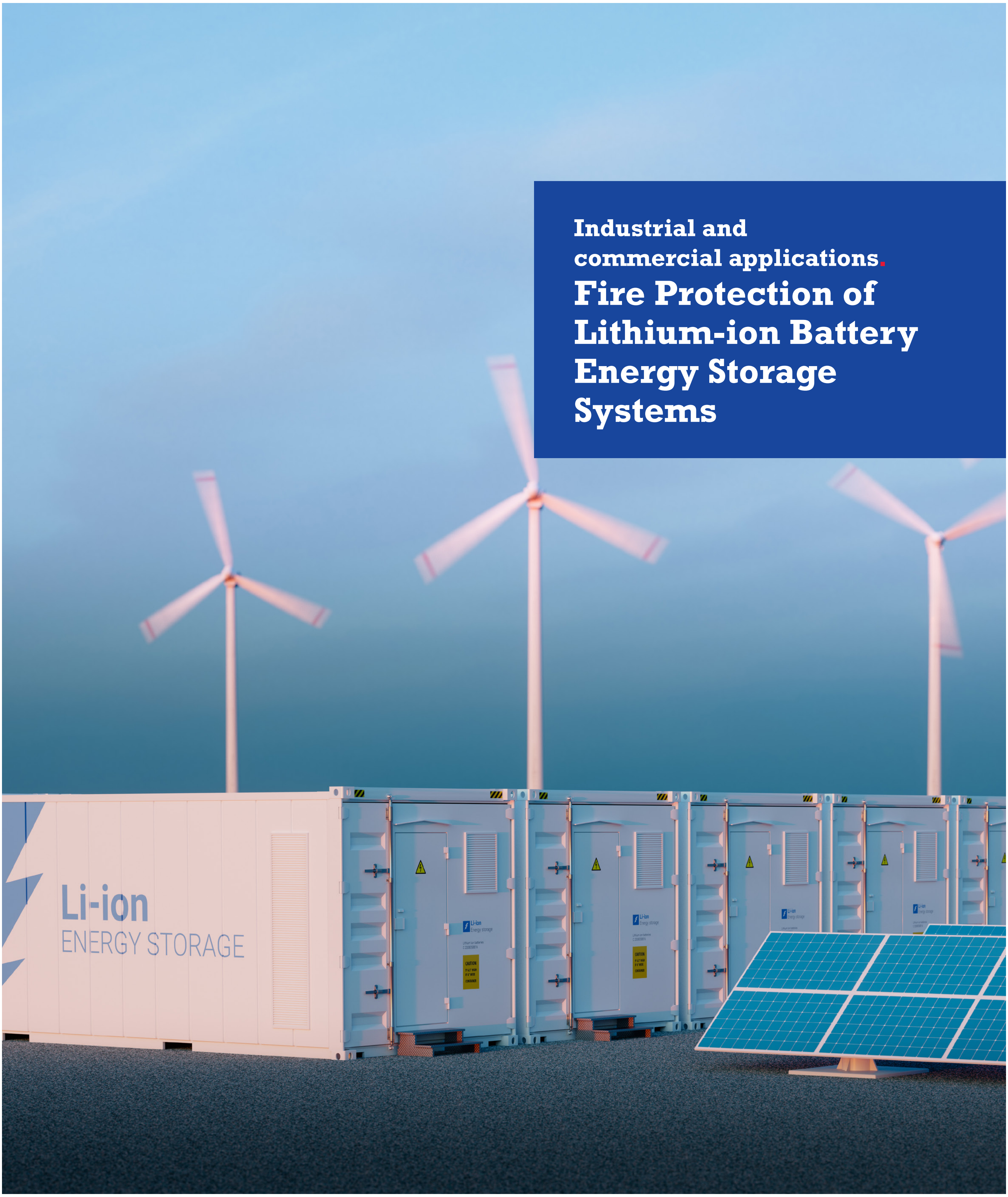
White paper



Industrial and
commercial applications.

Fire Protection of Lithium-ion Battery Energy Storage Systems

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Abbreviations

Li-ion	Lithium-ion
SOC	State of Charge
BMS	Battery Management System
ESS	Energy Storage System
AHJ	Authority Having Jurisdiction

1. Scope

The scope of this document covers the fire safety aspects of lithium-ion (Li-ion) batteries and Energy Storage Systems (ESS) **in industrial and commercial applications** with the primary **focus on active fire protection**.

An overview is provided of land and marine standards, rules, and guidelines related to fixed firefighting systems for the protection of Li-ion battery ESS. Both battery technology itself and related regulatory framework are under intense development and, hence, this document represents just a snapshot of the situation at the exact time this document was written. The document covers standards and guidelines published by:

- NFPA (National Fire Protection Association),
- UL (Underwriters Laboratories Inc),
- FM Global,

and the following marine classification societies:

- ABS (American Bureau of Shipping),
- BV (Bureau Veritas),
- DNV (Det Norske Veritas),
- LR (Lloyd's Register of Shipping), and
- RINA (Registro Italiano Navale).

The reader is instructed to check whether there are new revisions of the referred documents or whether the authority or organization of interest has published dedicated guidelines of their own.

2. Executive summary

Li-ion battery Energy Storage Systems (ESS) are quickly becoming the most common type of electrochemical energy store for land and marine applications, and the use of the technology is continuously expanding.

In land applications ESS can be used, e.g., to reduce peak energy demand swings, support high-voltage grids, and support green energy production, such as wind and solar. Typical marine applications are all-electric or hybrid ships with energy storage in large batteries. Optimized power control allow significant reductions, e.g., in fuel and maintenance costs and emissions. In all applications, land or marine, ESS can provide the flexibility and freedom to store electrical energy and utilize the energy when it is most beneficial for system operation.

From a fire safety point of view, Li-ion batteries have created a whole new challenge, as they behave in a fundamentally different way in fire conditions other than common batteries. The most notable and unique risk is the so-called thermal runaway, and the most notable differences as compared to other common rechargeable batteries relate to the combustible electrolyte and to the higher stored energy.

In a fault situation, a sequence of thermal runaway reactions inside a battery may lead to fires with short duration flareups one after another when combustible gases ignite instantaneously and ignite adjacent combustibles. A thermal runaway sequence inside a battery cannot be stopped by any external firefighting means and, hence, a realistic objective is to limit the fire spread within or close to the affected battery only.
This document provides a short overview of Li-ion batteries and the fire risks involved. The emphasis is on risk mitigation measures and particularly on active fire protection.

To improve the fire safety of batteries, battery manufacturers focus on

- electronic control of batteries: a Battery Management System (BMS) controls and monitors the battery condition and aims to prevent any malfunctioning,
- structural integrity and isolation to contain the heat of a malfunctioning battery within the affected unit only, and
- cooling of batteries by dedicated air or water-based circulation methods.

