STORING LITHIUM BATTERIES – THE SAFETY NEEDS AND REGULATORY REQUIREMENTS

Curtis Ashton
Director of Training
American Power Systems
Littleton, CO

Michael P. O'Brien
Technical Services Manager
Exponential Power
Buffalo, WY

Abstract
This paper addresses the safety needs and regulatory requirements for the proper storage of lithium-ion batteries. Unlike aqueous chemistry (such as lead-acid and Ni-Cd) batteries, Li-ion batteries are capable of going into thermal runaway even in a stored condition [7]. This is the reason you can't carry even excess small Li-ion batteries on commercial airliners (except in a limited amount in carry-on bags – and never in checked luggage) [3]. In addition, worldwide, there have been several very large warehouse fires caused by stored Li-ion batteries. While there were already international air transport regulations for Li-ion batteries due to past incidents, as well as Li-ion manufacturer guidelines and regulations for over the road or ship transport (both of which continue to evolve); until recently there has been little good guidance around the storage (in warehouses and containers) of Li-ion batteries for stationary applications. This presentation will cover new rules in the 2023 edition of NFPA (National Fire Protection Association) 855 [13], and the science behind them, as well as make suggestions that go above and beyond the rules for safe storage of these highly useful Li-ion batteries that become a larger part of our lives every day. It will point out that they can be safely stored, but proper procedures need to be followed for that "storage" to be safe enough.

Introduction
A major benefit of lithium-ion batteries is the amount of power they can store. Unfortunately, this can also be a drawback because if this energy is released in an uncontrolled manner a very intense fire is the typical result. This can occur during storage due to an internal fault in a single cell. Lithium-ion battery fires are very difficult to extinguish before the offending cell expends its stored energy. The intensity of the fire normally ignites anything in close proximity which is often other lithium cells resulting in a propagating intense fire that is not easily extinguished.

The 2023 edition of NFPA Standard 855 [13] address the safety aspects of storing lithium-ion and lithium metal batteries. This paper will discuss the requirements to safely store lithium-ion batteries, the "easy method" of doing so, and why the easy method may not be quite so easy. This paper does not address the requirements for storing small consumer grade lithium-ion or metal batteries such as those found in laptops, cellphones, eBikes, etc. Nor does it address the storage of lithium-titanate (LTO) technology[1].

[1] Note that it is nearly impossible, if not completely impossible, to get propagating thermal runaway from lithium titanate chemistry, and while the standards have not yet exempted this chemistry from some of the more onerous requirements applied to other Li-ion battery types, it is not the intent of the authors of this document to require all of these special storage provisions (including low State of charge [SoC], spacing, etc.) for LTO batteries.

First Things

All lithium-ion and lithium metal battery manufacturers must furnish test data for their product in accordance with sub-section 38.3 of the UN (United Nations) Manual of Tests and Criteria [25] before shipping their product. The user of these batteries needs to have this data before receiving lithium batteries or contracting for their shipment. This is the user's due diligence to prove that the battery they are purchasing is safe for shipment.

All rechargeable lithium metal and lithium-ion cells/batteries shipments are USDOT (United States Department of Transportation) class 9 hazardous materials [26] and must be packaged and shipped in accordance with applicable federal regulations. Unlike air shipments (where IATA {the International Air Transport Association} mandates [3] no more than a 30% SoC for shipment by air), the SoC (State of Charge) of surface shipments is not regulated. Many responsible stationary Li-ion battery manufacturers will ship their product at no more than a 50% SoC, however.

These 30% and 50% numbers have been proven by numerous tests across many Li-ion manufacturers and chemistries[2] to limit the temperature rise during a cell overheating event that could lead to thermal runaway (as just one example see the Figure below pulled from the Joshi, et al paper from the 2020 Journal of the Electrochemical Society [16]). By limiting the temperature rise, regardless of cell model/manufacturer or chemistry, the likelihood of thermal runaway of that cell is lessened, and the likelihood of cell-to-cell propagation is also lessened.

