CINS network

Lithium-Ion Batteries in Containers Guidelines

C-SAR

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Contact Information

CINS – Cargo Incident Notification System and Network
Suite 3, Charter House, 26 Claremont Road,
Surbiton KT6 4QU
United Kingdom

T: +44 (0)20 8390 0000
E: secretary@cinsnet.com
W: www.cinsnet.com

International Group of P&I Clubs
3rd Floor
78/79 Leadenhall Street
London EC3A 3DH
United Kingdom

T: +44 (0)20 7929 3544
E: secretariat@internationalgroup.org.uk
W: www.igpandi.org

ICHCA International
F15 The Bloc, 38 Springfield Way,
Anlaby, Hull HU10 6RJ
United Kingdom

E: secretariat@ichca.com
W: www.ichca.com

TT Club
90 Fenchurch Street,
London EC3M 4ST,
United Kingdom

T: +44 20 7283 4646
E: riskmanagement@ttclub.com
W: www.ttclub.com

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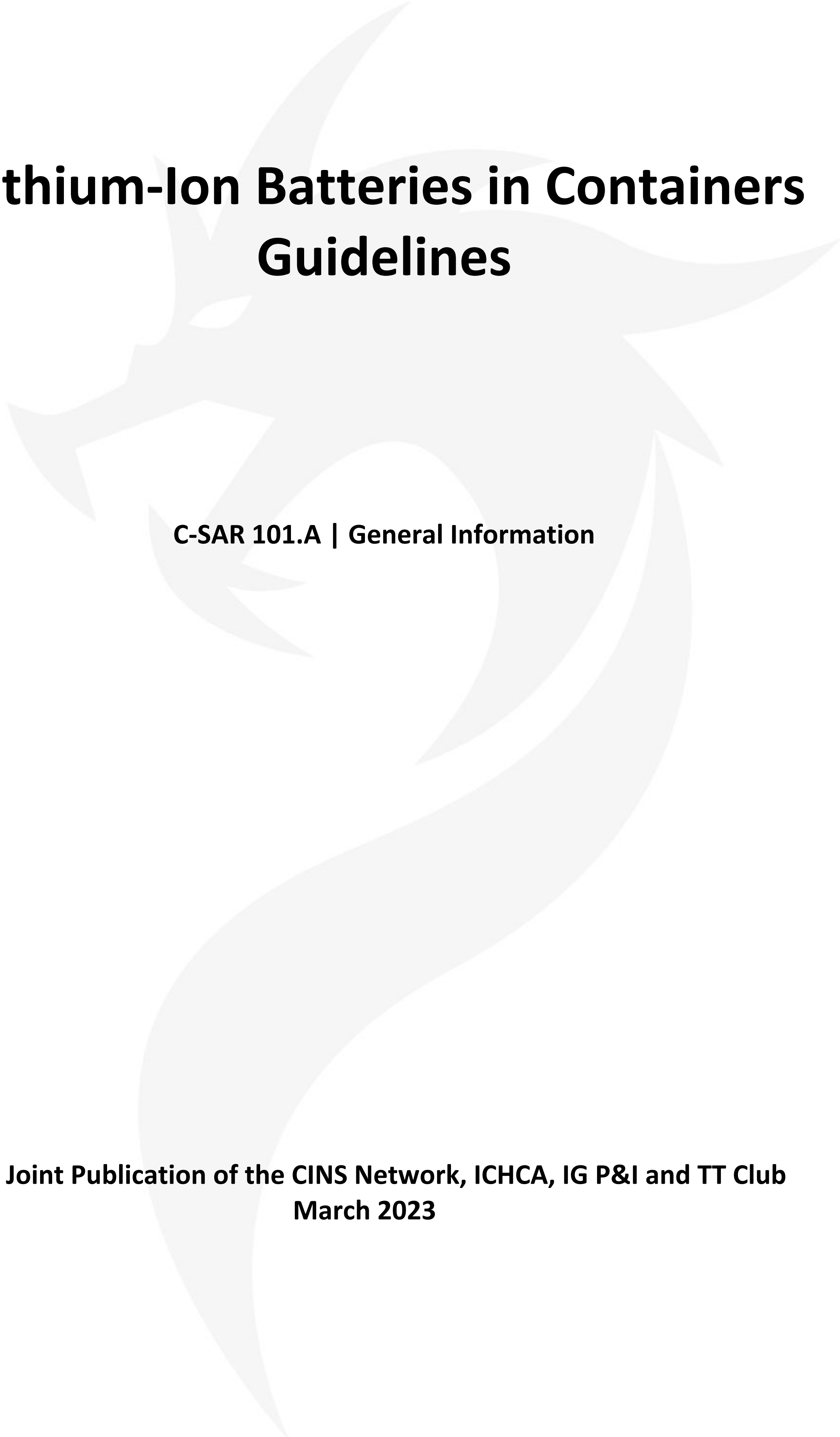

Lithium-Ion Batteries in Containers Guidelines

C-SAR 101.A | General Information

A Joint Publication of the CINS Network, ICHCA, IG P&I and TT Club
March 2023

Executive Summary

There is general recognition in the maritime industry of the need for a greater commitment to health, safety, security, and the environment. The need for business, government, and non-governmental organisations to work together to tackle the most pressing issues and societal challenges has never been clearer.

There is an urgent need to develop new sources of energy and energy storage methodologies to reduce environmental impact and dependency on fossil fuels. The development and use of Lithium-Ion Batteries is crucial in this context. However, these batteries can present a significant risk to people, property and the environment if not handled, packaged, classified, and declared properly. Consequently, one of the main obstacles restricting the wider application of Lithium-Ion Batteries is safety issues.

These Guidelines produced by the global carrier CINS Network is intended to highlight the risks that Lithium-Ion Batteries can present and provide suggestions for identifying those risks and ensuring the safe carriage of Lithium-Ion Batteries.

All stakeholders involved in the carriage of Lithium-Ion Batteries in containers are asked to carefully review these Guidelines to determine if they can be implemented and applied to their specific operations and requirements.

In particular, shippers and stakeholders handling, offering and providing storage or transport of Lithium-Ion Batteries should review the safe carriage of Lithium-Ion Batteries together with their customers, suppliers, manufacturers and producers, to apply and plan the supply chain transport in order to comply with international safety, health and environmental legislation and communicate the relevant information and documentation to all stakeholders in the supply chain including, but not limited to:

- International Maritime Dangerous Goods (IMDG) Code, Code of Practice for Packing of Cargo Transport Units (CTU Code) and Cargo Stowage and Securing (CSS) Codes, amongst others.
- national applicable legislation
- training and knowledge of the associated risks and hazards when a Lithium Ion Battery fails and goes into thermal runaway.
- fault / failure detection and related required actions
- suppressing, extinguishing and post-fire management.

Technology is constantly evolving, and risk control factors also require constant updates to deal with both risks and opportunities. Human risk control factors are particularly unpredictable, which is why any system must constantly take account of both the technological and human elements, new technologies, systems and devices and human judgement and behaviour. This Guideline addresses both the technological and human aspects of risk control for the carriage of Lithium-Ion Batteries.

About Us

CINS – Cargo Incident Notification System

CINS is a shipping line initiative, launched in September 2011, to improve safety in the supply chain, reduce the number of cargo incidents on-board ships and on land, and highlight the risks caused by certain cargoes and/or packing failures. Membership of CINS comprises over 80 percent of the world's container slot capacity, together with the Members of the International Group of P&I Clubs.

CINS provides analysis of operational information on cargo and container incidents which lead to injury or loss of life, loss or serious damage of assets, environmental concerns. Data relating to any cargo incident on-board a ship is uploaded to the CINS database. The data includes information on cargo type, nature, packaging, weight; journey (load and discharge ports); type of incident and root cause.

CINS – Technical Advisory Committee

The Technical Advisory Committee is a CINS committee that includes Members of CINS and leading professional experts in relevant fields.

ICHCA – International Cargo Handling Coordination Association

ICHCA International provides a focal point for informing, educating, networking, and sharing industry views to help improve cargo handling throughout international supply chains.

ICHCA's non-government organisation status enables it to represent its members, and the cargo handling industry at large, in front of national and international agencies and regulatory bodies.

IGP&I - International Group of P&I Clubs

The principal underwriting associations which comprise the International Group, between them provide liability cover (protection and indemnity) for approximately 90% of the world's ocean-going tonnage. Each Group Club is an independent, non-profit making mutual insurance association, providing cover for its shipowner and charterer members against third party liabilities relating to the use and operation of ships. Each Club is controlled by its members through a board of directors, or committee, elected from the membership. Clubs cover a wide range of liabilities, including loss of life and personal injury to crew, passengers and others on board, cargo loss and damage, pollution by oil and other hazardous substances, wreck removal, collision, and damage to property.

TT Club

TT Club is the established market-leading independent provider of mutual insurance and related risk management services to the international transport and logistics industry. TT Club's primary objective is to help make the industry safer and more secure. Founded in 1968, the Club has more than 1200 Members, spanning container owners and operators, ports and terminals, and logistics companies, working across maritime, road, rail, and air. TT Club is renowned for its high-quality service, in-depth industry knowledge and enduring Member loyalty. It retains more than 95% of its members with a third of its entire membership having chosen to insure with the Club for 20 years or more. TT Club has been actively involved in CINS since its foundation.

Acknowledgements

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Content

Abbreviations

Commonly used abbreviations in the carriage of Lithium-Ion Batteries in containers are set out below:

Abbreviation	Description
BESS	Battery Energy Storage System (BESS+ is fitted with tracking-tracing device)
BMS	Battery Management System
CAS	Chemical Abstracts Service
CDC	Critical and Dangerous Cargo
C-SAR	CINS Safety Alert and Related Guidelines
DGD/PC	Dangerous Goods Declaration / Packing Certificate
DOT	US Department of Transportation
EV	Electric Vehicle
FA	Factory Audit
HC or DC	Hazardous Cargo = Dangerous Cargo
HEV	Hybrid Electric Vehicle
HL	Harmless
HRR	Heat Release Rate
IMO	International Maritime Organization
IMDG	International Maritime Dangerous Goods (Code)
ISC	Internal Short Circuit
ISO	International Organization for Standardization
KYC	Know Your Customer
LFP	Lithium iron Phosphate (active cathode material)
LIB	Lithium-Ion Batteries
LMO	Lithium Manganese Oxide (active cathode material)
LIBESS	Lithium-Ion Battery Energy Storage System
MSDS	Material Safety Data Sheet
NMC	Lithium Nickel Manganese Cobalt (active cathode material)
OEM	Original Equipment Manufacturer
PHMSA	US Pipeline and Hazardous Materials Safety Administration
PIN	Pre-Incident Notification
QNC	Quality Non-Conformance
SAR	Safety Alert & Related Guidelines
SDS	Safety Data Sheet
SHS	Self-Heating-Substances
SMDG	Ship planning Message Development Group
SOC	State of Charge of the Lithium-Ion Battery
SOH	State of Health of the Lithium-Ion Battery
TS	Test Summaries (as per UN Test and Criteria UN 38.3)
TSL / TCL	Trusted Shippers List / Trusted Customers List

CINS Guidelines (C-SAR) for the Carriage of new Lithium-Ion Batteries

1. INTRODUCTION

Lithium-Ion Batteries are a relatively new technology and there is not yet a consensus on the best design and construction methods for their use in electric vehicles (EVs) and other applications requiring high density energy.

There are many different chemistries of lithium cells and batteries, but these generally fall into one of two basic types: lithium-ion (including lithium-ion polymer) and lithium metal.

Lithium-ion batteries (including lithium-ion polymer) are generally rechargeable and may present a higher risk than lithium metal batteries which are generally non-rechargeable. These Guidelines will only consider the carriage of **new** Lithium-Ion Batteries. Examples where Lithium-Ion Batteries are used include but not limited to e-bikes, e-scooters, electric vehicles and electric and electronic equipment, amongst others.

There has been a significant increase in the carriage of Lithium-Ion Batteries because of policies and trends for the “electrification of everything”. Electric vehicles are a common use, but Lithium-Ion Batteries are used in a wide range of products and equipment.

These Guidelines comes after many recent ship fires and fires ashore have demonstrated the major risks resulting from the potential thermal instability of high-energy Lithium-Ion Batteries in electric vehicles, electronic equipment and as individual and/or interconnected batteries. Incidents involving Lithium-Ion Batteries have caused significant fatalities, injuries, and property damage, and highlighted the potential fire hazards and the significant risk to crew, those involved in the supply chain and safety, including potentially catastrophic incidents.