In spite of the protection measures above, fires may still occur, and there are guidelines by various organizations that focus on

- fixed firefighting systems to stop external fire spread,
- sufficient separation distances between batteries, groups of batteries, and structural elements, to limit the fire within or close to the affected unit only, and
- structural means to prevent the fire from spreading out of the affected space.

In this document, international standards, regulations, and guidelines by the following organizations are addressed: NFPA, UL, FM Global, and marine classification societies ABS, BV, DNV, LR, and RINA.

3. Basics of lithium-ion battery technology

A Li-ion battery converts chemical energy directly to electrical energy. Li-ion batteries are rechargeable batteries just like common lead acid, NiMH, or NiCAD batteries, but with two significant differences:

- Li-ion batteries have a *much higher energy density* and, hence, they are very attractive from a technological standpoint in storing energy.
- The current Li-ion battery chemistries apply *flammable instead of aqueous electrolytes*.

From a fire protection point of view, these two properties combined have created a whole new challenge: in fire conditions, Li-ion batteries behave in a fundamentally different way than batteries with water-based electrolyte.

3.1 Working Principle

A Li-ion battery consists of one or more cells, and each cell consists of two different poles – a positive electrode (*cathode*) and a negative electrode (*anode*). These poles are separated by a thin dielectric layer, called the *separator*, to prevent the poles from touching each other. To allow movement of Li-ions between the anode and the cathode, there is electrically conducting material inside the cell called *electrolyte*. When charging a Li-ion battery, as illustrated in Figure 1, positively charged Li-ions travel through the separator from the cathode to the anode. Once the electric potential is stored in the form of Li-ions collected on the anode, it can be utilized as electric energy by connecting a load between the electrodes [1] [2] [3]. During discharge Li-ions travel back from the anode to the cathode.

The term State of Charge (SOC) describes the energy (typically referred to as capacity) available for use in the battery. A fully charged battery has an SOC of 100%, while a fully discharged battery has an SOC of 0%.

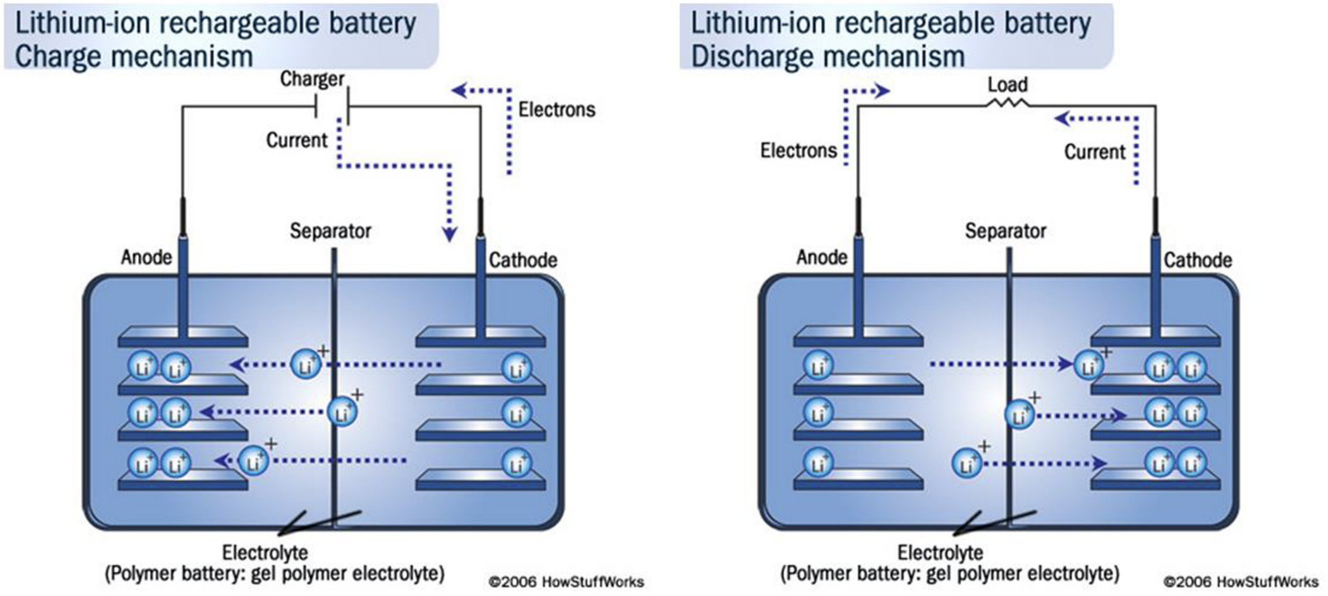

Figure 1. Basic principles and components of a Li-ion battery. [1]

3.2 Chemistry

The chemical composition of the cathode is one of the most determining aspects of a given battery's characteristics like power, safety, and cost. The chemistry also defines at which voltage range the battery operates [1].

The cathode composition is commonly referred to when describing different battery chemistries, such as

- LCO - Lithium cobalt oxide ($LiCoO_2$),
- LMO - Lithium manganese oxide spinel ($LiMn_2O_4$),
- NMC - Nickel manganese cobalt oxide ($LiNi_{1-x-y}Mn_xCo_yO_2$), and
- LFP - Lithium iron phosphate ($LiFePO_4$).

There is no "standard" Li-ion cell, and new battery chemistries continue to be under active research and development.

3.3 Packaging

The *cells* are packed in a variety of forms to protect the electrochemical components of the Li-ion cell, and they are usually distinguished by the shape of the packaging. The three most common types of Li-ion cells are cylindrical, prismatic, and pouch cells as shown in Figure 2 [4]. In cylindrical cells, alternating strips of anode and cathode (separated by a porous film and electrolyte material) are wound together to form a multilayer roll or cylinder. In prismatic cells the alternating electrode layers are stacked in a pile. The very light pouch cells come in different designs. All cell types can be inserted in hard cases for their intended final use.

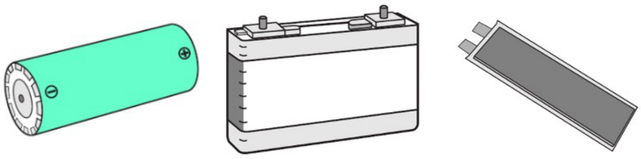

Figure 2. Cylindrical, prismatic, and pouch cells [4].

The term "cell" is often interchangeable with "battery" in small consumer applications. For example, a cylindrical cell with a top positive terminal and bottom negative terminal is common in many consumer applications and is called a battery.

3.4 Energy Storage Systems

Energy storage systems (ESS) come in a variety of types, sizes, and applications depending on the end user's needs.