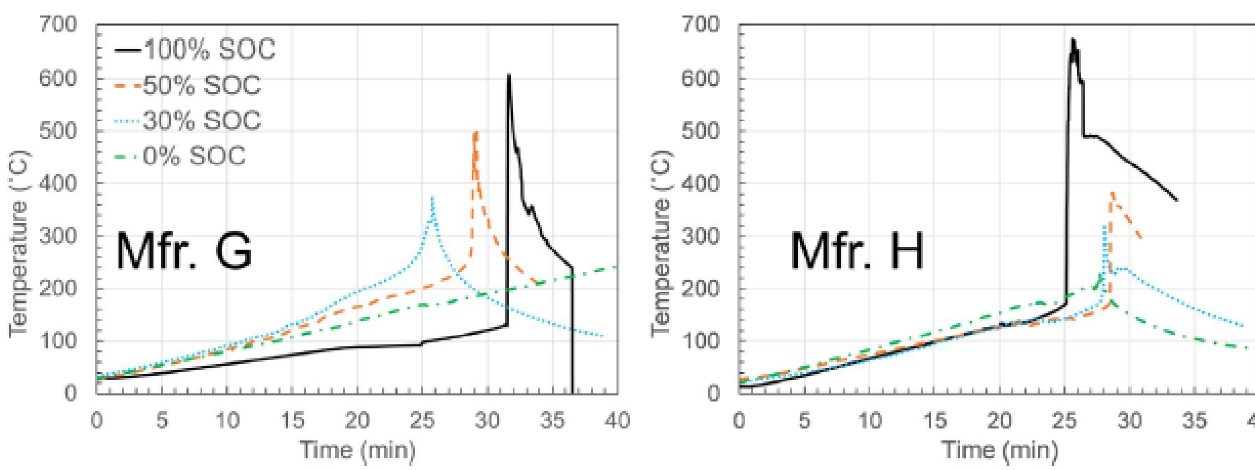

Figure 1. Example Temperature Rise from 2 Different Overheateded Cells at Differing SoC Values[3]

[2] While LFP (lithium iron phosphate) is typically considered to be a somewhat safer chemistry than some of the other Li-ion types due to slightly lower energy density and higher thermal runaway onset temperatures, it is treated the same from a safety/regulatory perspective so far until more data comes in.

[3] This is a reproduction of Figure 3 from the 2020 Journal of the Electrochemical Society 167 140547, "Safety of Lithium-Ion Cells and Batteries at Different States of Charge." [16]

UL Listings or Equivalent IEC Testing

It is a good idea to not accept any lithium cell or battery that does not have an appropriate UL (Underwriters Laboratories) listing. Lithium cells and batteries meeting UL standards provide the user with some assurance that the batteries/cells they are using have been designed and manufactured with some level of safety in mind. Lithium batteries should have the proper or applicable UL Listing for their intended use. Li-ion modules for stationary standby service should be UL 1973 (to the 2nd edition {2018} or later) [19] listed, or tested and marked as compliant to IEC (International Electro-technical Commission) 62619 [6]. Li-ion BESS (Battery Energy Storage System) should be UL 9540 [23] listed. UL 1642 [18] covers individual user replaceable lithium cells and thus does not offer a high degree of safety assurance batteries used in stationary or ESS (Energy Storage System) applications. In a similar vein, UL 2054 [20] covers the safety of small sets of individual or up to a few cells in consumer electronics applications, and thus is not adequate to cover the possibility of larger scale cell-to-cell propagation in stationary standby power applications.

UL 9540A, the Standard for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems [24], while not a pass/fail test, gives extremely valuable information about the heat and gasses emitted by a Li-ion thermal runaway event, including how much it propagates. Ideally, all lithium-based batteries used in stationary, or ESS applications, should be listed to at least UL 1973 [19] (and 9540 [23] for complete ESS systems) or tested to IEC 62619 [6], and have a 9540A [24] fire test performed with a summary report prepared by a fire protection engineer that allows the end user to design and produce a proper hazard mitigation plan to present to and be approved by the AHJ.