The likelihood and severity of fire risks associated with Lithium-Ion Batteries is evidenced by more than 300 fires or fire-related incidents with 40 fatalities reported over the past two decades. Serious vessel fires that may have been propagated by the carriage of Lithium-Ion Batteries include those that have occurred on board ships.

Marine safety investigators have been notified of several such fires involving Lithium-Ion Batteries on board container and cargo vessels, following which various investigation reports have been published. A review of available literature and data generated by safety investigations, reveals the extreme intensity of Lithium-Ion Battery fires, but also the reveals the challenges to control and extinguish those fires with the use of conventional fire-extinguishing systems.

Studies show that the common causes of fires and explosions involving Lithium-Ion Batteries have been due to internal manufacturing defects, physical damage or substandard quality, internal electrical failure (over-charge, over-discharge, or short circuit) all of which cause thermal runaway. Thermal runaway is where heat and gases are generated inside the cells of the battery, heat speeds up the exothermic reactions responsible for this and the cell enters uncontrolled positive feedback.

Other recent fires have been related to packaging failures and non-declaration or mis-declaration of Lithium-Ion Batteries. Ship Operators and Carriers should refuse to ship and transport Lithium-Ion Batteries if mis-declared. Cargo-screening and Container & Cargo inspections should reveal regulatory non-compliance and legal consequences.

Various national and international safety codes and standards that focus on the means to manage a lithium-ion fire have so far avoided prescribing solutions that restrict or slow cell-to-cell and module-to-module *thermal runaway* propagation. Standards currently also fall short in addressing the issue and risks associated with off-gassing.

The focus of these CINS Guidelines will be on identification of risks and prevention measures, to request compliance and responsibility and to offer recommendations to all stakeholders involved in the supply chain of Lithium-Ion Batteries, including manufacturers, shippers, carriers, transporters, warehouses, and governmental organisations.

These Guidelines do not cover Lithium-Ion Batteries that are part of a waste stream, waste, defective, leaking, damaged, for disposal or for recycling and only relates to the carriage of Lithium-Ion Batteries on container ships.

CINS will update these Guidelines as required, as new technological-methodological solutions are evolved and developed.

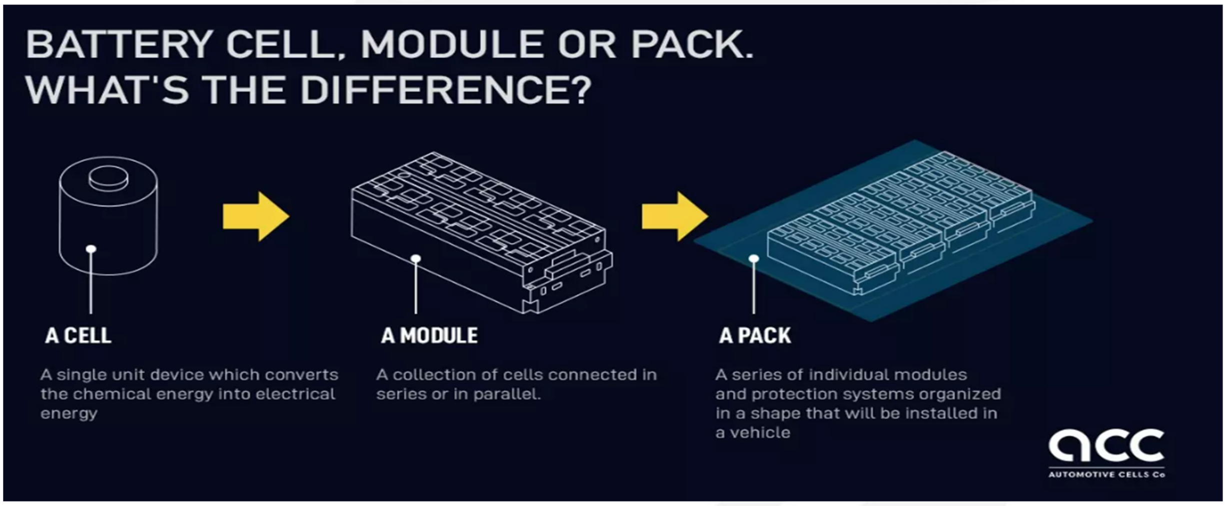
It is suggested that stakeholders bring these Guidelines to the attention of all agents, forwarders, terminals, and ship’s crew serving onboard and to all employees ashore dealing with Lithium-Ion Batteries. The precautions set out below are suggestions to enhance the safe carriage of Lithium-Ion Batteries in containers.

2. OPERATION OF LITHIUM-ION BATTERIES

2.1. Parts and Operation of a Lithium-Ion Battery

Lithium-Ion Batteries have the highest charge density of any comparable system. This means they can provide a lot of energy relative to their weight.

A lithium-ion battery is made up of several individual cells that are connected to one another. Each cell contains three main parts: a positive electrode (a cathode), a negative electrode (an anode) and an electrolyte.



BATTERY CELL, MODULE OR PACK.
WHAT'S THE DIFFERENCE?

A CELL
A single unit device which converts the chemical energy into electrical energy

A MODULE
A collection of cells connected in series or in parallel.

A PACK
A series of individual modules and protection systems organized in a shape that will be installed in a vehicle

acc AUTOMOTIVE CELLS Co

Figure 1: Difference between battery cell, module and pack (Source: ACC)

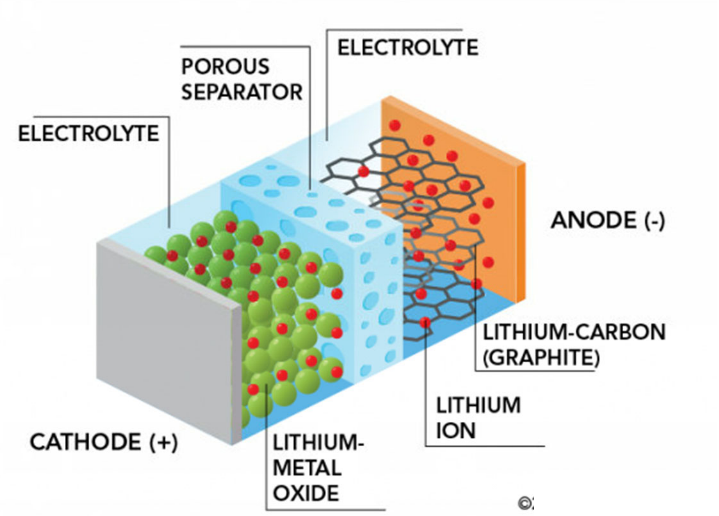


Figure 2: The principal parts of a Lithium-Ion Battery

Lithium-Ion batteries provide power through the movement of ions. Lithium is extremely reactive in its elemental form, which is why Lithium-Ion Batteries typically contain a lithium-metal oxide, such as lithium-cobalt oxide ($LiCoO_2$), to supply the Lithium ions. This chemistry is no longer generally used in Lithium-Ion Batteries as it is the most “unstable”. It is however the easiest to use as an example of charging and discharging.

When the Lithium-Ion Battery is being charged, positively charged Lithium ions (Li^+) move from the positive cathode to the negative anode as do the electrons.

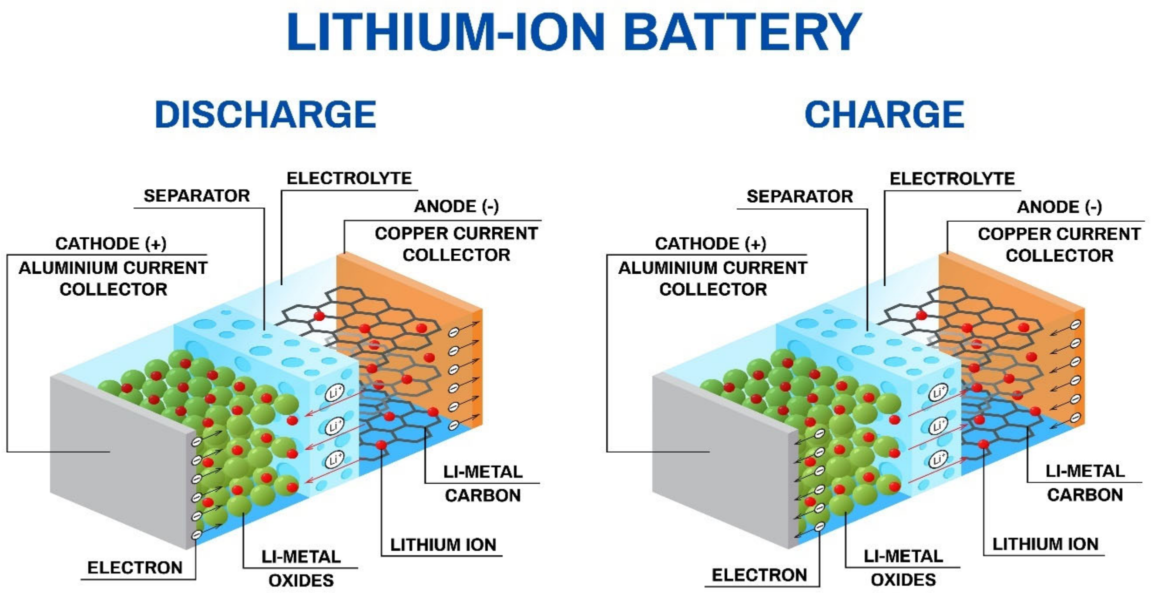


Figure 3: Discharge and charge of a Lithium-Ion Battery

Physical contact between the anode and cathode of a Lithium-ion Battery is prevented by employing a porous plastic separator soaked in the organic solvent and lithium hexafluorophosphate, the latter dissolving to give free lithium ions, Li^+.

If the separator is damaged, the electrodes can touch each other, causing electrical short circuit and significant Joule heating which triggers thermal runaway.

The heat in a single cell is rapidly transferred from cell to cell in a cascading effect called thermal propagation. Eventually, the gases are vented from the cell, taking with them droplets of the organic solvent producing a white vapour cloud.

If this ignites immediately, long flare-like flames are produced. If ignition is delayed, a vapour cloud explosion can occur, and indeed such VCEs have occurred involving Lithium-ion Batteries in E-scooters as well as grid-scale Battery Energy Storage Systems (BESS).

3. CLASSIFICATION AND REGULATION OF LITHIUM-ION BATTERIES

3.1. UN Manual of Tests and Criteria IMDG Code

The UN Manual of Tests and Criteria (UNECE, 2021), in section 38.3, sets out a series of procedures to be followed for the classification of Lithium-Ion Batteries under UN numbers 3090, 3091, 3480 and 3481. Nearly all Lithium-Ion Batteries are required to pass the tests specified in section 38.3 of the UN Manual of Tests and Criteria. Manufacturers are required to ensure that the Lithium-Ion Batteries will pass the test and should deliver the Lithium-Ion Batteries Test Summaries Certificate.

The UN Manual of Tests and Criteria contains criteria, test methods and procedures to be used for classification of dangerous goods according to the provisions of the "United Nations Related Guidelines on the Transport of Dangerous Goods, Model Regulations", as well as of chemicals presenting physical hazards according to the "Globally Harmonized System of Classification and Labelling of Chemicals" (GHS). It is regularly updated and amended.

3.2. IMO IMDG Code

The carriage of the Lithium-Ion Batteries by sea is regulated under the IMDG Code (UN IMO, 2022). Lithium-Ion Batteries are categorised as Class 9 (miscellaneous) hazardous materials.

The IMDG Code is mandatory and contains requirements for the safe carriage of packaged dangerous goods. It is published by the International Maritime Organization (IMO) and revised biennially.

The different classifications of Lithium-Ion Batteries, depending on their battery chemistry and purpose, are set out below. This Guideline relates only to the carriage of Lithium-Ion Batteries separately or contained in equipment under UN numbers UN 3480 or UN 3481 respectively.

It also relates to the carriage of electric and hybrid vehicles fitted with Lithium-Ion Batteries carried in containers under UN numbers UN 3166 and UN 3171 respectively as highlighted in the table below.