In general, all ESS consist of the same basic components, as illustrated in Figure 3, and are described as follows:

1. *Cells* are the basic building blocks.
2. Several cells are connected in parallel and/or series to build *modules*.
3. Modules are linked (typically in series) to form a *pack*.
4. Several packs form a full *ESS* with a Battery Management System (BMS) that monitors individual cells and safe operating conditions.

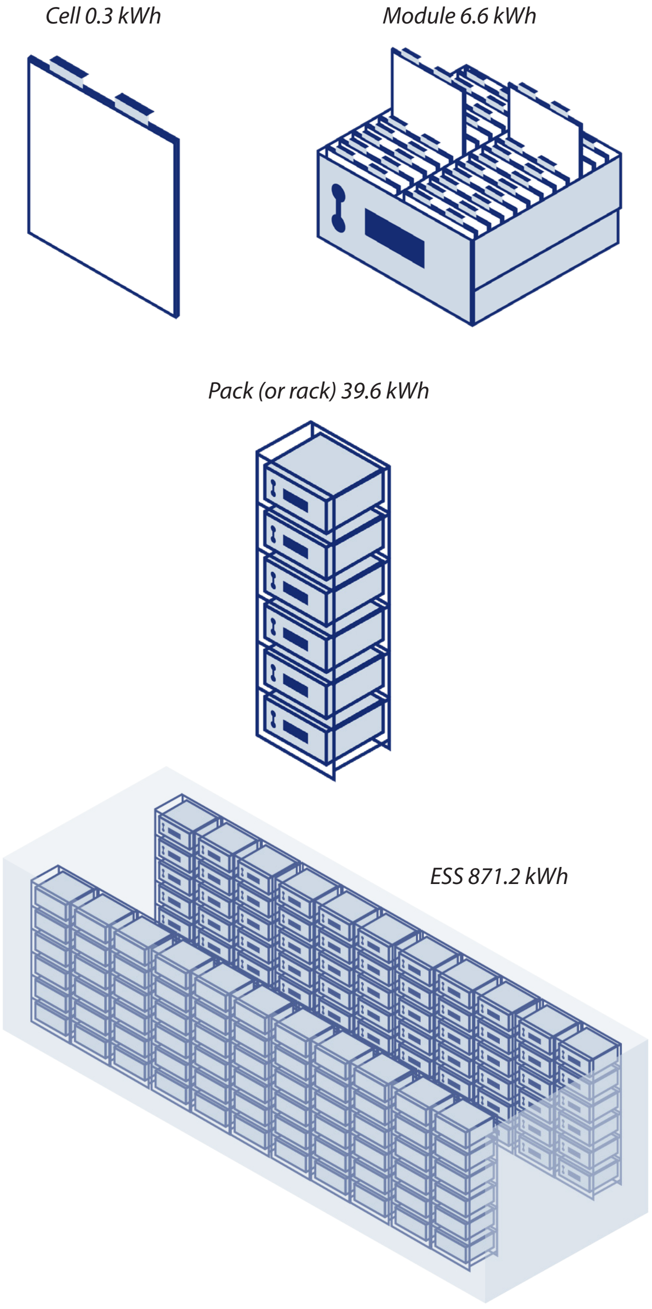

Figure 3. ESS from cell level to a whole system (1.

(1 In literature the terms may vary somewhat. In this document the terms 1 – 4 are being used in a consistent manner even though the referred source document may apply different terms. In some instances, for clarity, source terms are being used together with the terms 1 – 4.

3.5 Power Characteristics

Most battery packs are labeled with the nominal voltage and pack capacity in Watt hours (Wh), which is the battery pack capacity in Ampere hours (Ah) multiplied by the nominal voltage. By connecting cells or modules in parallel the pack capacity (Ah) is increased, and by connecting them in series the pack voltage is increased. An example of a consumer application is presented in Table 1.

Table 1. Example of battery pack characteristics with three cells of 3.6 V and 2 Ah .

	Connected in series	Connected in parallel
Nominal voltage (V)	10.8	3.6
Pack capacity (Ah)	2	6
Pack capacity (Wh)	21.6	21.6

In industrial applications the capacities range from less than one kWh of individual cells up to a few MWh of a full ESS as shown in Figure 3.

4 Fire risks related to Li-ion batteries

The most notable and unique risk related to Li-ion batteries is the so-called thermal runaway, and the most notable differences as compared to other common rechargeable batteries relate to the combustible electrolyte (instead of water) and to the higher stored energy [5]. It is worth noting that there is no free lithium metal within Li-ion batteries and, hence, the risk does not involve metal fires.

The principal risks are the same for all Li-ion batteries, but the probabilities and severities depend on the actual batteries. At the most fundamental level, the battery cell technology plays the key role in determining the fire risks involved [2]:

- **Cell chemistry**
  Some cell chemistries may go into thermal runaway at lower temperatures than others, and some chemistries will inherently produce less heat.
- **Cell capacity**
  Larger individual cells may produce more heat and/or more gas under the thermal runaway event.
- **Cell packaging and design**
  Different cell types have different levels of resiliency or tendency towards different failure modes and may act differently under the thermal runaway event. The packaging material itself affects the total fire load.
- **SOC**
  State of charge affects the growth and peak heat release, and the likelihood of thermal runaway (at SOC 100% a higher peak and thermal runaway is more likely).

4.1 Thermal runaway

Thermal runaway refers to rapid self-heating of a cell or several cells in an uncontrollable fashion. Heat is generated at a higher rate than it can be dissipated: it is an exothermic reaction that can lead to fire, explosion, and gas evolution. At a cell-specific critical temperature, the internal cell structure breaks and, due to the flammable electrolyte, flammable gas is generated. If the internal pressure within the cell increases above the mechanical strength of the housing, the housing may break, or a safety vent opens, and the flammable gas is released into the environment in an *off-gas event*. In the presence of an ignition source, the gas and the electrolyte may ignite.

See Figure 4 for an off-gas event and subsequent ignition(2:

i. The internal pressure within a module has increased after and during thermal runaway and a safety vent opens, allowing flammable gas out.
ii. Without an ignition source the gas may not ignite but
iii. with an ignition source
iv. it does ignite abruptly. The more gas has been accumulated in the space, the more violent is the ignition.

