IN LITHIUM-ION BATTERY MANUFACTURING WHAT CONSTITUTES A SAFE FACILITY?

A simple question from a colleague led to a deep dive on existing standards and no straightforward answer. The question was simply, what are the fire detection and suppression requirements, codes and standards for lithium-ion battery manufacturing?

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According to Allen Bernard's OneCharge Business Blog "US Role in Global Lithium Battery Manufacturing" Jan 2022 article, China had 70% of the lithium-ion battery production globally and according to Statista.com statistics, ten of the fifteen largest facilities in the world in 2020 were based in China[1]. Of the remaining five facilities, two were US-based and Poland, Hungary, and South Korea each had one.

These statistics indicate that based on global demand, growth of lithium-ion facilities will be spreading around the world. Historically, each country relies on its own safety standards, which hampers the development of a global standard across industries. As these facilities spread throughout the globe, the current challenge for officials, code authorities, insurance companies and engineers is the lack of developed standards available at the international, country, and local level on a fast-paced schedule. The international codes, standards and risk analyses required to protect this specific type of facility are in their infancy.

To solve current challenges faced by the battery industry, past examples of accelerated code adoption to meet the demands of a fast-growing industry exist. Several decades ago, the semiconductor industry faced similar challenges when the need for factory floor space was outpacing the ability of the codes to react to the construction requirements for these complex manufacturing facilities. At the time, there were no global standards and there were many local standards. To provide clarification and streamline development, the *International Code Council, Inc (ICC)* was established to align the codes internationally. They took the best practices from the available local and country codes and developed global standards. They produced the *International Building Code, International Fire Code*, etc. by pulling together building professionals on a regular basis to review and update their codes. This guidance now provides an international forum for discussion and deliberation about building design, construction methods, safety, performance requirements, technological advances, and innovative products. This consortium produces code revisions on a three-year cycle, with the most recent released in 2024[2]. Semiconductor facilities have their own Chapter (27) and their own occupancy classification (Group H)[3,4]. In the user notes, fire code officials are warned that the risk of extraordinary property damage is far more common than the risk of personal injuries from fire.

1. https://www.onecharge.biz/blog/u-s-role-in-global-lithium-battery-manufacturing/
2. https://global.iccsafe.org/about/
3. https://codes.iccsafe.org/content/IFC2021P2/chapter-12-energy-systems#IFC2021P2_Pt03_Ch12_Sec1207
4. https://codes.iccsafe.org/content/IBC2021P1/chapter-3-occupancy-classification-and-use. Section 302.1

In the 2024 IFC, Sections 907.2.2.2 and 907.2.4.1 have been added to encompass lithium-ion battery applications, however this is just the start. Until a chapter is added for lithium-ion battery manufacturing facilities in the IFC, what information is available today?

In the absence of lithium-ion battery manufacturing facility codes and standards, Energy Storage Systems (ESS) standards have recently been in development and are being issued for use. These standards give a possible framework for the requirements for protecting lithium-ion manufacturing plants.

The 2021 International Fire Code added Section 1207 Electrical Energy Storage Systems[5]. This section has thresholds for requirements based on technology type and energy capacity. For example, the maximum allowable quantity of lithium-ion is 600kWh[6]. In certain instances, it requires large-scale fire testing. For lithium-ion batteries it requires both the batteries and ESS to have a listed device or another approved method to prevent, detect and minimize the impact of thermal runaway. It references *UL 9540 Energy Storage Systems and Equipment* which was first issued in Nov 2016 and a second revision was issued in May 2020. This standard limits the size of the system unless certain testing has been conducted by approved agencies[7].

The Fire Protection Research Foundation (Research for the NFPA mission) has published three reports concerning lithium-ion Batteries between 2011 and 2016[8,9,10].The third report has an additional testing report for lithium-ion battery storage published by FM Global. The results of the testing were cautioned to be limited to the specific combination of packaging and battery testing but did show that key aspects are that larger pouch batteries contributed to damaging the rack system at 150s after ignition vs 300s for the cylindrical batteries. It also showed that plastic packaging material contributed more greatly to the early development of the fire before the battery involvement when compared to minimal plastic packaging. One notable item of interest is the propagation of thermal runaway of small cylindrical batteries occurs after the carton has been breached. This leads the report to make additional recommendations for standard sprinkler detection based on the type of battery, separation of pallets, and height and size of pallets.