IMDG Class	UN Number	Description	Special Provisions
Class 9	UN 3090	LITHIUM METAL BATTERIES (including lithium alloy batteries)	188, 230, 310, 376, 377, 384, 387
Class 9	UN 3091	LITHIUM METAL BATTERIES CONTAINED IN EQUIPMENT or LITHIUM METAL BATTERIES PACKED WITH EQUIPMENT (including lithium alloy batteries)	188, 230, 310, 360, 376, 377, 384, 387, 390
Class 9	**UN 3480**	**LITHIUM ION BATTERIES (including lithium ion polymer batteries)**	**188, 230, 310, 348, 376, 377, 384, 387**

Class 9	**UN3481**	**LITHIUM-ION BATTERIES CONTAINED IN EQUIPMENT or LITHIUM ION BATTERIES PACKED WITH EQUIPMENT**(including lithium alloy batteries)	**188, 230, 310, 348, 360, 376, 377, 384, 387, 390**
Class 9	**UN 3166**	**ENGINE, INTERNAL COMBUSTION or** **VEHICLE, FLAMMABLE GAS POWERED or** **VEHICLE, FLAMMABLE LIQUID POWERED or** **FUEL CELL ENGINE, or** **VEHICLE, FUEL CELL POWERED WITH FLAMMABLE GAS or** **VEHICLE, FUEL CELL POWERED WITH FLAMMABLE LIQUID**	**356, 388, 961, 962**
Class 9	**UN 3171**	**BATTERY POWERED VEHICLE or BATTERY POWERED EQUIPMENT**	**388, 961, 962, 971**
Class 9	UN 3536	LITHIUM BATTERIES INSTALLED IN CARGO TRANSPORT UNIT lithium ion batteries or lithium metal batteries	389

Lithium-Ion Batteries carried under UN numbers UN 3480 and UN 3481 can be stowed on deck or under deck in accordance with IMDG Stowage Category A, except for those to which Special Provisions 376 or 377 apply, which should be stowed on deck only according to IMDG Stowage Category C. The provisions of the IMDG Code, including any Special Provisions, for each cargo presented for carriage must always be complied with.

Stowage category A: Cargo Ships or passenger ships carrying a number of passengers limited to not more than 25 or to 1passenger per 3 m of overall length, whichever is the greater number – ON DECK OR UNDER DECK. Other passenger ships in which the limiting number of passengers transported is exceeded – ON DECK OR UNDER DECK (UN IMO, 2022).

Stowage category C: Cargo Ships or passenger ships carrying a number of passengers limited to not more than 25 or to 1passenger per 3 m of overall length, whichever is the greater number – ON DECK ONLY. Other passenger ships in which the limiting number of passengers transported is exceeded – ON DECK ONLY.

3.3. Document of Compliance

A container ship's SOLAS document of compliance (UN IMO, 2022) will designate which IMDG classes of dangerous goods can be carried in each cargo space.

The document of compliance for a particular ship will therefore designate whether Lithium-Ion Batteries under IMDG Class 9 may be stowed under deck in the hold of the ship, if allowed under IMDG Stowage Category A (UN IMO, 2022), see Section 3.2.

3.4. Hazardous Materials Regulations

An example of detailed national guidance for Lithium Batteries is provided under the US Hazardous Materials Regulations (HMR) (Pipeline and Hazardous Materials Safety Administration, 2022) with specific guidance provided by the US Pipeline and Hazardous Material Safety Administration (PHMSA).
Whilst not applicable to all shipments, the two principal guidance documents published by the PHMSA are:

- Lithium Battery Guide for Shippers (Pipeline and Hazardous Materials Safety Administration, 2021).
- Lithium Battery Test Summaries (Pipeline and Hazardous Materials Safety Administration, 2021).

Check with your national regulatory authorities if any specific regulations or guidance are applicable.

3.5. Categorization of Lithium-Ion Batteries

In addition to the classification of Lithium-Ion Batteries under the IMDG Code (see Section 3.2), Lithium-Ion Batteries can be categorized in different groups according to the cathodes and anodes used as set out in the table below.

Currently Used Cathodes

$LiCoO_2$	LCO	Cell Phones, Tablets, Cameras
$LiNiCoAlO_2$	NCA	Energy Storage and EVs
$LiNiMnCoO_2$	NMC	UPS, E-Bikes, Medical Devices, EVs
$LiMn_2O_4$	LMO	UPS, Power Tools, Medical Devices
$LiFePO_4$	LFP	UPS, many applications

Currently Used Anodes

Graphite (Carbon)	C

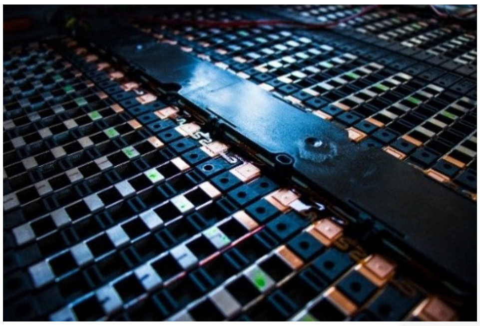
Emerging Anodes

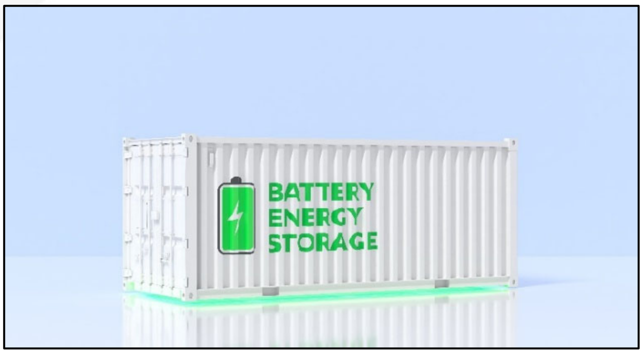
$Li4Ti_5O_{12}$	LTO	Lithium Titanate Oxide (LTO is not “emerging”, it is an established anode employed, e.g. in E-Buses and mine locomotives)
Alloy Anodes	Si / Sn	Silicon and Tin

Lithium Batteries can also be grouped by their cell formats as set out in the table below.

Type	Comments
Cylindrical	Provides best support for expansion and contraction of electrodes during cycling process. Suitable for higher capacity pr cell.
Prismatic	Better energy density with thermal barriers
Pouch	Difficult to seal for long life
Cell Capacities determined by geometry	Up to 80 Ah per cell
Winding Process variations	Results in different battery performance (Energy vs High Power)

Some examples are illustrated below:





4. LITHIUM-ION BATTERY CARGO ISSUES

4.1. Hazardous Properties of Lithium-Ion Batteries

Under certain conditions there may be an increase in the internal temperature of a lithium-ion cell, which in turn can initiate exothermic reactions (these are reactions which release heat).

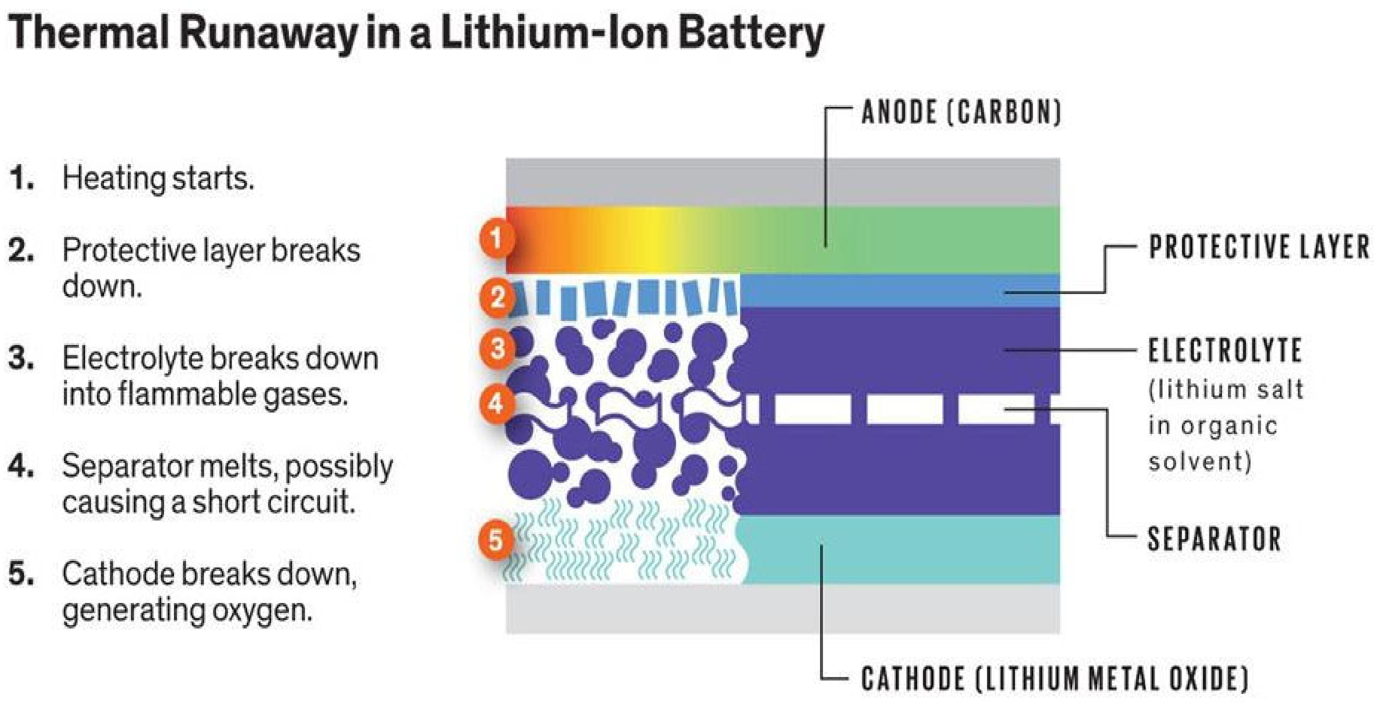
This can create a heat-temperature loop, leading to higher internal temperatures and further exothermic reactions.

If this heat does not dissipate, the battery cell temperature will elevate further, thereby accelerating the process of heat release. The battery enters an uncontrollable, self-heating state.

This process is called thermal runaway.

Thermal runaway will affect neighbouring cells in the battery and adjacent batteries, as well as other substances and commodities in the vicinity.

These exothermic reactions can give off oxygen enabling combustion.



Thermal Runaway in a Lithium-Ion Battery

1. Heating starts.
2. Protective layer breaks down.
3. Electrolyte breaks down into flammable gases.
4. Separator melts, possibly causing a short circuit.
5. Cathode breaks down, generating oxygen.

Figure 4: Typical exothermic thermal runaway reaction (Source: Scott)

4.2. Triggers for Thermal Runaway

Several hazards have been identified during storage, transport, and physical handling that may lead to thermal runaway and fire in Lithium-Ion Batteries:

- **Electrical abuse** (over-charging/discharging)
  The state of charge is crucial. Deep discharge or overcharging Lithium-Ion Batteries to voltages beyond the manufacturers specified parameters may cause thermal runaway.

  The effect of the thermal runaway reaction phenomenon of Lithium-Ion Batteries and the surface temperature of the batteries was examined in work carried out at the Department of Chemistry Defence, Institute of NBC Defence, Beijing: “Lithium-Ion Battery Thermal Runaway Electro-Thermal Triggering method and Toxicity Analysis” (H. J. Xie, 2021).

  This work selected the most representative ternary polymer lithium-ion battery (NMC), lithium cobalt oxide battery (LCO) and lithium iron phosphate battery (LFP) in the market as experimental samples, and then the state of charge of battery samples were adjusted to 0%, 30%, 50%, 100%. Electro-thermal triggering method was used to induce thermal runaway of the lithium-ion batteries.

  The results showed that with the increase of the state of charge, the thermal runaway reactions of the batteries are more severe.

  LIBs are thermodynamically unstable. During the very first charge, the lithiated graphite reacts exothermically with organic solvent to produce gases. Heat speeds up these reactions. If this is continued, the cell would enter thermal runaway and can explode!

  The reason it doesn’t is that a protective layer, the solid electrolyte interphase (SEI), forms around the graphite anode particles to prevent them touching the solvent but allowing free passage of lithium ions. Subsequent abuse damages this layer and exothermic reactions will start again.

  A maximum state of charge (SOC) between 30% and 40% is recommended for carriage of Lithium-Ion Batteries. We will refer in part 6.4 to related SOC information.

  It should be noted that, as SOC is decreased, the risk of ignition and fire decreases, but the risk of VCE increases as the vapour cloud is still produced at low SOC.

  It is understood that different original equipment manufacturers (OEM) and manufacturers may specify other state of charge percentages for transport, in which case it is recommended to follow such specific instructions to follow their requirements during the supply chain transport.

- **Thermal abuse** (over-temperature)
  Internal temperatures in the 90–120ºC range can cause the solid electrolyte interphase (SEI) within a Lithium-Ion Battery to decompose exothermically. At temperatures above 200ºC, the hydrocarbon electrolyte can decompose and release heat, but it depends on the type of Lithium-Ion Battery. When exposed to external heat sources causing a high temperature condition, Lithium-Ion Batteries have a greater risk of thermal runaway.

- **Mechanical abuse** (penetration, pinch, and bend)
  Mechanical abuse, usually caused by external mishap to the Lithium-Ion Battery or during installation, can result in electrical shorting between the electrodes, via the electrolyte, producing localised heating.