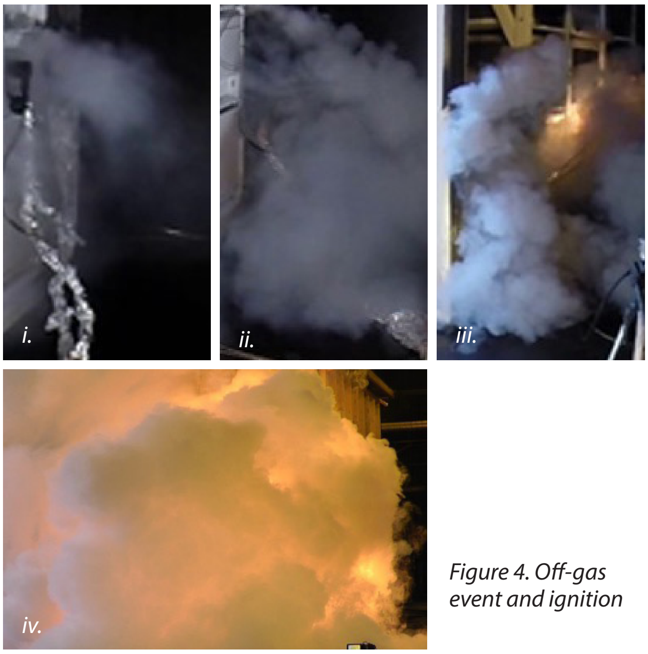

Figure 4. Off-gas event and ignition

(2 The photos are not from the same demonstration test but are chosen to best illustrate the different potential phases

In the thermal runaway reaction, the cell rapidly releases its stored energy, both electrical and chemical. The electrical energy relates to the cell capacity and the chemical energy of the flammable components in the cell. The ignition or the plain thermal runaway process can potentially heat adjacent cells to their critical temperatures, resulting in cascading thermal runaway. In energy storage systems, a single cell failure may therefore propagate or cascade to other cells and even to other modules, packs and so on [1] [2] if not interrupted by active or passive protection means.

An unpredictable risk relates to the fact that even when all external flames have been extinguished and the situation seems to be under control, thermal runaway may still gradually develop within a module, and a new flareup may appear even days after the initial fire event.

4.2 Off-gases

The amount of electrolyte and combustion gases released during a thermal runaway event is excessive. Off-gases are highly toxic with mixtures of CO, H2, ethylene, methane, ethane, benzene, HF, HCl, HCN, and other compounds. The exact composition varies between battery types.

Off-gas in the early stages of thermal runaway events is cooler than off-gas release in the later stages. The early off-gas can therefore be heavier than air, collecting at floor level.

If off-gas is allowed to accumulate within the space, there is a high risk of an instantaneous ignition of the gases creating a short duration flareup. The more gas has been accumulated in the space, the more violent is the deflagration: the pressure peak generated may even break structures.

4.3 Fire intensity

Due to the high energy content of Li-ion batteries, a common assumption is that, in case of fire, the Heat Release Rate (HRR) is also high. This is partially a misconception based on the assumption that all cells or modules would be involved in the fire *simultaneously* at their peak HRR. This is not a realistic approach. In the most likely fire event, thermal runaway is experienced within a single battery module, and combustible gases get released into the space and may ignite. The short duration flareup may then ignite other external combustibles within the space, but if the fire spread can be prevented from cascading to adjacent modules, the resulting fire is "just an ordinary fire" within the battery space/area.

With Figure 3 as an example, the following formula [6] can be applied to estimate the peak HRR, with E denoting the battery capacity:

$$\mathbf{HRR\ [kW] = 2 \times (E\ [Wh])^{0.6}}$$

The complete ESS with a capacity of 1100 kWh would generate a peak HRR of about 8.5 MW (plus cables and other solid combustibles) if all the batteries burned simultaneously and, yet, a more realistic initial situation is that a single module of 6.6 kWh is on fire, generating a peak HRR of some 400 kW.

5 Fire risk mitigation

5.1 Battery Level Measures

Possible causes or failure modes leading to thermal runaway and related consequences are summarized in Figure 5 [1] [2] [7].

Since overcharging is one of the potential causes of thermal runaway reactions, many protection measures aim at preventing the possibility of overcharging and other electrical faults. These measures are typically included in the comprehensive Battery Management System (BMS) that forms a critical part of safe use of a full ESS. The BMS monitors and controls all critical system parameters like voltage, current, temperature, and SOC, and electrically isolates cells or modules that are at risk of operating outside their safe operating range.

Also, as electrolyte chemistry plays a key role in fire safety, it is an active area of research with the objective of producing non-flammable or reduced-flammability electrolytes. Already today, some chemistries generate vent gases with lower flammability and/or a lower tendency towards thermal runaway. The battery packaging material may also be chosen to reduce flammability and the total amount of combustibles in the system.

Currently, despite all the battery level mitigation measures, fires may still be initiated by the batteries, or batteries may get involved in an externally initiated fire. Therefore, dedicated fire protection measures – passive or active – are also needed.

5.2 Passive Fire Protection

The purpose of passive fire protection measures is to contain the potential fire and prevent the spread to other cells, modules, packs, or outside the space/room. In practice, the measures may include:

- thermal barriers at all levels (cell, module, pack) and/or
- proper separation distances between battery packs and adjacent combustible materials, and
- locating the ESS in a dedicated battery space or room.

There are test protocols for evaluating the efficiency of thermal barriers and/or separation distances, and the outcome of the tests may also affect the active fire protection measures: the more robust is the structural barrier in preventing fire spread, the "lighter" may the active fire protection system be – although passive protection does not exclude the need for active protection altogether. These issues will be dealt with in Chapter 6.