UL 2271 [21] is for batteries in light electric vehicle (LEV) applications and UL 2849 [22] covers the electrical system of eBikes powered by a lithium-based, rechargeable battery. These standards are not directly applicable to stationary standby power or ESS applications.

NFPA Standard 855

NFPA 855 is the Standard for the Installation of Stationary Energy Storage Systems. It is a standard, and as such does not carry the force of law until it is referenced (or copied) by a locally-adopted code (typically a model fire Code such as the IFC {International Fire Code} [5] or NFPA 1 [11], or a locally modified code such as the California Fire Code {CFC} [2] or New York City Fire Code {NYCFC} [15]). NFPA 855 [14] applies to the design, construction, installation, commissioning, operation, maintenance, and decommissioning of ESS, including mobile and portable ESS installed in a stationary situation and the storage of lithium metal or lithium-ion batteries. This standard provides the minimum requirements for mitigating the hazards associated with ESS and ***the storage of lithium metal or lithium-ion batteries***[4] (see Chapter 14 specifically, which was rewritten for the 2023 edition)**.**

General Storage Requirements

A written *plan that provides for the prevention of fire incidents and includes early detection and mitigation measures shall be provided to the AHJ* (authority having jurisdiction, such as a fire marshal or electrical inspector) *for review and approval*. Additionally, *a written Hazard Mitigation Analysis (HMA) prepared by a registered design professional with expertise in fire protection engineering shall be submitted to the AHJ for review and approval*.

[4] Smaller font text in italics is a direct copy of text found in Chapter 14 of NFPA 855. Other text in the subsequent sections is added as explanatory or as recommendations beyond NFPA 855.

Explosion Protection

The potential for a deflagration involving the off gassing of flammable gases during a thermal runaway shall be analyzed. Explosion protection shall be installed if the potential for a deflagration involving the off gassing of flammable gases during a thermal runaway exists.

Building Requirements for *Indoor Storage*

The storage room(s) or space(s) may require explosion protection. Each storage *room or space shall be separated from the remainder of the building areas by fire barriers with a 2-hour fire resistance rating* [1] *and with horizontal assemblies with a 2-hour fire resistance rating* [17] *constructed in accordance with the local building code* [4]. Each storage *room or space shall be provided with a fire alarm system activated by an air-aspirating smoke detector system or a radiant-energy detection system with occupant notification installed in accordance with NFPA 72* [13]. Each storage r*oom or space shall be provided with an automatic sprinkler system designed and installed in accordance with NFPA 13* [12]. These indoor storage requirements are also applicable to *prefabricated portable buildings or* structures/*containers*.

Lithium batteries can be *stored in approved transportation containers that will prevent an event from propagating beyond the container*. When these *approved* transportation *containers* are *stored indoors the container* can*not exceed 900 ft^2* and must be s*eparated from other battery storage areas by a minimum of 10 feet*. The building housing these approved transportation containers does not require a *2-hour fire resistance rating* because the container itself has that rating, but it does require *a fire alarm system activated by an air-aspirating smoke detector system or a radiant-energy detection system with occupant notification installed in accordance with NFPA 72* [13] *and an automatic sprinkler system designed and installed in accordance with NFPA 13* [12].

In addition to traditional ISO (International Standards Organization) “shipping” containers [9], NFPA 855 [14] also refers to the use of *metal drums* (such as a *55-gallon drum*) for storage. These type of barrels (with individual *battery* modules s*eparated by vermiculite or other approved* non-flammable *material*s) are not only useful for safe storage, but are also an excellent way to transport damaged Li-ion batteries.

Outdoor Storage Requirements

Trailers or ISO containers [9] used for lithium storage should have a minimum of *10 feet* of *separation*. Additionally, these trailers or containers should be a *minimum* of *20 feet from lot lines, public ways* (sidewalks, pathways, bike trails, etc.), *buildings*, *hazardous materials*, energized electrical equipment, (substations, transformers, building electrical service entrance), and *other exposure hazards*.