- **Internal short circuit**
  An internal short circuit occurs due to the failure of the separator, allowing contact between the cathode and anode via the electrolyte. This can happen due to any of the above abuse conditions, or because of a manufacturing fault.

- **Contaminants in Lithium-Ion Batteries**
  Analytical techniques must be used to measure elements at trace levels and to look for the presence of contaminants (such as iron) in the cathodes. Unusual voltage profiles can identify the presence of contaminants which may be detrimental to the safety of the battery. Keep in mind that large batteries with 1000’s or 100,000’s of cells do not allow such fine measurements.

- **Lithium-Ion Battery Quality**
  If a Lithium-ion Battery is overcharged, lithium metal plating takes place on the graphite particles: the lithium metal reacts exothermically with the solvent to produce explosive and toxic gases. Plating reduces the temperature for the exothermic reactions to become self-sustaining, the time taken to reach thermal runaway and time to reach the maximum temperature during thermal runaway.

  In addition, the consequences of thermal runaway are much more violent reaction when plating present, partially to the production of significantly more gas. If plating continues, lithium dendrites (tiny tree-like structures of lithium metal) may be formed that can cyclically grow to penetrate the separator, causing internal short circuit and initiate thermal runaway.

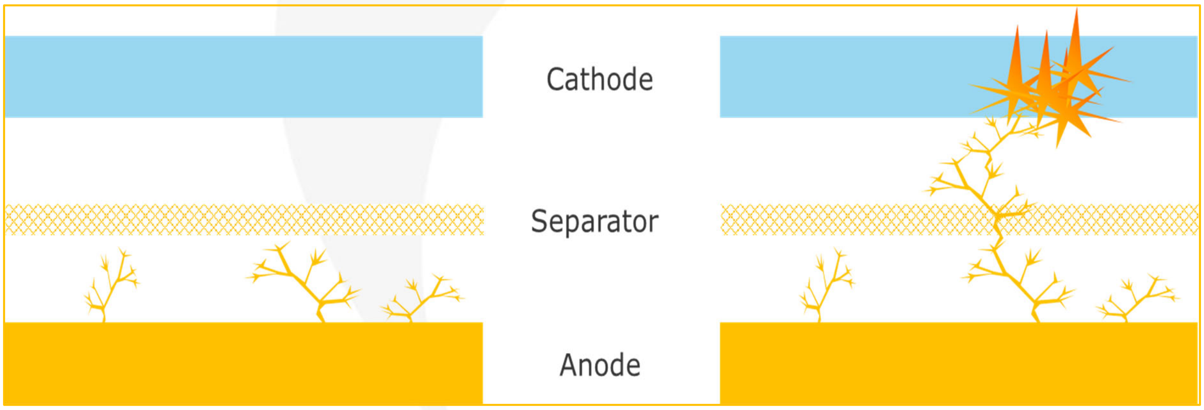


Figure 5: Lithium dendrites (Source: DNV-GL)

4.3. Lithium-Ion Battery Fire Risks

The consequences of a Lithium-Ion Battery fire can be severe. See Section 8 which explains the fire tetrahedron and demonstrates how a fire can be sustained.

Typical fire risks, whether on board ship or ashore, are:

- **Thermal runaway events and conditions**
  See Section 4.2.

- **Fire suppression**
  The effects of thermal runaway may start a fire which is difficult to extinguish. Normal fire extinguishing tools and materials may not be efficient and/or sufficient.

- **Fire propagation and heat flux**
  Another effect is related to the related reactivity characteristics and the heat flux of the materials in the vicinity of the fire. Especially when other Lithium-Ion Batteries are in the direct vicinity. This is known as “fire propagation”.

- **Fire and explosion**
  The reaction and fire may evolve into an explosion, depending on the circumstances.

4.4. Lithium-Ion Battery Toxicity Hazards

Thermal runaway reaction products contain many toxic substances, and prevention and protection is necessary.

The study carried out at the Institute of NBC Defence, Beijing, in 2021 (see Section 4.2), also examined the reaction gases from thermal runaway.

The substances collected and analysed included very toxic, highly toxic, and toxic substances which are the three most dangerous levels of poison classified under China National Standards.

These toxicity characteristics are applicable not only to the gas cloud and to the residue that remains after the fire.

The thermal gas reactions generated different type of toxicity risks that were directly related to the state of charge of the Lithium-Ion Battery with a battery at 100% state of charge being the most dangerous in terms of toxicity and hazards.

5. CONTAINER SELECTION

5.1. Ambient Temperature Inside Container

Where the ambient temperature during the voyage is expected to be higher than 30° Celsius, the Safety Data Sheet should be consulted.

The ambient temperature inside a container might be higher, depending on the geographical location and meteorological conditions. Refrigerated container units could be used if deemed necessary.

Studies have shown that internal ambient temperatures in dry container were almost the double of the outside ambient temperature.

This is particularly the case when containers were stored in transhipment ports in equatorial zones (SGS Survey September 2022, Belgium, Antwerp S11).

Shippers should comply with all appropriate national and international safety, health, and environmental requirements. They should review the predicted transport conditions, together with their customers, manufacturers, and producers, to plan safe supply chain transport.

If the Voyage Risk Assessment indicates that ambient in and out temperature of the container will exceed 40° Celsius and/or the critical reaction temperature, as indicated in the MSDS / SDS, the shippers, forwarders, Manufacturers should use Temperature Controlled Cargo Units for the cargo transport, providing the transport temperature settings for the intended voyage. Carriers should monitor those transports accordingly.

6. CARGO CONTAINER PACKING

6.1. Lithium-Ion Battery Cargo Groups

The differences in the principal Lithium-Ion battery cargo groups are set out in the table below. It is based on Ship planning Message Development Group (SMDG) codes for planning and operations.

Lithium-Ion Battery Cargo Group (New)	Abbreviation	IMDG SP188	IMDG Code	State of Charge
Electric vehicles (new)	EVN	-	Yes	30-40%
Battery energy storage system (new)	BES	-	Yes	30-40%
Battery energy storage system + (new) (Fitted with track, trace, alert…)	BES	-	Yes	30-40%
Lithium-Ion battery packaged (new)	LIB	-	Yes	To be determined (*)
Lithium-Ion battery packaged (new)	LIB	Yes	-	To be determined (*)

(*) see "NOTE FROM WSC'S LOCAL COUNSEL ON MSA DRAFT NOTICE ON SAFE TRANSPORT OF LITHIUM BATTERY PRODUCTS CARRIED BY DOMESTIC TRADE SHIPS", January 10th, 2023.

6.2. Cargo Packaging

The IMDG Code, 2022 edition, defines what packaging should be used for Lithium-Ion Batteries classified as dangerous goods.

It is critical for the transport of Lithium-Ion Batteries that compliant packaging types are used to help keep the cargo protected from mechanical damage or abuse that could trigger the fire conditions during the voyage. This is currently set out in the applicable Packing Provisions of the IMDG Code.

In addition, packaging of Lithium-Ion Batteries should take account of the following:

- Ambient temperature during the planned voyage
- Ingress Protection is very important, especially on board ships
- State of charge (SOC) of the battery
- Availability of a battery management system (BMS)
- Availability of a safety venting device
- Whether battery terminals are covered and protected. Always protect against seawater ingress.

6.3. Propagation of Fire in a Container

Lithium-Ion Batteries classified as IMDG Class 9 can be loaded together with other IMDG Code dangerous goods allowed under the Code.

To prevent fire propagation to other cargoes inside a container, a cargo risk assessment should be carried out to exclude cargoes that might react or create a harmful reaction with Lithium-Ion Batteries in the event of an emergency such as fire. See Section 6.4.

In case of an LCL (less than container load) shipment where multiple types of cargoes may be co-loaded in the same container, it is recommended to carefully select the other cargoes to prevent harmful reactions and fire propagation.

A cargo risk assessment should be carried out by shippers and forwarders before the start of the loading operations.

It is suggested that no other type of dangerous cargo is packed in the same container (although this is allowed in the IMO IMDG Code and regulations).

6.4. State of Charge (SOC) and State of Health (SOH)

The state of charge (SOC) of a Lithium-Ion Battery describes the difference between a fully charged battery compared to the same battery in use.

It is associated with the remaining quantity of electricity in the battery or cell. The state of health (SOH) of a Lithium-Ion Battery indicates the level of degradation and the remaining capacity of the battery, essentially describing the difference between a battery being studied and a new battery. It considers the cell aging.

Lithium-Ion Batteries, including battery energy storage systems (BESS and BESS+), should be kept only partially charged during storage and transport.

The maximum state of charge should be identified in the Shipper Voyage Risk Assessment based on the manufacturer and producer recommendations and any other relevant information.

The shipper should take adequate steps to check that the cargo falls within the defined parameters before the cargo reaches the carrier(s) and inform the carrier what the charge level is, so that the carrier can assess what it needs to do to carry them safely. Involved parties should make a voyage risk assessment in order to define transport parameters.

The SOC of Li-ion cells is a critical heat release parameter that can influence the combustion kinetics and therefore the associated fire hazard.

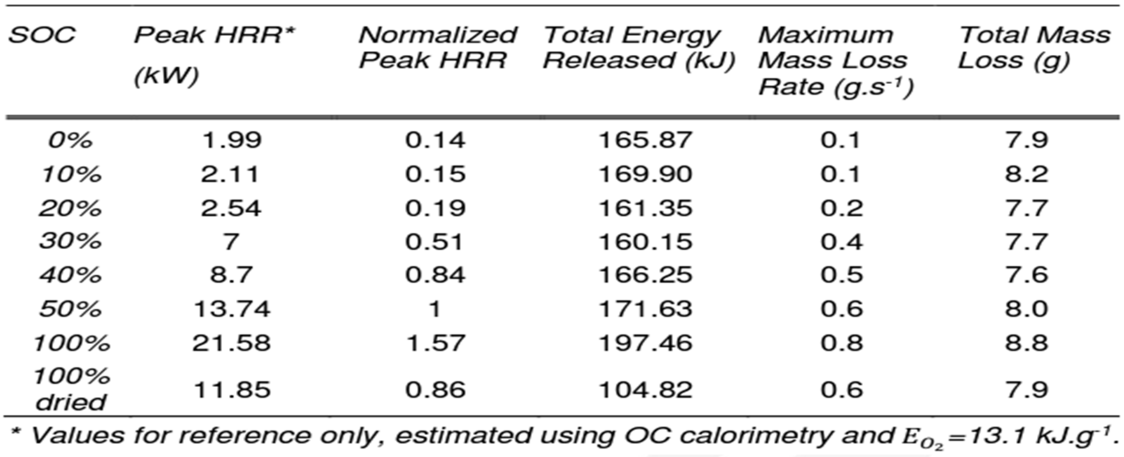
Despite the absence of requirements limiting the SOC of Li-ion cells being shipped, a few studies have shown that it is a critical contributor to heat generation when a Li-ion cell undergoes thermal runaway (P.A.Christensen, 2021) (T. Cai, 2021)

Important is to capture the evolution of the heat release rate (HRR) and the influence of the Lithium-Ion cell SOC with regards to the intensity of the combustion reaction.

The results show that the HRR and burning rate increase as SOC of the Li-ion cells increases.

The applicability of OC (oxygen consumption) calorimetry with the general energy assumptions is questionable given the complex chemistry involved in the combustion of Li-ion cells (ISO 5660-1:2015, 2015).

Consequently, peak HRRs are presented in the Table below (Figure 6) for reference only. It can be seen that an order of magnitude separates the combustion of Li-ion cells at 0 % SOC and 100 % SOC.



SOC	Peak HRR* (kW)	Normalized Peak HRR	Total Energy Released (kJ)	Maximum Mass Loss Rate ($g.s^{-1}$)	Total Mass Loss (g)
0%	1.99	0.14	165.87	0.1	7.9
10%	2.11	0.15	169.90	0.1	8.2
20%	2.54	0.19	161.35	0.2	7.7
30%	7	0.51	160.15	0.4	7.7
40%	8.7	0.84	166.25	0.5	7.6
50%	13.74	1	171.63	0.6	8.0
100%	21.58	1.57	197.46	0.8	8.8
100% dried	11.85	0.86	104.82	0.6	7.9

* *Values for reference only, estimated using OC calorimetry and* $E_{O_2} = 13.1\ kJ.g^{-1}$.

Figure 6: Flammability parameters from the combustion of Lithium-Ion Batteries at various SOC (Somandepalli, 2014)

The 100% SOC dried cell released energy levels comparable to full Lithium-Ion cells with a SOC between 40 % and 50 %.

The peak HRR of the 100 % SOC dried cell corresponds to 86 % of the one obtained at 50 % SOC and about half of the peak energy release of the same Li-ion cell with electrolyte and 100 % SOC.