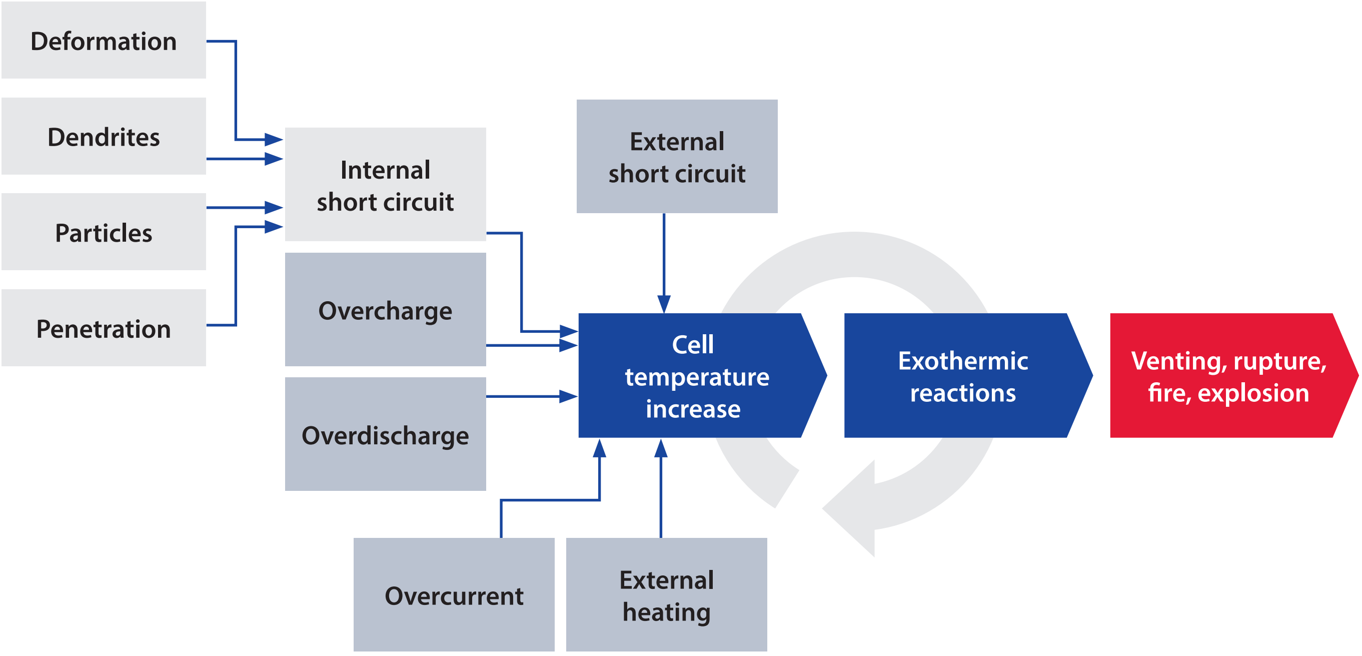

Figure 5. Causes and consequences of thermal runaway in a Li-ion battery. [1]

5.3 Active Fire Protection

Li-ion cells are typically structurally well-concealed, and a cell-level thermal runaway cannot be prevented nor stopped by any external fire protection system. The only way to ensure cell level protection would be to inject the extinguishing agent directly into the cell. Given the thousands of cells in an ESS, this is not possible in practice. The next best option related to extinguishing efficiency is to inject the extinguishing agent into each module housing several cells and, in fact, such systems are commercially available. Still, it is a major effort to incorporate a dedicated discharge mechanism into every single module in an ESS with hundreds of modules – but it is possible.

The most practical protection option is usually an external, fixed firefighting system. A fixed firefighting system does not stop an already occurring thermal runaway sequence within a battery module, but it can prevent fire spread from module to module, or from pack to pack, or to adjacent combustibles within the space. The affected module is likely to be fully lost, but the adjacent modules can be saved.

The most common fixed firefighting systems are water-based and gaseous systems, but aerosol systems are also used in some applications. In Li-ion battery applications, the performance objective and focus are on preventing the fire from spreading to adjacent modules, surrounding structures and equipment and, hence, the most desired property of the system is cooling, which guides to water-based systems. Different systems are discussed in Chapter 7.

6 Guidelines and standards

Battery and ESS development has been so fast that the development of regulatory framework has had difficulties in keeping pace with the technology, and partly it has been left behind. There are already standards focusing on safe performance of Li-ion cells, consumer safety, safety in storing and transporting the batteries, etc., but **this document concentrates exclusively on the fire safety aspects and active fire protection** of Li-ion batteries and ESS.

In recent years several research projects have been initiated for the purpose of creating justified fire protection requirements – both for active and passive measures – and several new standards and guidelines have been published with continuous follow-up and revision. This chapter presents current rules, regulations, standards, and other guidance documents but – due to the fast development – it is of particular importance to always check the requirements from the latest edition of the document.

The challenge in all standardization and test protocol development is that there are so many different Li-ion battery types that defining a "representative" type for generic and comprehensive testing is impossible: all tests are manufacturer and battery-specific, and would need to be repeated for all battery types of interest. This is not possible in practice and, hence, the suitability of any conducted testing would need to be evaluated on a case-by-case basis by the relevant stakeholders.

6.1 Land

Many research projects have been conducted by several organizations about fire safety and fire protection of Li-ion batteries. This chapter focuses on the outcome of studies by NFPA, UL, and FM Global, i.e., on the guidance documents and standards listed in Table 2. The NFPA and FM Global guidelines are largely based on the same research project [8] [9] and are therefore similar, although not fully identical.

Table 2. Guidance documents and standards related to Li-ion battery installations in land applications.

Document ID	Title
NFPA 855 (2020) [10]	Standard for the Installation of Stationary Energy Storage Systems
UL 9540 (2020) [11]	Standard for Safety Energy Storage Systems and Equipment
UL 9540A (2019) [12]	Standard for Safety Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
FM Global Loss Prevention Data Sheet 5-32 (July 2022) [13]	Data Centers and Related Facilities
FM Global Loss Prevention Data Sheet 5-33 (July 2020) [4]	Electrical Energy Storage Systems

While no fixed firefighting systems can be expected to stop thermal runaway within a cell, the current protection concept in the guidelines focuses on preventing the thermal runaway event from propagating from the affected battery module or pack to an adjacent one. This is achieved through the following primary measures:

- Limiting the acceptable total energy capacity of individual modules or packs, which reduces the potential fire size
- Setting up a minimum spacing between individual modules or packs
- Requiring physical barriers (plates) within packs
- Setting up minimum separation from walls, openings, and other structural elements.

6.1.1 NFPA 855

The National Fire Protection Association NFPA 855 *Standard for the Installation of Stationary Energy Storage Systems* [10] provides the minimum requirements for mitigating hazards associated with ESS of different battery types. The standard applies to Li-ion battery systems with a total capacity higher than 20 kWh within the potential fire area. (Smaller devices are typically consumer devices that are evaluated by other dedicated standards.)

NFPA 855 divides industrial and commercial ESS applications into:

i. non-dedicated-use buildings and
ii. dedicated-use buildings, and the latter ones further into
    a. remote location buildings and
    b. buildings near exposures.

Remote location is defined as 30.5 m or more from other buildings, equipment, and structures. The requirements are strictest in non-dedicated-use buildings but may be somewhat relaxed in dedicated-use buildings near exposures. In remote dedicated-use buildings some of the requirements may even be ignored altogether. Table 3 summarizes the key requirements.

The standard includes prescriptive design requirements for traditional sprinkler systems together with battery capacity limitations and passive protection means like separation distances and barriers, but it allows alternative designs both for traditional sprinklers and other types

Table 3. NFPA 855: Key design parameters and requirements for the protection of ESS with Li-ion batteries.