The Easy Method of Lithium Storage

None of the storage requirements discussed to this point are required if the *SoC of all the lithium-ion or metal batteries in storage is ≤30%*. No written fire plan, no hazard analysis, no AHJ involvement, no explosion protection, no building or room fire rating, no fire detection or sprinkler systems. Lithium batteries at ≤30% SoC can still catch fire or contribute to a fire, but the fire is less intense with less propagation.

Sounds great, right? What are the drawbacks?

The “Easy” Method May Not Be So Easy?

This first issue is how do we get the batteries to ≤30% SoC? The easy method would be to have the battery supplier ship the batteries at ≤30% SoC. But what if these are older batteries heading for a secondary use or recycling, or if they are shipped by sea or land at 50% SoC? Batteries being removed from service should preferably be discharged to ≤30% SoC (and definitely to no more than 50% SoC) before being shipped to a storage facility. Discharging the battery to ≤30% SoC at the storage facility is often more difficult due to disassembly of the battery for shipment and lack of technically qualified personnel and discharge equipment at the storage facility.

The storage time is reduced at ≤30% SoC. The actual reduction in storage time will depend upon the details of battery chemistry, construction, and storage conditions. Provisions need to be made to periodically verify the SoC to ensure that it doesn’t degrade to the point of battery damage. Some module electronics or BMS (Battery Management Systems) will do a better job than others of trying to keep the battery from going below 2-3% SoC; and a responsible “storer” of batteries will check open circuit voltages (OCV) or module electronics/BMS readouts fairly frequently to ensure that SoC does not go below 5% before a freshening charge is given to restore the stored battery to somewhere between 25-30% SoC. Recharging an over-discharged lithium-ion battery can lead to a dangerous thermal runaway condition.

Most storage facilities are not well suited to recharging batteries in storage due to lack of available electrical power, suitable chargers, and qualified personnel. The electronics or BMS in many lithium-ion battery modules may have a low tolerance of charging current with significant AC ripple. Accidental over-charging negates the easy storage method and in the case of extreme over-charge may trigger thermal runaway in a facility not designed to handle such an event. In this extreme case, the responding fire department may not be prepared to handle a lithium fire since the easy method doesn’t require advance notification through the AHJ. Additionally, charging while in storage will require some unpackaging and repackaging and may require time consuming partial or full assembly and disassembly of the battery

If a storage facility does have the equipment, personnel, and training to properly partially discharge and partially freshen charge Li-ion batteries, it is helpful to know how to find the 5% and 30% SoC points. Many BMS or other module electronics allow the user to connect a laptop to their communication port (sometimes with special cables or software) and read the estimated SoC from the software. This is by far the best way to check state of charge, since cells self-discharge at slightly different rates, and you want to do the freshening charge when the lowest cell falls to the 5% SoC level. Also note that it is important to put the BMS or module electronics back into “sleep” mode (if possible) after powering them up to check SoC so that they do not drain the battery too quickly. If unable to determine individual cell SoCs or open circuit voltages (OCVs) through module electronics or a BMS, a reasonable estimate of the SoC can be made from the open circuit voltage in storage. While there are slight variations between manufacturers due to differences in their chemistries, the following table summarizes the typical approximate 100%, 50%, 30%, and 5% SoC values for the most common Li-ion chemistries used in stationary standby applications.