Given this information, at 100 % SOC, the electrolyte contributes to half of the energy release.

To allow a clearer qualitative comparison, HRR results were normalized using the HRR measurement at 50% SOC as reference (see Fig. 7 below).

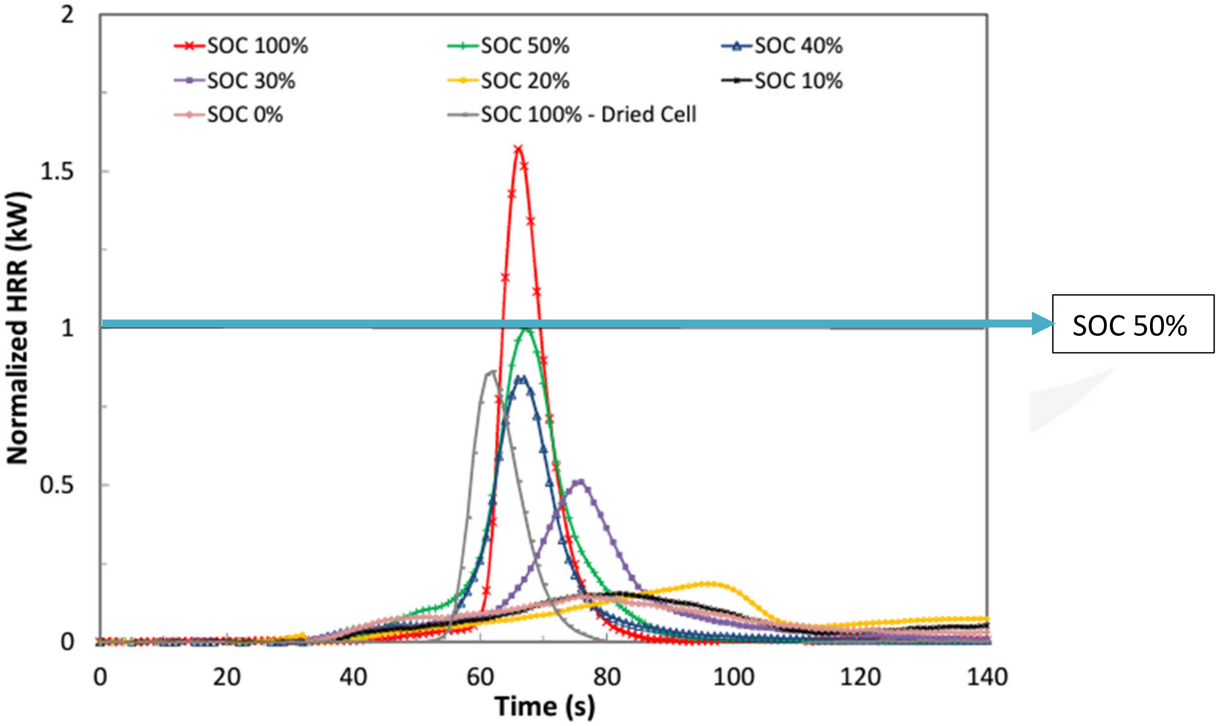


Figure 7: Normalized HRRs of tested Lithium-Ion cells at various SOC (Somandepalli, 2014)

The electrolyte is a large contributor to the energy release, but the SOC increases the reaction rate. In a Li-ion cell, the SOC is controlled by the balance of lithiation between the anode and cathode which modifies the electrodes composition. At 0 % SOC, Li+ ions are mostly intercalated into the cathode with a chemical composition LiCoO2.

When the cell is charged, the cathode becomes progressively delithiated. At 100 % SOC, the composition of cathode is approximated by Li0.5CoO2 (Spotnitz, 2004). The thermal decomposition of a delithiated cathode is characterized by a release of O2 which may account for the fast and large release of heat at high SOC.

In addition to the internal O2 supply, cell combustion will cause shorts within the Li-ion cell releasing enough heat to vaporize the combustible electrolyte and, therefore, increase the combustion kinetics. As cell SOC increases, the amount of stored electrical energy that can be released as heat due to shorting increases. (Maleki, 2004)

The studies we refer too (Somandepalli, 2014) (L.B. Diaz, 2020) (Christensen, et al., 2021) demonstrates that at 100% SOC, the electrolyte contributes to about half of the overall energy release, however, the SOC is another critical safety parameter to take into account.

The International Civil Aviation Organization (ICAO) requires that the upper limit of battery transportation power is not higher than 30% state of charge. Generally, lithium-ion batteries at 30% state of charge are considered to have better safety performance (ICAO,2020).

Prior practice among the manufacturers was to generally limit the SOC of Li-ion cells to 50 %, which as shown during testing, yielded the potential to create a substantial heat release. The experimental results clearly demonstrate that exposure of a 30 % SOC cell reduced the peak heat released to half that of a 50 % SOC cell.

Clearly this demonstrates the relevance and value of the new limitations on the SOC to at most 30 % during the transportation of Li-ion cells or batteries. Notably, as the SOC decreased below

30 %, the peak heat released during exposure was even less and nominally equivalent for a cell with no charge at all (0 % SOC).

The actual state of charge at delivery before transport is the responsibility of the manufacturers and producers of the Lithium-Ion Battery. In the current battery transportation process, the battery is usually adjusted to 30-70%.

It is understood that different original equipment manufacturers (OEM) may specify other state of charge percentages for transport, in which case it is recommended to follow such specific instructions to follow their requirements during the supply chain transport.

Research into different types of incidents has shown that the outcome depends on the state of charge (Christensen, et al., 2021). This agrees with the research carried out by the Institute of NBC Defence, Beijing (see Section 4.2). Both studies conclude that:

- A higher state of charge >50% - tends to lead to fire and jet flames.
- A lower state of charge <50% - tends to lead to release of white vapours, which are explosive and toxic. If an ignition source is present, this can lead to an or unconfined vapour cloud explosion (UVCE), which is like the damage caused to buildings by gas leaks.

The explosion risk or UVCE (below deck) can significantly increase. A state of charge of 30% is suggested for carriage of battery energy storage systems in containers. A state of charge between 30% and 40% is suggested for carriage of Lithium-Ion Batteries fitted to electric vehicles and hybrid vehicles packed in containers.

Transportation regulation is paramount to ensure safe shipments. Although omitted in the past, new transportation regulations now impose a limitation on the SOC of Lithium-Ion Batteries being shipped. (Somandepalli, 2014)

6.5. Packing Lithium-Ion Battery Cargo in Containers

6.5.1. Cargo Package Verification

Before loading the cargo into the container, the condition of all packages should be checked by the shippers. Checks should include, but not be limited to:

- Package integrity is maintained. Keep in mind that vibration might cause damage to the Lithium-Ion Batteries.
- Packages are of a type capable of withstanding a drop from an appropriate height (industry good practice is at least 1.20 meters, but this may depend on context)
- Batteries are short circuit protected
- Packages are not ruptured and no debris or fragmentation outside is observable outside of the packaging
- No leakages are observable
- No smoke is observable
- No external flames observed
- Labelling and marking complies with all relevant standards
- Exterior sidewall temperatures of the packages should be at the ambient temperature of the storage facility and industry good practice is that it never exceeds 40° Celsius in any location.

If the Voyage Risk Assessment indicates that ambient in and out temperature of the container will exceed 40° Celsius and/or the critical reaction temperature, as indicated in the MSDS / SDS, the shippers, forwarders, Manufacturers should use Temperature Controlled Cargo Units for the cargo transport.

6.5.2. CTU Code

It is strongly recommended that guidance contained in the CTU Code (UN IMO / ILO / UNECE, 2014) should be followed. In particular, the weight distribution of the cargo should be considered together with the packaging being used.

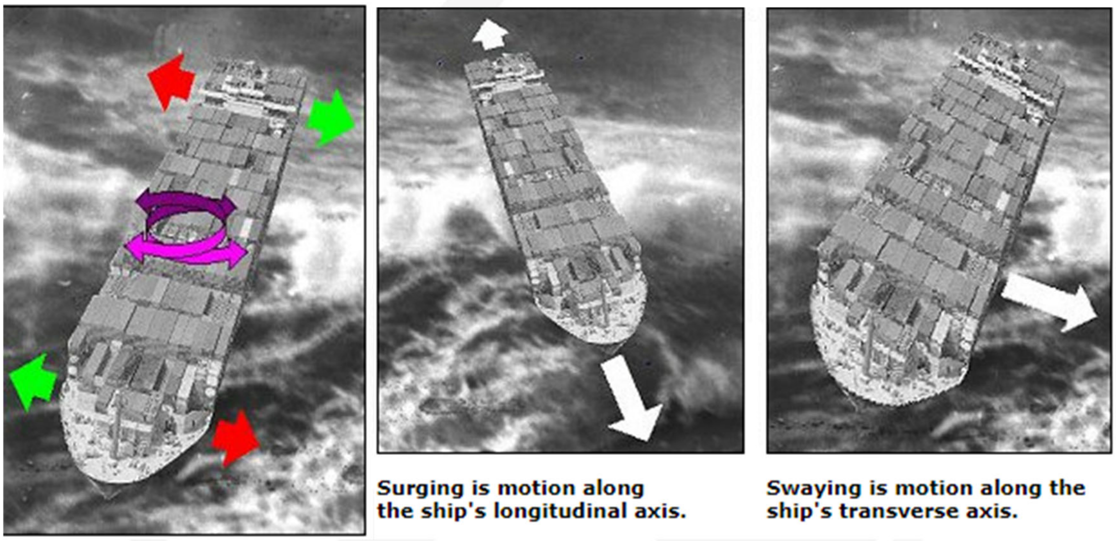
This to ensure that the stacking and stowage of Lithium-Ion Batteries in a container will not sustain excessive forces. All batteries should be loaded in an upright position as indicated on package labelling.

6.5.3. Mechanical Stress During Sea Transport

The general transport conditions of the CTU Code note that voyages are made in a variety of weather conditions which are likely to exert a combination of forces upon the ship and its cargo over a prolonged period.

Such forces may arise from pitching, rolling, heaving, surging, yawing, swaying or a combination of any two or more and causing serious vibration. Many studies have demonstrated that extreme G-forces can impact the cargo in a container. Note that vibration effects can have effects on the stability of the Lithium-Ion Battery.

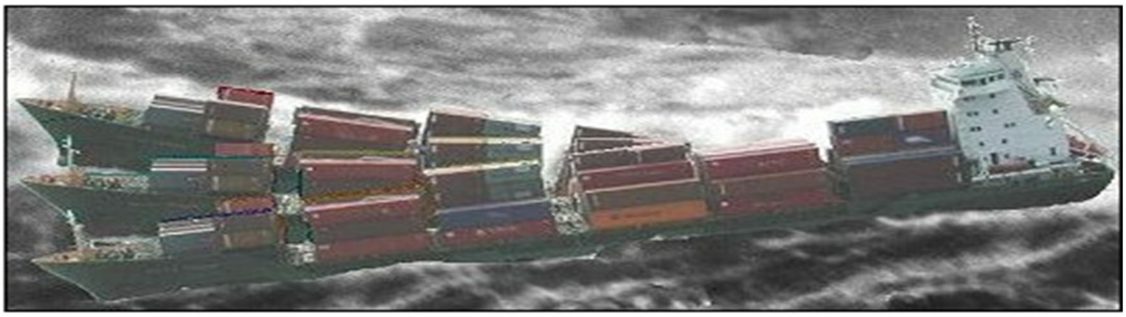
Packing and securing of cargo into/onto a container should be carried out with this in mind. It should never be assumed that the weather will be calm and the sea smooth or that securing methods used for land transport will always be adequate at sea.



Surging is motion along the ship's longitudinal axis.

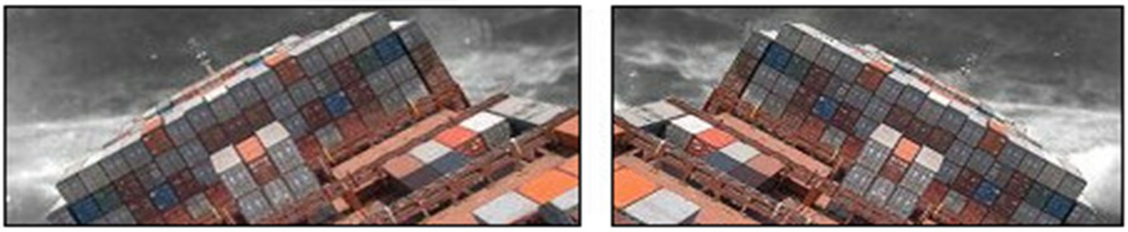
Swaying is motion along the ship's transverse axis.