	General requirement				
Battery level	Battery capacity limitations	Total ESS	> 20 kWh / ≤ 600 kWh (1,2		
		Pack	≤ 50 kWh (1,3		
Passive fire protection	Min distance between packs and to walls		0.914 m (1,3		
	Room structures		2 h fire resistance rating		
Active fire protection	Fixed suppression system (3	Options	Traditional sprinkler		Alternative system, e.g., water mist
			Option1	Option2	
			Prescriptive	Performance-based	
		Water flux density	12.2 mm/min	UL 9540A, Installation Level Test (or equivalent)	
				Method 1	Method 2
		Design area (4	230 m²		
		Discharge duration	Not clearly specified – case-by-case		
	Smoke detection system required				
Other	Mechanical exhaust ventilation				
	Explosion control (5 or deflagration venting				

(1 Modifications up to Authority Having Jurisdiction (AHJ) based on Hazard Mitigation Analysis and UL 9540A test results.
(2 In remote dedicated buildings no upper limit
(3 In remote dedicated buildings the requirement can be omitted altogether at AHJ approval
(4 For water-based systems
(5 May be part of BMS

of systems based on large-scale fire testing. Water is “the agent of choice” in NFPA 855, but the standard does not categorically exclude any system types. Different firefighting agents are discussed in general terms in NFPA 855, Annex C *Fire-Fighting Considerations (Operations)* (see chapter 7).

For defining alternative fire protection systems and designs, or when aiming at relaxed requirements for battery sizes or separation distances, UL 9540A (or an equivalent test standard) is given as a suitable basis for large-scale fire testing. For acceptable performance, the fire involving one module or pack shall not propagate to an adjacent unit, and the fire during the test shall be contained within the room or enclosed area for a duration equal to the fire resistance rating of the room separation.

6.1.2 UL 9540 & 9540A

UL has released two standards specifically addressing ESS:

- UL 9540 Energy *Storage Systems and Equipment* [11] and
- UL 9540A *Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems* [12].

The standards are closely linked with NFPA 855 as described in the previous chapter. UL 9540 covers all essential aspects of ESS, including fire detection, suppression, and propagation. Fire detection and fire suppression equipment may or may not be provided as an integral part of an ESS, or it may be optional. Depending on the case, the ESS shall comply with all applicable performance requirements in the standard with and/or without the fire detection and fire suppression equipment in place and operational. The guidance on capacity and separation distance limits given in Appendix E are aligned with those of NFPA 855 as given in Table 3.

UL 9540A provides large-scale test methodology for validating the safety of an ESS installation *in lieu of* meeting the prescriptive capacity, location, separation, and firefighting system criteria and/or to determine the required explosion control system. Essentially, UL 9540A presents four levels of testing: Cell, Module, Unit (Pack), and Installation level tests, with the logic presented in Figure 6. The Cell level test provides alternatives for extreme abuse conditions and methods for forcing a cell into thermal runaway. The applicable method is defined by testing for each cell type separately and it is to be applied in all subsequent tests as appropriate.

If a cell cannot be forced into thermal runaway by any means, there is no need to run any further tests – nor would it even be possible. Passing the test is not very likely with the current Li-ion battery chemistries, but if the test is passed, it may be that no dedicated fire protection measures need to be taken due to the batteries.

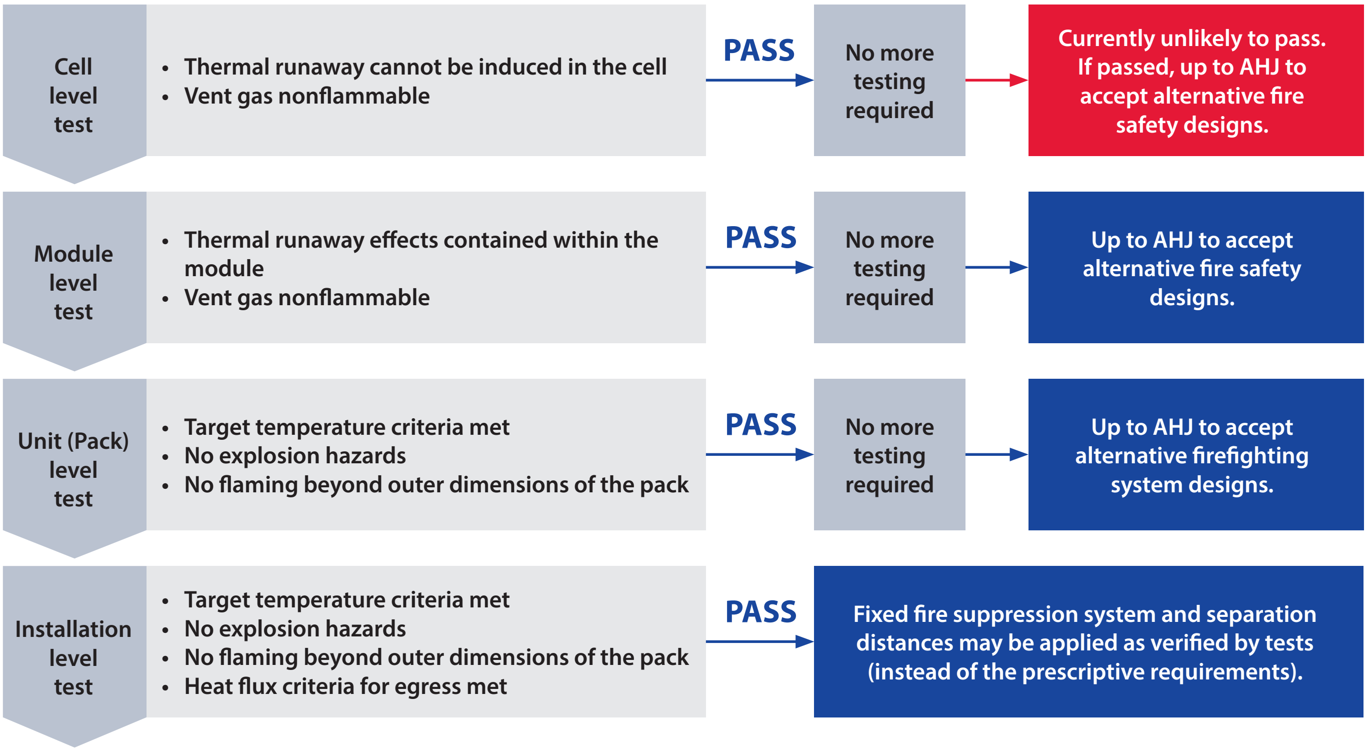

Figure 6. UL 9540A test sequence with some practical considerations.

With a robust module structure, thermal runaway effects can be contained within a module, but the vent gases with the current chemistries are flammable, and the Module level test is practically impossible to fully pass either. The results may be applied in evaluating the need for further tests if the aim is to relax any of the prescriptive fire safety requirements.