NFPA 855: Standard for the Installation of Stationary Energy Storage Systems, 2023 Edition Chapter 14 Storage of Lithium Metal or Lithium-Ion Batteries defines requirements for ESS but has an exception for areas where batteries are staged in the manufacturing area or along assembly lines during the manufacturing process.[11]

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5. https://codes.iccsafe.org/content/IFC2021P1/chapter-12-energy-systems#IFC2021P1_Pt03_Ch12_Sec1207
6. Ibid. Table 1207.5, Maximum Allowable Quantities of Electrochemical ESS.
7. https://www.shopulstandards.com/ProductDetail.aspx?productId=UL9540&ShowFreeviewModal=1, p45, Section 26.2.4
8. Lithium-Ion Batteries Hazard and Use Assessment, https://content.nfpa.org/-/media/Project/Storefront/Catalog/Files/Research/Research-Foundation/Reports/Hazardous-materials/rflithiumionbatterieshazard.pdf?rev=234ffb9ebc07497ea7205d6a94cdd72e&hash=FB23E8E7A49368CF78A5A2D1335A647B
9. Lithium-Ion Batteries Hazard and Use Assessment Phase IIB - Flammability Characterization of Li-ion Batteries for Storage Protection. https://content.nfpa.org/-/media/Project/Storefront/Catalog/Files/Research/Research-Foundation/Reports/Hazardous-materials/RFLithiumIonBatteriesIIB.pdf?rev=99626af679bd4111914787dc63492b0a&hash=47C1BF30B20226D1F19CD4755885066C
10. Lithium-Ion Batteries Hazard and Use Assessment - Phase III
11. NFPA 855 - Standard for the Installation of Stationary Energy Storage Systems. 203 Ed. https://link.nfpa.org/free-access/publications/855/2023

In all this referenced research, there is none referencing manufacturing facilities specifically, only ESS and storage – what does this mean to those who manufacture the cells, modules, and packs? Because the industry has been dominated by a few companies, widespread knowledge of challenges in the design engineering of these facilities does not exist and as a result, international code developers and local officials are just now starting to experience the hazards associated with this type of manufacturing process. One or two facilities in a country are insufficient for the comprehensive development of codes and standards necessary for manufacturing. To effectively establish standards and acceptable risk levels, as well as to build the expertise needed for code development, a more extensive network of facilities is required. The track record for what works well to determine the minimal level of safety standards has not yet been experienced.

What do the manufacturers, insurance companies, Authorities Having Jurisdiction (AHJs), designers, constructors, and suppliers need to understand about managing the risk associated with this type of manufacturing?

What knowledge and standards should be leveraged from battery energy storage systems to manufacturing applications?

CELL MANUFACTURING FACILITIES

Can be typically broken up into four areas with a total of fifteen manufacturing steps: Electrode Production with six steps, Cell Assembly with four steps, Cell Finishing with four steps and Storage each with a subset of processes and hazards. Each of the processes needs a specific type of environment and comprises different material hazards. Each process can be implemented differently, causing a change in the hazard assessment and method of risk reduction. Some facilities may execute the process in a different manner requiring a modification to the hazard and hazard monitoring.

For building protection, most of the process environment would be considered a normal operating environment with a few exceptions. Much of the cell manufacturing area is a clean room and should use the standards for clean room applications; the mixing area is a dust-controlled environment; the vacuum drying environment is a dry room; and finally, the aging area is temperature-controlled. Any of the life safety systems that are put in place, need to ensure that people and property are protected. Minimizing the impact on production during an event may also be considered but needs to be understood and documented to ensure standards and compliance are met and additional requirements are understood, documented, and approved by the AHJ and/or insurance company.

The process hazards that need to be evaluated in areas where the process safety risk is higher are impacted by process implementation methods and will vary from facility to facility. For example, the mixing area has flammable dust and flammable solvents which are mixed into a slurry and thus may lead to requiring flame detection and VOC/LEL detection. If the vessels are sealed and the process is fed by enclosed piping, no detection is required in this area as it is self-contained. If the vessels are open, then providing flame detection and VOC/LEL detection reduces the risk. Detection should be provided wherever the bags are loaded into the bins that push the product into the system. The coating area uses the hazardous slurry that was created in the mixing area and should have flame detection coverage.