Figure 8: Ship Rolling (Source: CTR HB TIS)



Pitching is the movement of a ship around its transverse axis.

Figure 9: Ship Motions (Source: CTR HB TIS)



Rolling angles of 30° are not unusual in heavy weather.

Figure 10: Ship Rolling (Source: CTR HB TIS)

7. LITHIUM-ION BATTERY STOWAGE ON SHIP

7.1. Sources of Heat

To reduce the risk of fire, containers carrying Lithium-Ion Batteries should be stowed away from sources of heat. This means that locations such as proximity to heated fuel tanks, machinery spaces, or top stowage on deck, should be avoided.

Consideration should be given to the likely ambient temperatures throughout the voyage, bearing in mind that the ambient temperature inside a container is likely to be significantly higher than the outside ambient temperature.

7.2. Propagation of Fire Between Containers

Propagation of fire can occur between multiple containers, particularly because Lithium-Ion Battery fires are characterized by an extremely quick rise in temperature.

Block stowage of containers carrying Lithium-Ion Batteries, or proximity to other containers carrying dangerous goods or flammable materials should be avoided. Below is an example of how domino planning can be organized (green containers).

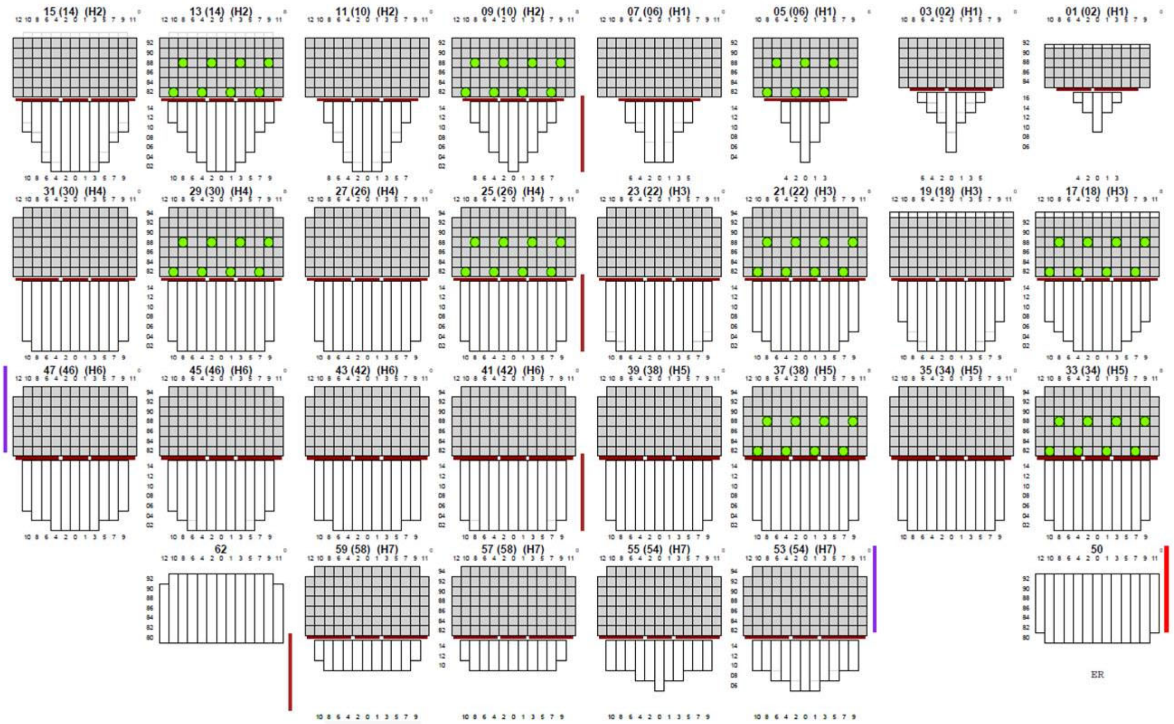


Figure 11: Stowage plan showing segregated stowage of Lithium-Ion containers (green) (Source: Seaspan)

7.3. Container Stowage Location

Lithium-Ion Batteries should be transported in compliance with the stowage and segregation requirements set out in the IMDG Code.

In addition, consideration should be given to stowing Lithium-Ion Battery containers:

- **"Separated from" other critical and dangerous cargoes, with the degree of separation identified through suitable and sufficient risk assessment.**
- **Considering the fixed and portable fire-fighting equipment available on board.**

Containers should also be stowed in an accessible position to allow appropriate fire-fighting procedures to be carried out. Arrangements should consider factors such as, but not limited to, operational height and range limitations of the equipment, safe access and positioning of personnel attempting to operate firefighting equipment and ability to apply containments measures such as boundary cooling.

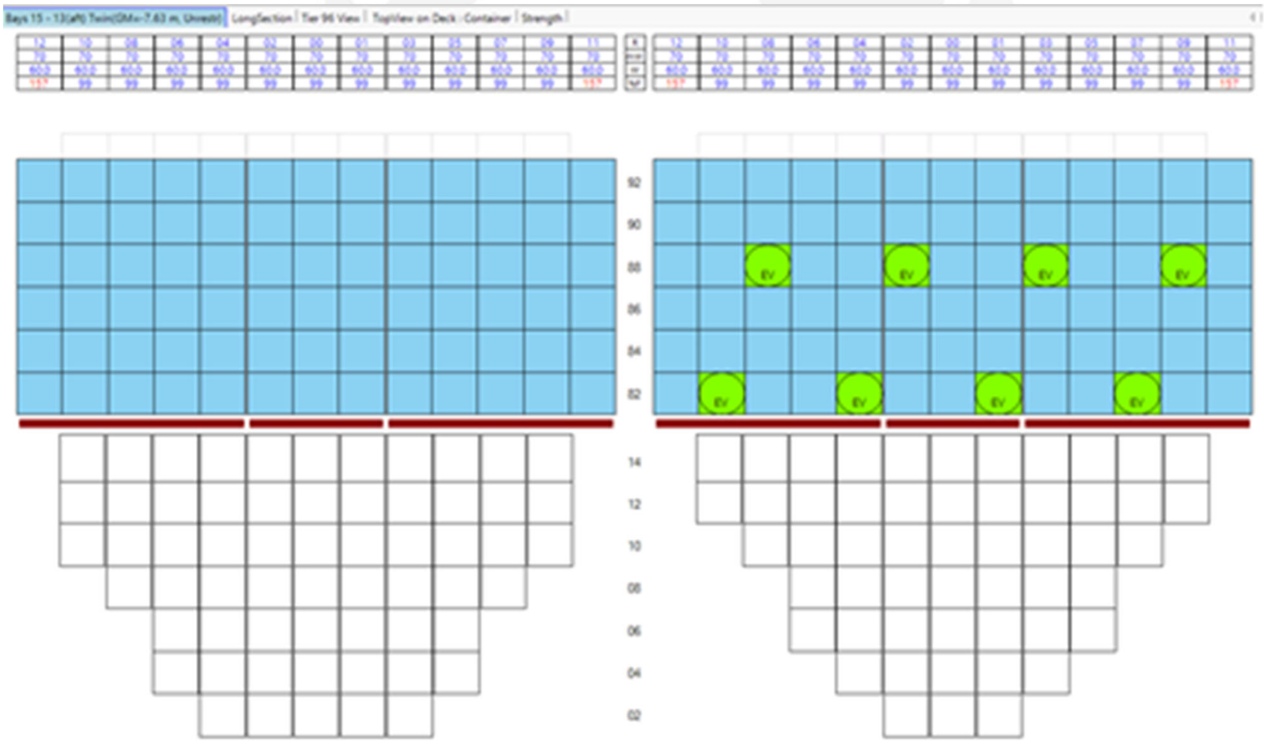


Figure 12: Example of a Stowage Plan showing stowage of electric vehicles in containers (green) (Source: Seaspan)

It is recommended under this Guidelines that containers with Lithium-Ion batteries are stowed in locations where effective fire-fighting can be deployed in the event of an emergency.

8. LITHIUM-ION BATTERY FIRES

8.1. Evolution from the Fire Triangle to the Fire Tetrahedron

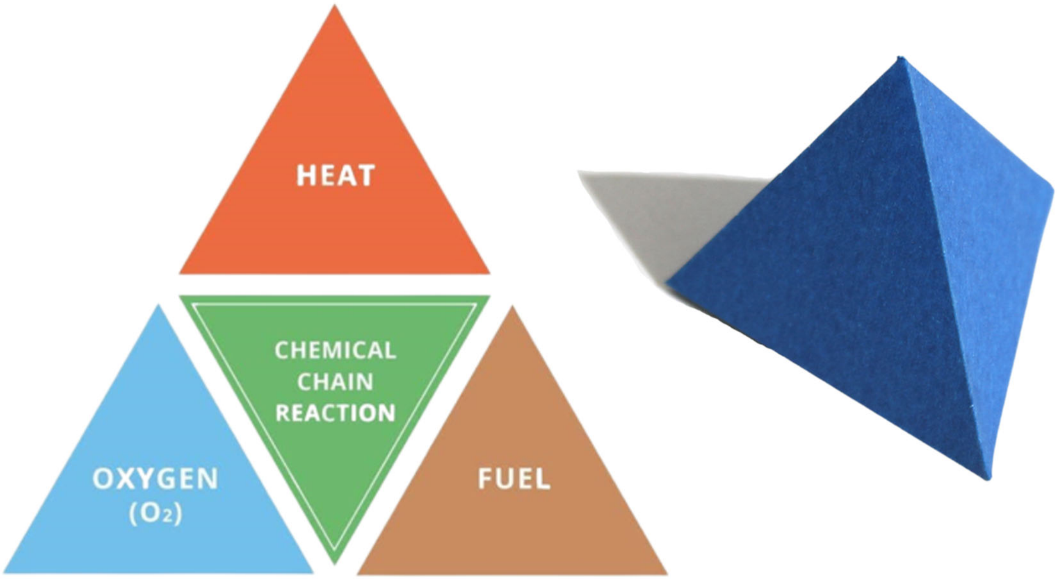


Figure 13: Fire tetrahedron (Source: The Fire Safety Advice Centre UK)

In a Lithium-Ion Battery, when the pressure build-up ruptures a lithium-ion cell, the flammable electrolyte is released, and the thermal runaway process can supply adequate heat to initiate a fire. Oxygen, heat and fuel are frequently referred to as the “fire triangle". The fourth element is the chemical reaction, which is included in the “fire tetrahedron” shown in Figure 12.

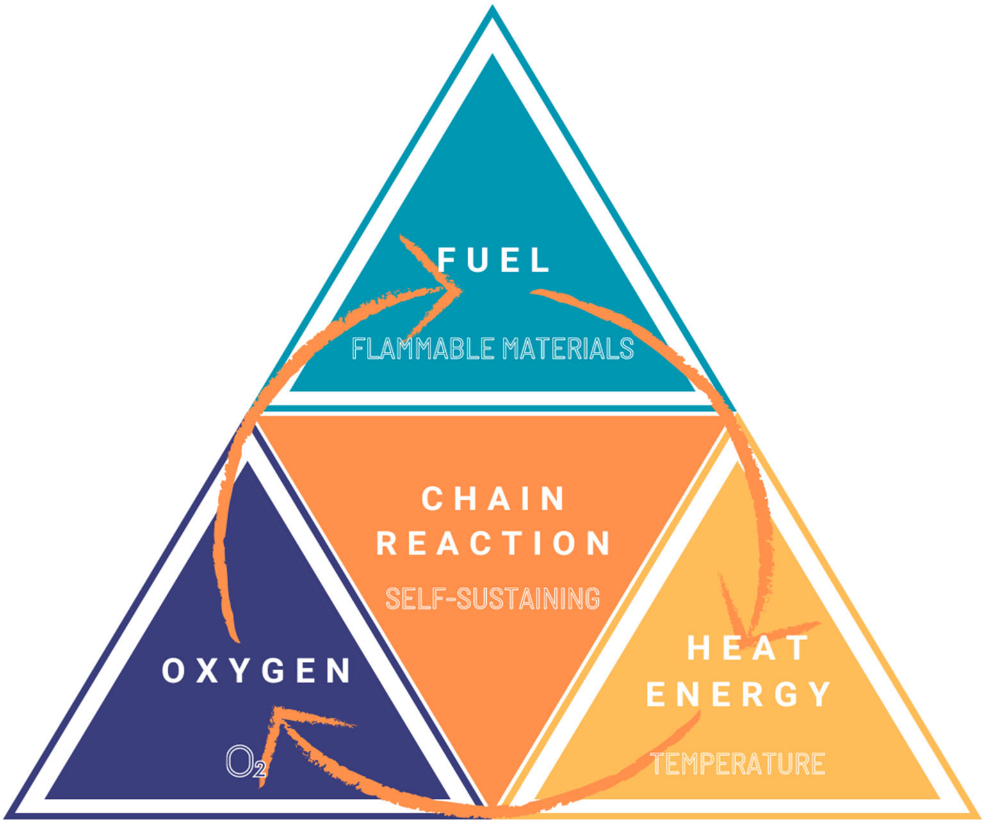
Fire initiates when a fuel and an oxidiser are exposed to a source of heat, raising the temperature above the flash point of the fuel-oxidiser mixture.