In the Unit (Pack) level tests the battery packs are arranged in the test area as they would be in a real installation, with the minimum separation distances from each other and the walls. Only the fire initiating pack must be a complete battery pack, whereas the target packs contain only the enclosure and rack hardware that physically supports and contains the components that comprise a pack. The target packs serve to enable instrumentation for measuring the thermal exposure from the initiating pack. Target temperatures form part of the acceptance criteria. If the pack includes an integral fire suppression system, it can be applied in the tests as well. If the integral fire suppression system is optional, the tests must be done without it.

The Unit level test results may be applied in evaluating the need for further tests if the aim is to use an alternative firefighting system design, or whether Installation level tests would be required to verify the design. The Installation level test arrangement is the same as the Unit (Pack) level arrangement, but it includes the fixed firefighting system to be evaluated.

6.1.3 FM Global Loss Prevention Data Sheets 5-32 and 5-33

DS 5-32 Data Centers and Related Facilities [13] includes recommendations for the protection of data center equipment using Li-ion batteries in battery back-up units (BBU), uninterruptable power supplies (UPS), and energy storage systems (ESS) with a maximum capacity of 20 kWh per rack. If the capacity exceeds 20 kWh per rack, DS 5-33, *Energy Storage Systems* [4] is to be followed. Table 4 summarizes the key fire protection guidelines of Data Sheets 5-32 and 5-33 with respect to sprinkler protection and physical separation and/or barriers between equipment with Li-ion batteries.

The guidelines for ESS are based on a dedicated research project [8] that covered traditional sprinkler systems only. The guidelines for data centers are presumably based on the same project but with somewhat relaxed design parameters. DS 5-33 recognizes that the research was

Table 4. FM Global DS 5-32 and 5-33: Key design parameters for the protection of ESS and data centers with Li-ion batteries.

			DS 5-32: Data centers	DS 5-33: ESS
Battery level	Battery capacity limitations		Max 20 kWh per server rack located in max two shelves. If higher -> DS 5-33	N/A
Passive fire protection	Batteries within racks		In max two distant shelves	N/A
	Vertical barriers		Spaced every third rack	Between all racks (1
	Min aisle width between racks		1.2 m	1.8 m
	Min distance from non-combustible / combustible materials		N/A	1.8 / 2.7 m
	Room structures		N/A	1 h fire resistance rating (2
Active fire protection	Sprinkler system	Water flux density	8 mm/min	12 mm/min
		Design area	230 m^2 / 320 m^2 wet, non-interlock & single interlock pre-action systems / double interlock pre-action systems	230 m^2
		Discharge duration	60 min	Number of adjacent racks x 45 min (3
	Smoke detection system required			
Other	Damage-limiting construction			
	Mechanical ventilation			

(1 Without sufficient water supply, additional mechanical barrier requirements apply.
(2 In non-dedicated buildings
(3 Estimate – TBD on a project basis

limited in scope, and the effect of rack design, materials of construction, battery specifications and chemistry, and other design features are not well understood. It is stated that the recommendations in DS 5-33 represent the current state of knowledge, and that the data sheet will be updated as additional information is available.

6.2 Marine

Minimum safety requirements for merchant ships are given in the *International Convention for the Safety of Life at Sea* (SOLAS), [14] an international maritime treaty by the International Maritime Organization (IMO). Fire safety is one of the critical aspects addressed in SOLAS, and dedicated, more detailed codes, resolutions and circulars linked to it apply. New requirements and guidelines are being added and amended as needed, but dedicated guidelines for battery installations have not yet been formulated and finalized to be included in SOLAS.

The increasing number of battery installations for ship propulsion and power generation, and the lack of IMO guidelines, have forced classification societies to develop their own class rules and guidelines to address various fire and other safety aspects related to Li-ion batteries and battery spaces. Table 5 summarizes the class rules and other guidance documents covered in this chapter.

The class rules and guidelines cover essentially all hazards related to Li-ion battery systems, but the level of detail and emphasis on different issues varies between classification societies. All classification societies require a comprehensive, project-specific review and risk assessment of the whole installation with all the safety aspects included, and some of them also require a dedicated class approval for the batteries themselves.

In most cases Li-ion battery spaces in marine applications are relatively small and they are treated as machinery spaces, which leads to one principal difference between the Land designs (Chapter 6.1) and Marine designs for the fixed firefighting system: the default system in NFPA, UL, and FM guidelines is an automatic sprinkler system with individually activating sprinklers, whereas in marine applications a total flooding system is the default system.

Table 6 summarizes some key contents related to Li-ion battery space fire safety in the documents listed in Table 5, but a more detailed study and the most current versions of the class rules of interest is left to the reader.

Table 5. Documents with guidance related to the safety of Li-ion battery installations in marine applications.

Classification society	Document ID
ABS [15]	Guide for Use of Lithium batteries in the marine and offshore industries
BV [16]	Rules for the Classification of Steel Ships Part F - Additional Class Notations Chapter 11 - Other Additional Class Notations Section 21 – Battery System
DNV [17]	Rules for classification – Ships Part 6 - Additional Class Notations Chapter 2 - Propulsion, power generation and auxiliary systems Section 1 - Electrical energy storage
LR [18]	Rules and Regulations for the Classification of Ships Part 6 – Control, Electrical, Refrigeration and Fire Chapter 2 – Electrical Engineering Section 12 – Batteries
LR [19]	Battery installations Key hazards to consider and Lloyd’s Register’s approach to approval A Lloyd’s Register Guidance note
RINA [20]	Rules for the Classification of Ships Part C – Machinery, Systems and Fire Protection Appendix 2 – Battery Powered Ships
RINA [21]	Rules for the Certification, Installation and Testing of Lithium Based Storage Batteries

Table 6. Marine class rules: Key design aspects for the fire protection of Li-ion battery spaces.

Classification society			ABS	BV	DNV	LR	RINA
Battery/ESS level			>25 kWh Optional class notation or TA(1	TA(1,2 or case-by-case approval	20-50 kWh: TA(1,3 >50 kWh: PC(3,4	>20 kWh: TA(1,5	Case-by-case acceptance
Passive fire protection	Occupancy category (6		Auxiliary Machinery Space, or Machinery Space other than Cat A	Other machinery space	<100 kWh: Other machinery space ≥100 kWh: Machinery space of Cat A	Machinery space of Cat A, or A60 compartment	Auxiliary machinery space with high fire risk (in larger passenger ships)
Active fire protection	Fixed suppression system	Design basis	Battery manufacturer recommendations	TA(7 and battery manufacturer recommendations	Space: TA(7 ESS integral(8: Fire testing	TA(7 and battery manufacturer recommendations	Battery manufacturer recommendations
		Fire testing required	No	No	Yes for ESS integral system	Yes if other than water is used as the agent	No
		Fire testing specified	N/A	N/A	Yes for ESS integral system	No	N/A
		Acceptance	Technical validation(9	TA(7 and case-by-case acceptance	Space: TA(7 ESS integral: TA(1	TA(7 and/or case-by-case acceptance	Case-by-case acceptance
	Detection system		In general, fire detection (smoke/heat) is required, and battery manufacturer requirements are referred to in some of the rules. Off-gas detection is specifically required in most rules.				
Other			In general, a comprehensive, project-specific review is required for the full battery space, including issues such as battery arrangement in the space, ventilation, explosion control, and run-off water management.				

