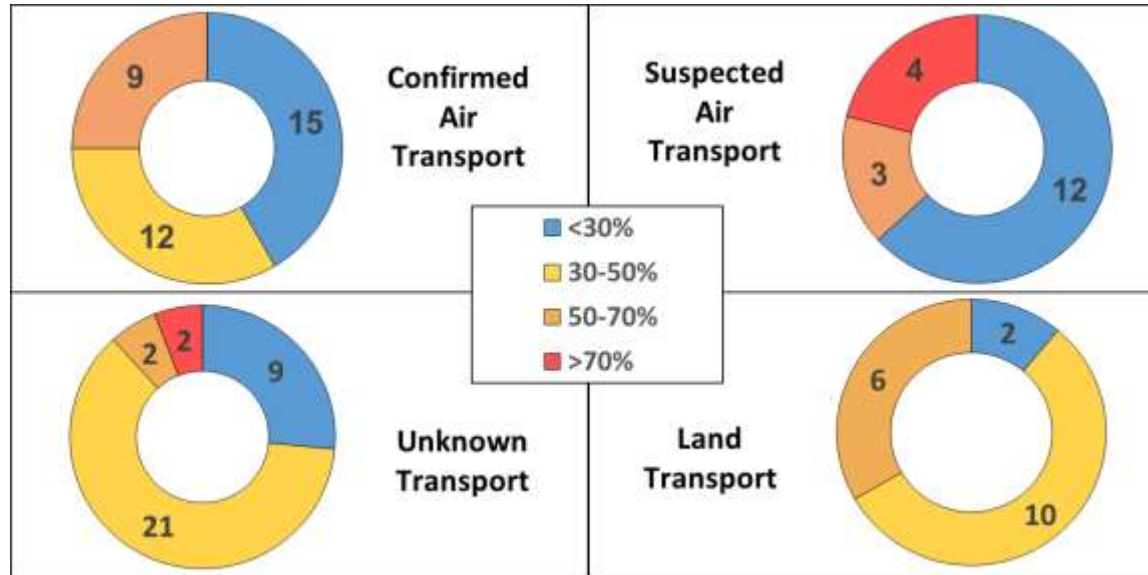
Assortment of some of the evaluated cells

Categorization

- There was difficulty in determining the mode of transportation for some delivered packages
- Many did not have a tracking # listed or an identifiable business address
- Batteries were categorized based on the suspected method of transport
 - Confirmed Air Transport – Confirmed transported via air through package tracking #
 - Suspected Air Transport – No available tracking # but the package arrived from across the country within less than two days
 - Unknown Transport – No package tracking # or business address available
 - Land Transport – Package confirmed delivered through land transport from tracking #
- A sample size of 4-5 cells were tested per package, or less than that if the package contained <4

Results

- Of the 107 tested cells, 64.4% (69 of 107) exceeded the 30% SOC limit
- Of the cells confirmed to have been shipped by air, 58.3% (21 of 36) were greater than 30%
- Cells shipped by land do not have to adhere to the 30% SOC restriction.
 - Cells from this category was still tested as different shipment options were available during purchase. Therefore, a higher priority shipment option could have been transported via air



Observations

- Cells shipped from multiple e-commerce platforms were observed to fail
- Many cells from the “major brand” manufacturers were found to have been shipped at a SOC less than 30%
- Largest violators of SOC requirements were second-hand sellers and lesser known brands
- Some of the delivered packages did not have UN3480 labeling on the exterior of the package

Packaging Fire Threat

- One package was ordered from an e-commerce platform and delivered via air transport
- Over 70 cells were scattered within the box without any protective packaging
 - Cells could have made contact with terminals of the opposite polarity, causing a short circuit and thermal runaway event
- The voltages of the cells were evaluated
 - Many cells were found to be dead
 - Some cells were found to have high voltages and most likely would have exceeded the 30% limit



Interior of package and underneath plastic wrap

Packaging Fire Threat (Continued)

- The transportation of damaged cells or batteries are forbidden from air transport
- Some cells within the package were found to be severely damaged
 - Pouch cells were swollen and showed signs of corrosion
- This indicates that the cells were damaged prior to or during transport

Swollen/damaged
pouch cell



Corroded
material



Packaging Fire Threat (Continued)

- A different package containing 32 RCR123A cells was received
- Cells were shipped within cardboard/plastic inner packaging
- Inner packaging was damaged and some of the cells fell out to the bottom of the package
- Loosely packed cells are a risk of short circuiting if contact is made with other metallic surfaces
- Package contained other charging equipment with exposed metal



Summary

- An analysis was conducted on lithium-ion cells that could be ordered online and delivered to everyday consumers
- A substantial amount of lithium-ion cells confirmed or suspected to be transported via aircraft were found to exceed the 30% SOC limit for UN 3480
 - 58.3% (21 of 36) of evaluated cells confirmed to have been shipped by air exceeded 30% SOC
 - 25% (9 of 36) of those cells were greater than 50% SOC
- Some batteries were found to be damaged/packed unsafely
- These observations show that a fire threat is still present for some lithium-ion battery aircraft shipments despite regulations currently in place

Next Steps

- Although there are a sizable amount of vendors not following regulations, enforcement of this regulation is difficult
- There is no easy way to calculate the SOC in the field, as voltage is not a reliable way to get an estimate due to differences in battery types and chemistries
- Additional steps may be needed to ensure that SOC regulations are being followed, as SOC has been shown to be one of the primary factors in a batteries' ability to be a significant fire threat in addition to its ability to propagate to nearby cells
- A technical note with full data from this study will be released in the near future

Questions?

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