Fire is ultimately a reaction between heat, fuel, and an oxidising agent. Once a heat source has been introduced to a combustible fuel, ignition will occur. The reaction between the ignited fuel and the oxidising agent will allow the fire to become self-perpetuating. The uninhibited chemical chain reaction refers to this process of the self-perpetuation of a fire based on the combustion capability of the fuel and the oxidising agent.

The uninhibited chemical chain reaction was included in the fire tetrahedron to demonstrate that a fire must be able to produce heat from continuous chemical reactions to continue burning. To extinguish a fire, you must break the uninhibited chemical chain reaction.

A fire in a Lithium-Ion battery cell is not a metal fire, but a chemical decomposition reaction in which a lot of energy is released.
The released heat causes an increasing part of the cell contents to decompose and can even cause a decomposition reaction in adjacent cells. This phenomenon is called thermal runaway (see Section 4).

Interrupting the four elements of fire — isolating the fuel from the ignition source, isolating the oxygen from the fuel, cooling the fuel below the ignition temperature, or interrupting the combustion reactions — will reduce the combustion.



● Burning is initiated by the process of oxidation, in which the gases released by fuel are heated, broken apart, and combined with oxygen, which is supported by the presence of **oxygen**.

● **Fuel** is a combustible substance that, when heated above its flash point, turns into gas and releases vapor pressure that can ignite and fuel combustion.

● The exothermic combustion reaction produces **heat energy**, which is sufficient to sustain the fire because it is a self-perpetuating process.

● **Chain reactions** that are not controlled or inhibited result in a continuous production of heat through ongoing reactions, which is the primary factor that enables a fire to sustain itself.

Figure 14: Fire Tetrahedron Explained (Source: UNWMO -TAC - F&S)

IMPORTANT:
Keep in mind that if the fire is suppressed, the THERMAL PROPAGATION IS NOT STOPPED and the HAZARD SWITCHES FROM FIRE TO EXPLOSION.
This can happen when using aerosols, dry powder, gaseous suppression, fire blankets to extinguish the fire.

8.2. Hazards Identified for Lithium-Ion Battery Fires

The following hazards (National Fire Protection Association, 2020) may arise from a Lithium-Ion Battery fire:

- Fire and explosion
- Chemical
- Environmental concerns
- Electrical
- Stranded energy
- Physical
- Structural (especially after the fire and/or explosion (that was caused by LIB's)

The gases (DNV GL AS Maritime, Joint Development, 2019) given off during a fire may include, but are not limited to:

- Carbon monoxide (CO)
- Hydrogen (H)
- Nitrogen Dioxide (NO2)
- Hydrogen Chloride (HCL)
- Hydrogen Fluoride (HF)
- Hydrogen Cyanide (HCN)
- Benzene(C6-H6)
- Toluene (C7-H8)
- Methane (CH4)

Figure 15: Example of a Lithium-Ion Battery fire (Source: Free)

The first obvious indication of a thermal runaway can be white vapour, which is flammable and toxic. It is often mistaken for steam. Below is an example of an Unconfined Vapour Cloud Explosion (UVCE) case during an explosion. Droplets of solvent are likely to be what deflagrates. (Hill, Davion | DNV GL, 2020).

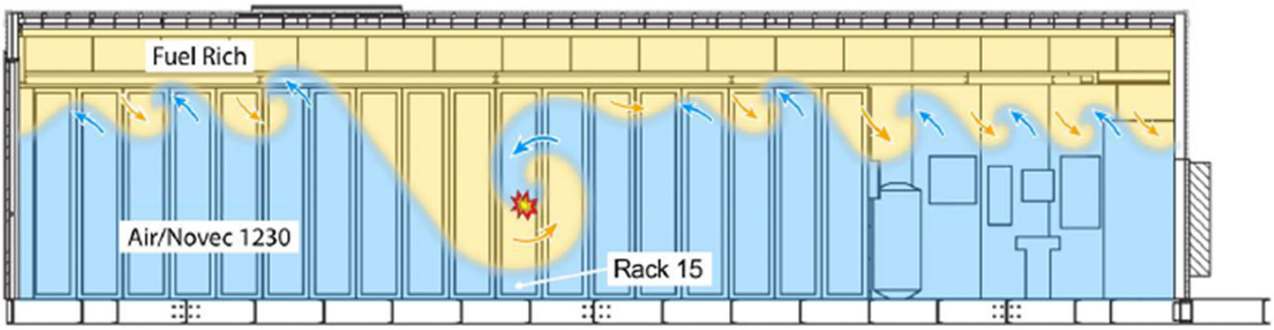


Figure 16: Colwell's simplified illustration of flammable gases near the top of the container rolling back as a reaction to the door opening, putting them in contact with residual heat or spark at Rack 15 (Source: DNV GL | image credit Colwell)

If the vapour does not ignite, it poses an entirely different hazard in terms of high toxicity but still has the potential for a violent Unconfined Vapour Cloud Explosion **(Christensen, et al., 2021)**.

8.3. Regulations for Fire Protection, Fire Detection and Fire Extinction on Container Ships (SOLAS CHII/2)

At the MSC 102/INF.3, GDV from Germany submitted a paper for the 'Analysis of current safety regulations concerning firefighting onboard containerships'.
Their paper stated that for SOLAS Chapter II-2,

- '*It is evident that the regulations do not keep up with the significant increase of the size of containerships.'*
- *'The conventional flooding of a cargo hold with CO2 fails largely because the fire will spread by the high thermal conductivity of the container structure made of steel to other containers, which contain their share of oxygen for supporting the fire in them'.*
- *Searching for the burning container in the cargo hold filled with smoke is a very risky operation for the crew and should be avoided.*

Following this submissions at MSC, EMSA launched its CARGOSAFE study on container ship fires. This is for the Formal Safety Assessment of IMO, which is due to report in 2025. The 'Cargo Safe' reports:

Fire detection: *the current fire detection systems based on smoke detection by air aspiration from selected cargo hold locations have proven to be insufficient for an adequate location of the fire outbreak. Therefore, it is not possible to assess the fire propagation risk or define adequate fire containment barriers.*

Fire containment: *the applicable regulations do not have special considerations for the ultra-large ship designs, where practically no thermal barrier exists to protect the ship structure and avoid fire propagation to adjacent compartments*.

Fire Suppression: *fire suppression systems on large containerships have demonstrated to be insufficient to respond to cargo fires, especially where propagation escalates. The combination of fixed CO2 flooding in cargo holds with mobile water monitors fighting upwards has been reported ineffective in extinguishing cargo fires and protecting life and ship during firefighting operation.*

Consequently, the regulation of fire protection, fire detection and fire extinction on container ships has not evolved at the same rate as the significant increase in the size of the ships and the number of containers carried on a single ship.

The amendments to SOLAS convention in 2014, saw all new keels laid after 1 January 2016 requiring additional firefighting equipment, but this is relatively minor and does not apply to ships built before this date.

This IMO / Cargo Safe research confirms that container ship fires were already difficult to deal with, and this is before the inclusion of Lithium-Ion Battery fires.

8.4. Fire Detection

Heat and flammable/toxic gases originating from Lithium-Ion Batteries can be an indication of an abnormal and hazardous condition. Battery thermal runaway fires are preceded by a period where flammable/toxic gases are given off that may ignite at any time.

Container ship cargo spaces are generally fitted with smoke extraction and detector systems to detect a fire (reportedly the slowest method of detection and therefore of limited use).

Lithium-Ion Battery fires can also be detected using conventional heat detectors such as IR detectors or combined smoke-heat detectors (reportedly the fastest method and considered more useful).

Searching for a specific container in a hold filled with smoke is a very risky operation for crews and should be avoided.

New technology that may be more effective includes sensors that are connected to the ships and shore safety management systems to alert parties immediately.
Thermal imaging cameras may also be effective in detecting temperature increases, both on and under deck.

Early detection allows more time to control the spread of the fire.

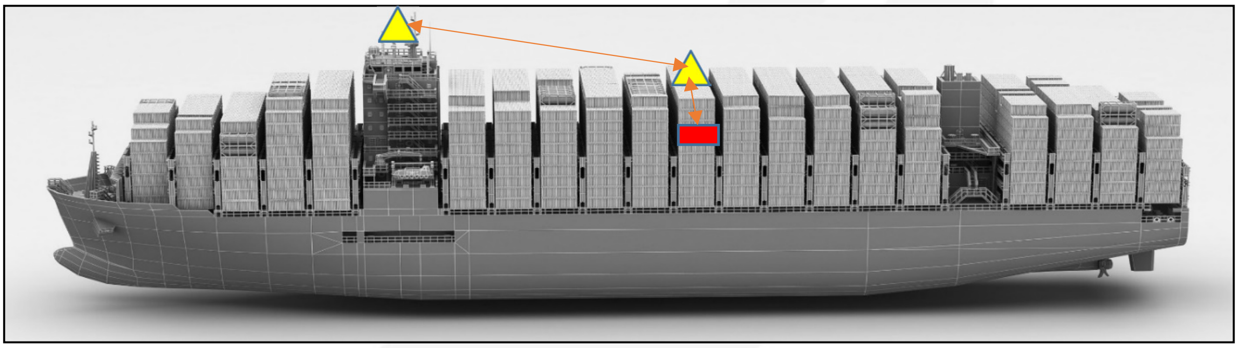


Figure 17: Early fire detection using thermal imaging camera (Source: Waves).

8.5. Emergency Response Procedures

The level of risk should be determined through proper assessment and organisations should create emergency response procedures based on sound response and battery handling data. The Lithium-Ion Battery Manufacturer should provide suitable fire-fighting procedures for the type of Lithium-Ion Battery cargo being transported.

The IMO Emergency Schedules (EmS) for IMDG Class 9 dangerous goods contained in Emergency Response Procedures for Ships Carrying Dangerous Goods should be followed and/or on the information received from the Lithium-Ion Battery cargo booking stakeholder(s).

8.6. Fire Suppression

Thermal runaway causing Lithium-Ion Battery fires are harder to manage than normal fires with continuous cooling requirements. The chosen fire suppression method should aim to suppress any Lithium-Ion Battery fire and control any rise in battery temperature. If not sufficiently cooled, thermal runaway reactions may continue, and the battery re-ignite; this is a major challenge for Lithium-Ion Battery fire suppression systems.

Adjacent cells may also undergo thermal runaway if heat propagation from the initial cell is not controlled. It is more important to cool the cells in a large battery pack, to prevent heat propagation, than to extinguish fires from a single cell.
Lithium-Ion Battery fire-fighting strategies should be based on not only extinguishing the burning cell but include cooling the burning cell as well as its adjacent cells.

The use of generally available fire extinguishants to suppress Lithium-Ion Battery fires is described below. In all cases it is recommended that the duty holder seeks relevant advice from the shippers, forwarders, producers, and manufacturers of the Lithium-Ion Batteries.

8.6.1. Water

Water-based extinguishants can provide an effective method to fight Lithium-Ion Battery fires. Water is an excellent cooling medium due to its high heat capacity and latent heat of vaporization and may be able to mitigate or halt the propagation of thermal runaway to surrounding batteries. Water is generally available for fighting container fires. Water spray or mist could be used for fire-suppression and cooling when a container is in a suitable location, particularly on deck.

8.6.2. Foam

Foam is a medium that is being investigated by car manufacturers at present. It can be used but to be effective the foam must encapsulate the container, the Lithium-Ion Battery, and the cell(s). This is unlikely to be effective on a single 20- or 40-foot container.

8.6.3. Powder

Powder extinguishants work by chemically interrupting the fire reactions. However, they do not provide cooling and re-ignition may occur.

8.6.4. Carbon Dioxide (CO_2)

CO_2 is not an ideal extinguishing agent for Lithium-Ion Battery fires due its low cooling capacity, but it will reduce the availability of oxygen considerably, which can slow down the fire process and reduce the reaction time and directly related heat flux.

IMPORTANT:

Keep in mind that if the fire is suppressed, the THERMAL PROPAGATION IS NOT STOPPED and the HAZARD SWITCHES FROM FIRE TO EXPLOSION.
This can happen when using aerosols, dry powder, gaseous suppression, fire blankets to extinguish the fire.