(1 Type Approval of the battery
(2 As per [22]
(3 May include an ESS integral fire suppression system
(4 Product Certificate of the battery
(5 Type Approval based on [24]
(6 Structural requirements are built in the occupancy category
(7 Type Approval of the fixed firefighting system for machinery spaces
(8 An ESS integral system is a dedicated system that may be used to fulfill the requirement of module-to-module propagation.
(9 As per [23]

7 Firefighting agent considerations

In the following section, the advantages and disadvantages of different firefighting agents are discussed briefly in generic terms. FM Global [4] [13] is very restrictive and allows only systems based on their own dedicated testing with traditional sprinklers. Hence, any negative statements against other agents and systems are not based on experimental proof but on generic assumptions. In contrast to FM Global, NFPA 855 [10] and marine rules do not categorically exclude any agents or system designs, but their suitability must have been validated by testing.

7.1 Water

In practically all the literature dealing with fire safety of Li-ion batteries, cooling is recognized as the key property of the potential firefighting system. It is acknowledged that thermal runaway cannot be stopped within a cell or battery module by external means, but efficient cooling may prevent the spread of thermal events to adjacent modules and surrounding structures.

Water is the preferred or recommended firefighting agent in NFPA 855 [10], in the relevant FM Data Sheets, and in marine rules. For example, an extract of Annex C *Fire-Fighting Considerations (Operations)* in NFPA 855 states the following in C.5.1 *Lithium-Ion (Li-ion) Batteries*:

> *Water is considered the preferred agent for suppressing lithium-ion battery fires. Water has superior cooling capacity, is plentiful (in many areas), and is easy to transport to the seat of the fire. While water might be the agent of choice, the module/cabinet configuration could make penetration of water difficult for cooling the area of origin but might still be effective for containment. Water spray has been deemed safe as an agent for use on high-voltage systems.*

Water mist is addressed in A.11.3.2:

> *Water mist fire suppression systems need to be designed specifically for use with the size and configuration of the specific ESS installation or enclosure being protected. Currently there is no generic design method recognized for water mist systems. System features such as nozzle spacing, flow rate, drop size distribution, cone angle, and other characteristics need to be determined for each manufacturer's system through large-scale fire testing in accordance with 4.1.5 to obtain a listing for each specific application and must be designed, installed, and tested in accordance with NFPA 750.*

For example, the HI-FOG systems have been evaluated for Li-ion battery protection in four different full scale fire test programs:

- Total flooding system for the protection of marine battery spaces, generic study [7]
- Total flooding system for the protection of marine battery spaces, proprietary study with a battery manufacturer
- Two test programs with ESS integral system (external local application system) for the protection of battery packs, proprietary studies with another battery manufacturer but with the outcome of DNV Type Approval for the batteries with the integral system.

Based on the test programs, dedicated guidelines have been developed both for total flooding and for local application systems for the protection of ESS with Li-ion batteries in commercial and industrial applications, including marine applications. As the guidelines are based on testing with certain battery types and capacities in certain configurations, the guidelines are subject to project specific evaluation, adjustment, application, and acceptance by the relevant Authority Having Jurisdiction.

7.2 Gaseous agents, powders, and aerosols

Annex C of NFPA 855 [10] addresses agents other than water in C.5.1 *Lithium-Ion (Li-ion) Batteries*:

> *Fire-fighting dry chemical powders can eliminate visible flame. However, they also lack the ability to cool burning battery components. Quite often, even if visible flame is removed, the thermal runaway inside the battery will continue resulting in reignition.*
>
> *Carbon dioxide and inert gas suppressing agents will also eliminate visible flame but will likely not provide sufficient cooling to interrupt the thermal runaway process. ESS with clean agent suppression systems installed have ventilation systems that are tied in with the fire detection and control panel so that the HVAC shuts down and dampers close to ensure the agents have sufficient hold times at the proper concentration levels to be effective suppressants.*

FM DS 5-32 [13] and 5-33 [4] do not recommend applying gases at all for the following reasons (extract from DS 5-33):

> *3.3 Gaseous Protection Systems*
>
> *Generally, gaseous protection systems are not recommended for ESS applications for the following reasons:*
>
> A. *Efficacy relative to the hazard. As of 2019, there is no evidence that gaseous protection is effective in extinguishing or controlling a fire involving energy*

storage systems. Gaseous protection systems may inert or interrupt the chemical reaction of the fire, but only for the duration of the hold time. The hold time is generally ten minutes, not long enough to fully extinguish an ESS fire or to prevent thermal runaway from propagating to adjacent modules or racks.

B. Cooling. FM Global research has shown that cooling the surroundings is a critical factor to protecting the structure or surrounding occupancy because there is currently no way to extinguish an ESS fire with sprinklers. Gaseous protection systems do not provide cooling of the ESS or the surrounding occupancy.

C. Limited Discharge. FM Global research has shown that ESS fires can reignite hours after the initial event is believed to be extinguished. As gaseous protection systems can only be discharged once, the subsequent reignition would occur in an unprotected occupancy.

DC 5-32 raises concerns against aerosols as well due to potential effects of aerosol extinguishing agent discharge residue on sensitive equipment and other objects.

8 Closing words

This document was prepared to provide an easy-to-read review of regulatory requirements primarily related to active fire protection of Li-ion battery installations. The review is just a snapshot at the exact time of writing the document, and it is not intended to be a comprehensive review of all globally existing guidelines.

The review hopefully gives a good general idea of the field, but the reader is always instructed to check whether there are new revisions of the referred documents or whether the authority or organization of interest has published dedicated guidelines of their own.

One piece of advice is common and clear in all guidelines: fires involving Li-ion batteries require cooling, and there is no better cooling agent than water.

Water can be applied in many ways, and with more than 30 years of research and full-scale fire testing with the HI-FOG water mist systems, Marioff has the expertise to optimize the use of water.

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Marioff is a leading developer of water mist fire protection technology and supplies system solutions worldwide. The company's innovative HI-FOG® water mist fire protection system safely controls and suppresses fire using significantly less water than conventional sprinkler systems, reducing water damage, cleanup time and operational downtime. For more information, visit ***www.marioff.com.***

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