Lithium batteries don't commit suicide. They're murdered.

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LiBs batteries are increasingly used in the marine industry. Their advantages are many: compact and cheap, with higher energy density, they can help to cut down sharply on fossil fuel use. Problems are rare, but when things go wrong the results have a high impact and take up emergency resources for a considerable time.

What is a lithium battery

A LiB is what is sometimes referred to as a rocking chair battery and was invented in the 1970s. Types are named by their Cathode material chemistry, LFP (Lithium Iron Phosphate), and NMC are the most common. The current collectors are metal foils (Cu) Copper for the Anode and, (Al) Aluminium for the Cathode. Spread with a thin paste layer of Carbon nano particles on the (Cu) Anode and the Lithium chemical compound paste on the (Al) Cathode. Between them is a layer of organic solvent with a microns-thick Polyethylene Ion porous separator in the middle. This completed sandwich is then, rolled or folded into form factor called a cell and packed into casing.

Lithium cells come in three types or form factors:

A. The cylindrical cell, such as the lithium 18/6/50. This is shaped like an AA battery and can be used alone or linked in series. It is usually used for smaller devices such as power tools but can be linked up to power larger things like Tesla cars.

B. The soft flexible Pouch cell often the size of an A4 sheet of paper but can be smaller: it can be shaped to fit within a housing and was originally developed for Electric Vehicles (EVs).

C. The Prismatic cell with a plastic case. This is about the shape and size of a 6 cigarette pack stacked in pairs side by side. Victron LPF marine batteries use this cell type. LFP cells produce higher volumes of hydrogen gases and take longer to ignite the vapour cloud increasing the risk of VCE.

The cells are made into strings connected in series and then made into modules connected in parallel which form the battery pack. This is packaged into a metal or plastic enclosure suitable for the intended use.

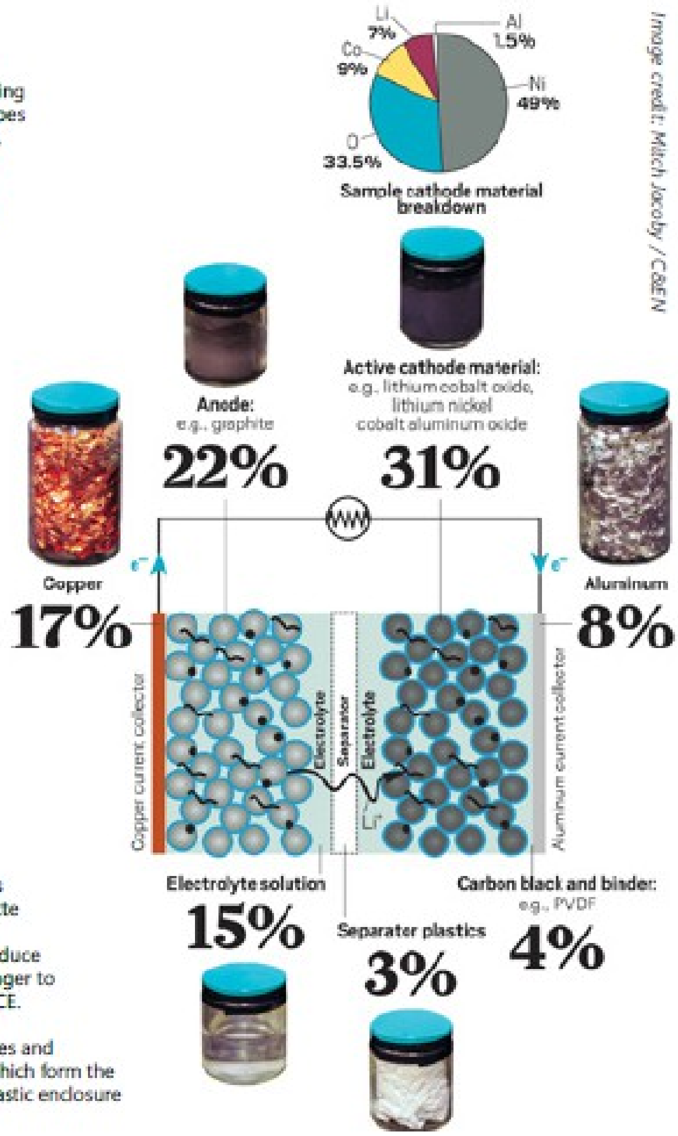


Image credit: Mitch Jacoby / C&EN

When LiBs fail

LiBs can store a large amount of energy in very small space and can be cycled many times over their lifetime with very little loss of capacity. However, if the stored energy is released all at once it can be very destructive.

In normal operation charged lithium ions enter the carbon particle matrix on the anode by leaving the lithium paste at the cathode and pass through the solvent and separator. When discharging, or in use, this ion flow is reversed. When LiBs are made the fist charge is very slow and the batteries are left for 10 or more days to form an SEI (Solid Electrolyte Interface): a passive layer of solids around the carbon partials. Without this SEI layer, the charged lithium ions chemically attack the carbon partials. This creates an exothermic reaction that releases a huge amount of heat and gas and the cell explodes. This reaction can also be triggered if the SEI layer or polymer separator is damaged, leading to TR (thermal runaway) in a cell and then TP (Thermal Propagation) from cell to cell. This is the big baddie!