9. LOSS PREVENTION

The growth in the use of Lithium-Ion Batteries in commercial and industrial applications is enormous but little data exists relating to the risks during transport, fire, and safety prevention, storage, and fire response.

A fire involving significant quantities of Lithium-Ion Batteries may exceed the fire suppression capabilities of the ship and crew which may lead to a catastrophic failure of the ship's structure. Proper planning, risk assessment, storage methods and response protocols can help to manage the fire risks of Lithium-Ion Battery, which includes the measures set out below.

9.1. Training

Since Lithium-Ion batteries present critical challenges to ships, storage facilities, public sites, transport units, etc that possess them, it is recommended that training be included in any risk management strategy. Ships' crew, transporters, facilities, and individuals should be aware of the unique hazards that these types of batteries present. This is particularly important for ships' crew as their STCW fire-fighting training courses do not generally cover Lithium-Ion Battery fires.

Companies that transport or store Lithium-Ion batteries in high quantities are urged to work with experts to develop training that seeks to mitigate the fire issues and ensures additional layers of safety insofar as practicable. Training might address, but not be limited to, issues such as battery awareness, detailed situational training such as battery fire behaviour, emergency response procedures and fire extinguisher use. This type of training is critical to the preservation of life.

9.2. Emergency Response Procedures and Fire Suppression

Shippers should put into place arrangements to pack containers according to relevant codes, including the IMDG and CTU Codes, plan the safe journeys of the cargo and inform all persons involved in the transport of relevant risks and carriage arrangements, considering the information in the associated Safety Data Sheets (SDS) and other information from manufacturers and distributors.

These documents prescribe possible methodologies for proper storage, handling, and emergency response. It should be noted that Safety Data Sheet recommendations can sometimes vary widely. The IMO Emergency Schedules (EmS) for IMDG Class 9 dangerous goods contained in Emergency Response Procedures for Ships Carrying Dangerous Goods should be followed and /or on the information received from the Lithium-Ion Battery cargo booking stakeholder(s).

The Lithium-Ion Battery Manufacturer and the ship's Safety Management System should provide suitable fire-fighting procedures for the type of Lithium-Ion Battery cargo being offered for transport.

9.3. Standard Operating Procedures

Carriers and organisations that are involved in the transportation of Lithium-Ion Batteries should develop suitable Standard Operating Procedures for their carriage. Effective standard operating procedures for the carriage of Lithium-Ion Batteries should include processes that guide shipping and receiving, handling, storage and other functions involving the batteries.

A Lithium-Ion Battery checklist is recommended to help involved parties to create Standard Operating Procedures.

The verification process should include, but not be limited to, procedures for:

- Know Your Customers (See Section 9.4)
- Dangerous Goods Declaration and Packing Certificate
- UN Manual of Tests and Criteria
- Container inspection or vanning survey
- Incident reporting
- RCA – Root Cause Analysis
- Non-recurrence process plan or NRP-plan.

9.4. Know Your Customer (KYC)

It is suggested that individual carriers should undertake an internal identification process for shippers and customers to communicate and ensure compliance with its Standard Operating Procedures. This should include processes which guide shipping and receiving, handling and storage, stowage, and segregation, including, but is not limited to, compliance with:

- IMO IMDG Code (mandatory)
- IMO/ILO/UNECE Code of Practice for Packing of Cargo Transport Units (CTU Code)
- Lithium-Ion Battery Guide for Shippers (Pipeline and Hazardous Materials Safety Administration, 2021)
- Test Summaries for Lithium-Ion Batteries - UN Manual of Tests and Criteria, Section 38.3 (Pipeline and Hazardous Materials Safety Administration, 2021)
- ISO 9001:2015 quality standards
- ISO 19001 quality standards. This contains guidance on managing an audit program, the principles of auditing and the evaluation of individuals responsible for managing the audit programs.

The provision of test summary documents required under the Manual of Tests and Criteria, Section 38.3, is extremely important and legally required. The implementation of suitable Know Your Customer processes are the individual responsibility of each Carrier and associated stakeholders.

9.5. Factory Audit

The Know Your Customer process may include a factory audit by an independent competent surveyor or authorities. Example guidance on the carriage of Lithium-Ion Batteries in containers that can be used as part of a Lithium-Ion Battery Factory Audit can be found in the following publications:

- Lithium-Ion Battery Guide for Shippers, published by the US Department of Transportation Pipeline and Hazardous Materials Safety Administration
- Lithium-Ion Battery Test Summaries, published by the US Department of Transportation Pipeline and Hazardous Materials Safety Administration.

10. FUTURE

Events have clearly demonstrated the hazards associated with cascading thermal runaway in Lithium-Ion Batteries and related Lithium-Ion Battery energy storage facilities.

There is an urgent need for the supply chain to improve its incident records related to the transport of Lithium-Ion Batteries. This includes identification, analysis, root cause analysis and effects of the hazards, to improve the knowledge of all supply chain stakeholders.

To prevent similar incidents from occurring in the future, manufacturers and supply chain stakeholders should consider implementing the following proposals:

- Address vulnerabilities to thermal runaway cascading, ventilation, and suppression in existing and operational Lithium-Ion Battery packaged systems in containers.
- Update industry standards, transport regulations and codes to directly address cascading thermal runaway in Lithium-Ion Batteries and future energy storage systems.
- Develop performance-based standards for Lithium-Ion Batteries based on the principle that dangerous effects will be contained within the package.
- Develop ventilation and extinguishing or cooling systems to manage thermal runaway, especially in battery energy storage systems.
- Develop Lithium-Ion Battery and battery energy storage systems designs that aim to slow or halt cascading or propagation of battery cells and modules during thermal runaway.
- Develop education, training, and emergency response procedures that account for the risks and hazards of cascading thermal runaway—including toxic and flammable gases—and how to enter containers after a fire.
- Introduce transparency related to factory audit and supply chain know your customer procedures.
- Introduce Lithium-Ion Battery cargo screening, inspections, and vanning surveys.
- Apply the same packaging instructions for maritime transport as for aviation.
- Research and consider new Fire Fighting Techniques, such as new “aerosol techniques”.
- Introduce early warning systems from specific Lithium-Ion Battery “off gas” detection systems.

11. CONCLUSION

Lithium-Ion Battery technology is evolving rapidly. Therefore, the control of risks related to the transport of Lithium-Ion Batteries may also need to develop and evolve over time, as well as IMO IMDG Code classification of Lithium-Ion Batteries and other related legislation.

All stakeholders involved in the carriage of Lithium-Ion Batteries in containers are asked to carefully review these CINS Guidelines to determine if they can be implemented and applied to their specific operations and requirements.

The main challenges are:

- The proper classification of the Lithium-Ion Batteries, including the proper division in accordance with the power and energy storage capacity.
- Quality of Lithium-Ion Batteries, and compliance with the Test Summaries.
- Correct declaration and the responsibilities of shippers, forwarders, manufacturers, and producers.
- Implementation of an effective supply chain and Know Your Customer (KYC) programme.
- Compliance with the relevant regulations including, but not limited to, the IMDG and CTU Codes, and proper completion of the Shippers Declaration and Packing Declarations. This is mandatory for Lithium-Ion Batteries classified as dangerous cargoes but could be initiated for Lithium-Ion Batteries that are declared under SP188 of the IMDG Code and which are considered as less dangerous, but nevertheless must be considered as “critical” (Critical Cargo Declaration and Packing Certificate). This can be considered by each individual ship operator.
- Container and cargo inspections and vanning surveys. This can be considered by each individual ship operator.

It should be noted that the volumes transported by air are small when compared to maritime transport, where thousands of tonnes are shipped in containers daily. The above reflects part of the requirements for the transport of Lithium-Ion Batteries by air and its strictly regulated transport conditions.

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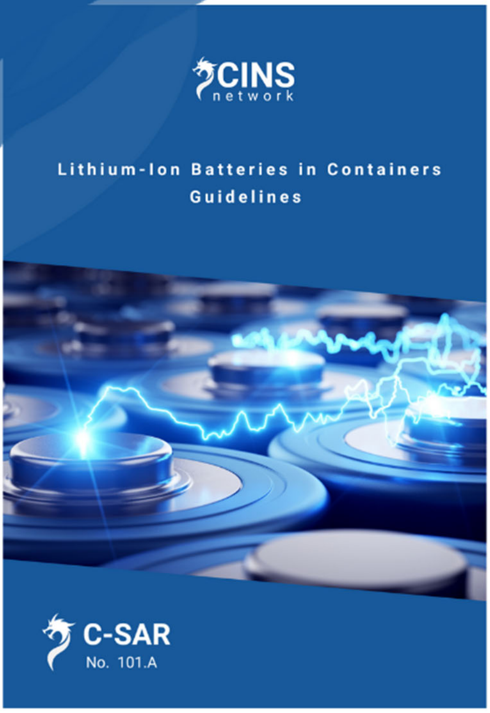

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C-SAR No. 101.A

Lithium-Ion Batteries General

CSAR 101.A | version 1.0
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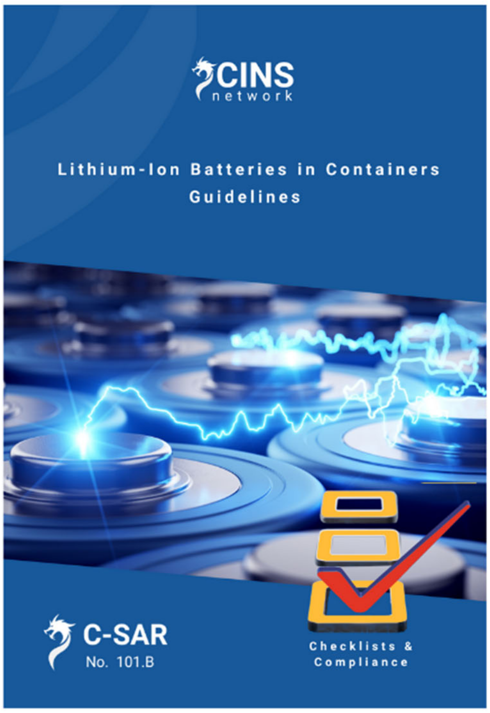

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Checklists & Compliance

Lithium-Ion Batteries Checklists & Compliance

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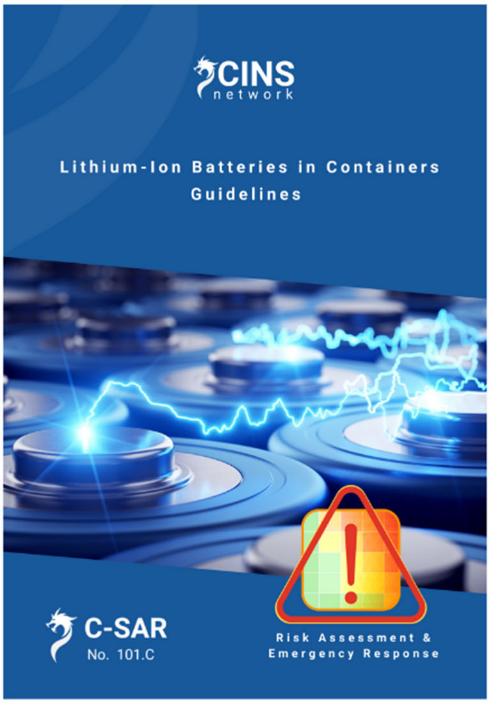

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Risk Assessment & Emergency Response

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CSAR 101.C
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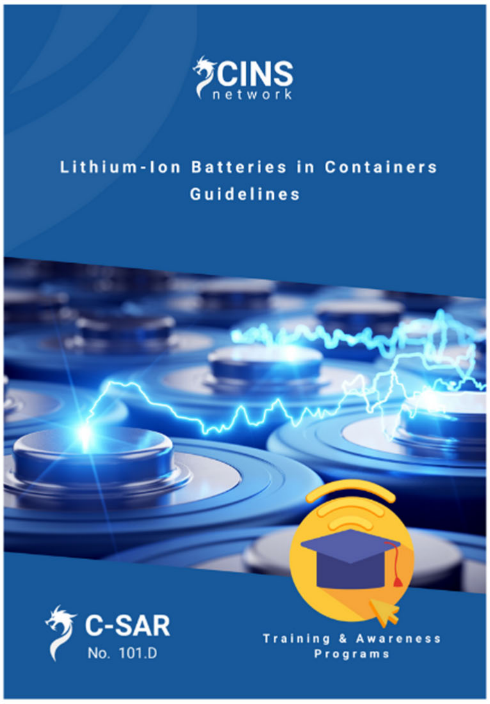

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