Electrolyte Filling and Degassing

Have similar process hazards – the electrolyte. However, even though both processes could release hazardous gases from the electrolyte, both are performed under vacuum in normal conditions. If the vacuum condition is lost, not only must the process be stopped but the hazard determined from the loss of vacuum. Aspirating smoke-detecting systems such as VESDA are recommended for both processes, the monitoring changes from Electrolyte Vapor Detection in Electrolyte Filling to VOC/LEL detection in Degassing.

The formation and aging areas have the highest likelihood of the process event called thermal runaway. The formation area is part of the cell finishing process and is where cells are charged and discharged for the first time. It tends to be a high bay area with many racks of cells undergoing an electrochemical transformation into a usable cell. The aging area is another zone where the cells are stored in shelves or towers and are monitored, usually near 100% State-of-Charge (SOC) for up to three weeks for quality assurance purposes.

According to UL website (*https://ul.org/research/electrochemical-safety/getting-started-electrochemical-safety/what-thermal-runaway*):

"Thermal runaway is one of the primary risks associated with lithium-ion batteries. It is a phenomenon in which the lithium-ion cell enters an uncontrollable, self-heating state.

Thermal runaway can result in:

- Ejection of gas, shrapnel and or particulates (violent cell venting)
- Extremely high temperatures
- Smoke
- Fire

...In ideal conditions, the heat can dissipate from the cell. However, in thermal runaway, the lithium-ion cell generates heat at a rate several times higher than the rate at which heat dissipates from the cell and therefore poses a significant safety hazard.

When its temperature rises at a rate greater than 20 degrees centigrade per minute, the cell has reached thermal runaway."[12]

According to DOT/FAA/TC-15/59 Lithium Battery Thermal Runaway Vent Gas Analysis, while the flammable gas percentage varied slightly by the specific battery chemistry, the flammable gases released during thermal runaway include methane, ethylene, acetylene, ethane, propylene, propane, I-butane, and butane. Other studies have shown hydrogen, carbon monoxide, carbon dioxide, hydrogen fluoride, phosphoryl fluoride, phosphorus pentafluoride, and ethyl fluoride can also be released during thermal runaway. Therefore, not only does the reaction itself need to be addressed, but also the hazardous gases that are released during a runaway event need to be addressed.

Each manufacturer will have to determine how they address the hazards generated by a thermal runaway condition. Options must be comprehensively reviewed and questioned: can energy be removed from the cell before causing thermal runaway? Should the cells be removed before they are in full thermal runaway? If they are left in place can the cells be insulated to prevent cell-to-cell propagation while still addressing the gases being released? Are there interlocks to prevent hazardous conditions if the air system has issues? If material is to be moved, is there an interconnection to the automated material handling system? As events typically require a lot of water to cool and prevent the spread, is there a water reclamation process required to address the toxins that are added to the water used to cool an event? These are just a few of the questions that must be asked and answered to document the safety of the facility for the people, property, and the environment.

12. UL Research Institutes. "What Is Thermal Runaway?". https://ul.org/research/electrochemical-safety/getting-started-electrochemical-safety/what-thermal-runaway

As the industry matures, there will be a standardization of the safety systems deployed within these facilities. Until that standardization occurs and is accepted, each plant will need to develop its own solutions to mitigate the new process hazards, conduct the cost analysis and ROI concerning each hazard and its solution, and work closely with the local AHJ to come to a resolution. The use of manufacturing limits, technology and system integration can all play a greater part in allowing faster reaction times to a possible event permitting more options for mitigations of hazards. Integrated VESDA, material handling, HVAC, VOC gas detection, and thermal runaway off-gassing detection through Li-ion Tamer® are a select few technologies to provide layered detection to safely protect both people and property.

The Gen 3 Li-ion Tamer® sensor is Honeywell's latest technology designed to mitigate thermal runaway.

For More Information

To learn more about Honeywell lithium-ion battery manufacturing solutions, visit https://hwll.co/batterygigafactories or contact your Honeywell Account Manager.

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