Table 1, Typical Li-ion Battery Cell/Module Voltages at Various SoC									
Chemistry	series “cells”	V_{nom}	V_{max}	$V_{100\%SoC}$	$V_{50\%SoC}$	$V_{30\%SoC}$	$V_{5\%SoC}$	V_{eod}	$V_{abs\text{-}min}$
NMC (nickel manganese cobalt), or NCA (nickel cobalt aluminum)	1	3.70	4.20	4.10	3.70	3.45	3.20	3.00	2.50
	4	14.80	16.80	16.40	14.80	13.80	12.80	12.00	10.00
	8	28.60	33.60	32.80	29.60	27.60	25.60	24.00	20.00
	13	48.10	54.60	53.30	48.10	44.85	41.60	39.00	32.50
	14	51.80	58.80	57.40	51.80	48.30	44.80	42.00	35.00
	22	81.40	92.40	90.20	81.40	75.90	70.40	66.00	55.00
LMO (lithium manganese oxide)	1	3.70	4.20	4.10	3.85	3.75	3.20	3.00	2.80
	48	177.60	201.60	196.80	184.80	180.00	153.60	144.00	134.40
LFP (lithium iron phosphate)	1	3.20	3.70	3.65	3.30	3.20	2.90	2.80	2.50
	4	12.80	14.80	14.60	13.20	12.80	11.60	11.20	10.00
	8	25.60	29.60	29.20	26.40	25.60	23.20	22.40	20.00
	12	38.40	44.40	43.80	39.60	38.40	34.80	33.60	30.00
	15	48.00	55.50	54.75	49.50	48.00	43.50	42.00	37.50
	16	51.20	59.20	58.40	52.80	51.20	46.40	44.80	40.00
	24	76.80	88.80	87.60	79.20	76.80	69.60	67.20	60.00
	75	240.00	277.50	273.75	247.50	240.00	217.50	210.00	187.50
LMO/NMC	1	3.70	4.20	4.10	3.75	3.60	3.20	3.00	2.65
	8	28.60	33.60	32.80	30.00	28.80	25.60	24.00	21.20
"super” LFP	1	3.30	3.80	3.75	3.40	3.30	2.95	2.80	2.50
	7	23.10	26.60	26.25	23.80	23.10	20.65	19.60	17.50
	14	46.20	53.20	52.50	47.60	46.20	41.30	39.20	35.00
This Table is derived from Table E.1 and Figures B.1 and B.2 in draft 32 of the yet to be released IEEE P2962 [8], Recommended Practice for Installation, Operation, Maintenance, Testing, and Replacement of Lithium-ion Batteries for Stationary Applications. In turn those Figures and Table had their genesis in KEPIC (Korean Electric Power Institute Code) EEG 1400 [10], Guide for the Installation Design, and Installation of Lithium-ion Batteries for Stationary Applications.									

Note that due to the differing rates of self-discharge among individual cells, checking only external module voltages before determining when to start the freshening charge becomes less and less accurate with increased numbers of cells in series. In those cases of many cells in series, and the only available information being the OCV of the module, it is recommended to start the refresh charge at an even higher voltage threshold than the 5% point. The authors of this document recommend checking SoC monthly to determine whether refresh charging is needed.

Recommended Safe Storage

This is a combination of the easy method (≤30% SoC), and some commonsense facility protection.

1. Establish a designated lithium storage area. This area should meet the following criteria:
    a. The lithium-based battery storage area must not be within 10-feet of a building exit.
    b. The l*ithium-based battery storage area* must have a minimum *separation of 10-feet from all other areas and combustibles*.
    c. The floor of the lithium storage area must be a non-combustible floor.
    d. The *lithium-based battery storage area shall be provided with an automatic sprinkler system designed and installed in accordance with NFPA 13* [12].
    e. The *lithium-based battery storage area shall be protected by a radiant-energy detection system installed in accordance with NFPA 72* [13].
    f. Lithium and lithium-ion cells/batteries can be stacked no higher than 15-feet, measured from the floor to the top of the stack/package.
    g. *Only lithium metal and lithium-ion cells/batteries may be stored in the lithium-based battery storage area*.
    h. *No combustible materials may be stored in the lithium-based battery storage area*. This does not apply to the package material for the lithium/lithium-ion cells/batteries in storage.
    i. The lithium storage area should be maintained at a temperature of 20°C +/- 15°C, (41°-95°F.) with ≤95% non-condensing humidity.
    j. Have a separate storage area for damaged or defective lithium batteries.
        i. Shall be discharged to ≤30% SoC before securing the facility for the day[5].
        ii. Shall be stored at ground level in a sprinkler-equipped area.
        iii. Shall not be stored with anything above them such as full or empty shelving or racking.
        iv. Shall have a minimum horizontal *separation of 3 feet from other lithium metal/lithium-ion cells/batteries*.
        v. *Shall have a minimum separation from combustible materials of at least 3 feet*. When stored on a combustible pallet the minimum separation is measured from the outer edges of the pallet.
        vi. Damaged cells can be stored and *shipped in metal drums filled with vermiculite*. Such containers must have a *minimum of 3 feet separation from other lithium batteries and combustibles and be a minimum of 5 feet from exits*.
2. Don't accept batteries that are not Listed to UL 1973 (2nd edition or later) [19] or UL 9540 [23] or tested to IEC 62619 [6].
3. *Prepare a* written *plan that provides for the prevention of fire incidents and includes early detection and mitigation measures*.
4. Notify and involve your insurance company and the AHJ.

[5] Batteries whose terminals or electronics are damaged to the point where they cannot be discharged to ≤ 30% by conventional methods (such as a load bank) may need to be discharged outdoors (preferably at the site where they were damaged rather than at the storage facility) in a saltwater bath where the resultant contaminated water is properly treated before disposal.

Summary

The best ways to minimize the possibility of fire in the storage of Li-ion batteries for stationary applications is to only store modules that have been certified to UL 1973 [19] (or tested to IEC 62619 [6]) or systems certified to UL 9540 [23], and to keep them (except for LTO chemistry which is a much safer chemistry) at an SoC of between 5-30%.

References

1. ASTM E119-20, Fire Tests of Building Construction and Materials
2. CFC-2022, California Fire Code.
3. IATA 2021 Lithium Battery Guidance Document for the Transport of Lithium Metal and Lithium-Ion Batteries.
4. ICC (International Code Council) IBC-2021, International Building Code.
5. ICC IFC-2021, International Fire Code.
6. IEC 62619, Secondary Cells and Batteries Containing Alkaline or Other Non-Acid Electrolytes—Safety Requirements for Secondary Lithium Cells and Batteries, for Use in Industrial Applications
7. IEEE 1635-2022 / ASHRAE 21, Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications.
8. IEEE P2962 draft (d32) Recommended Practice for Installation, Operation, Maintenance, Testing, and Replacement of Lithium-ion Batteries for Stationary Applications.
9. ISO 6346:2022, Freight containers – Coding, identification, and marking.
10. KEPIC EEG 1400, Guide for the Installation Design, and Installation of Lithium-ion Batteries for Stationary Application.
11. NFPA 1-2021, Fire Code
12. NFPA 13-2022, Standard for the Installation of Sprinkler Systems.
13. NFPA 72®-2022, National Fire Alarm and Signaling Code®.
14. NFPA 855-2023, Standard for the Installation of Stationary Energy Storage Systems, Chapter 14.
15. NYCFC-2022, New York City Fire Code.
16. Tapesh Joshi, *et al,* 2020 *Journal of the Electrochemical Society. 167 140547.* "Safety of Lithium-Ion Cells and Batteries at Different States-of-Charge*".*
17. UL 263, Fire Tests of Building Construction Materials, Edition 14.
18. UL 1642, Lithium Batteries, 6th Edition.
19. UL 1973, Batteries for Use in Stationary and Motive Auxiliary Power Applications, Edition 3.
20. UL 2054, Household and Commercial Batteries, Edition 3.
21. UL 2271, Standard for Batteries for Use in Light Electric Vehicle (LEV) Applications, Edition 2.
22. UL 2849, Electrical Systems for eBikes, 1st Edition.
23. UL 9540, Energy Storage Systems and Equipment, Edition 2.
24. UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems.
25. UN Manual of Tests and Criteria, Sixth Revised Edition, Sub-Section 38.3, Lithium metal and lithium-ion batteries.
26. U.S. DOT (United States Department of Transportation) 49CFR (Code of Federal Regulations) Part 172.101, Hazardous Materials Table.