TR (Thermal Runaway)

Thermal runway is just heat, not a fire. It occurs when the limited chemical reactions within the cell become self-sustaining. Once this state is reached it can't be stopped. Degradation of the separator can start at as low as 60 C. Heat is produced in the volume of the object but only dissipated by its surface area. Thermal propagation heats up adjacent cells which then go into TR.

Lithium batteries don't commit suicide. They can be murdered by abuse. Physical damage, overcharging, over discharge, short circuit, overheating, or manufacturing defect.

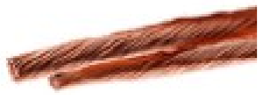
Image from BSLBATT Lithium

Cylindrical cell

Pouch cell

Prismatic cell

It's not smoke... and apply common sense



When LiBs go into TR a number of things can happen. The first is the battery may simply explode. Throwing hot shrapnel around. This has happened with light electric vehicles (LEVs), scooters, bikes, water hover boards, jet skis, etc.

If it doesn't explode, you may hear pressure caps popping and hissing of gas escaping with a chemical smell. You might briefly see a black cloud as the carbon particles are blasted out. The flammable gas escapes at high pressure and can ignite producing jet or rocket like flames at 1,000 C. If ignition is delayed the gases vent off creating an explosive atmosphere with an LEL of 11% to 16% with a risk of VCE (Vapour Cloud Explosion). This vapour contains hydrogen, hydrogen cyanide, hydrogen fluoride, hydrogen sulphide, carbon monoxide, CO_2 and visible droplets of the solvent mistaken for smoke or steam. Hydrogen fluoride turns into hydrofluoric acid on contact with water or sweat on skin. The DTLH (Danger to Life and Health) level is well below the LEL.

The volume of gas boiled off is huge. In the region of 300 to 5000 litres per kWh of battery capacity. There are also two vapour clouds. One is lighter than air, and the other denser than air. At the moment it's not known how to predict which will dominate.

It's the VCE risk that is the real problem, especially for the marine industry. And current fire suppression systems cut out active fire burning time. But flip the risk to VCE. Because TR continues and cells continue to boil off vapour. As the cells are watertight **"It's like pouring water on the roof of your house when your kitchen is on fire."**

Marine Safety Regulations

The current European guidelines, published by P&I clubs, IACS and state authorities for the use of builders and vessel operators are a good starting point. But this is a fast-moving technology though. And the guidelines reveal large gaps in the industry's understanding of TR and its behaviour beyond the theoretical cell or module testing level and how that practically translates into failures in a large installation in a propulsion system battery room, UPS, super yacht water toys or power tools. The focus is on fire because it's familiar and easy to understand but, but TR is not a fire, its heat, although fire can be a result. And suppression of active fire is good and buys useful time to remove people or other fire hazards from the area, but in the case of LiBs it flips the risk from fire to VCE. With old-style battery technology, fire suppressants such as water or powder would safely resolve a dangerous situation. LiBs are different. The TR and TP continue as we currently can't stop it directly as explained above, and it can lead to VCE with all its risks to life and property.

Moving forward

The Underwriters Laboratories (UL) in the USA has freely shared its understanding of full-scale LiB failures in Battery Energy Storage systems (BESS). It has created a clear set of full-scale testing goals in UL9540A, based on full scale test results, and observations from real world accidents. ULs work has led to safety improvements in BESS designs, and clear development of domestic BESS installation regulation via Building Fire Codes like the (National Fire Protection Association's) NFPA 855 in the USA. This testing, observation, and feedback approach is now being adopted in Canada. This is a practical approach to potential challenges that the marine industry has and could be adopted to fill the gaps in industry understanding and address the real risks posed by LiBs in marine applications. Full scale safety testing of marine installations using LiBs which nobody seems to be considering would be needed. Freely sharing available information and the feedback from real world marine incidents, via a central or international database, would be an ideal to aim for. This is an ongoing process of review and improvement as technology develops, and would lead to an internationally agreed, practical set of up to the minute minimum safe installation standards to guide marine surveyors, insurance companies, vessel builders, vessel crews, and designers and port state authority safety enforcement. Plus, the bloke who just wants to upgrade his electrical system on his yacht or narrowboat who is dire need for proper information rather than looking for guidance on the internet via YouTube videos.

The developing chemistry of sodium batteries can also undergo thermal runway but seems to produce more gas, than being an ignition source. There are also batteries like the Goliath P1 battery chemistry and the LG battery design that claim to have solved the TR problem. Further testing is required but early statements from the developers look interesting at least.

We need to work together as an international industry to fill the gaps in our knowledge and that of the wider public about the advantages and the safety risks of this new technology. The IIMS and others within the connected maritime industries are welcome to join in on this ongoing process.

I would like to thank Professor Paul Christensen for the information he has shared on the safety risks of LiBs.

Useful links

www.fsri.org Fire training and resources for US fire fighters, free to join. Videos or conferences and presentations.
www.bsigroup.com A PDF copy of new PAS 63100:2024 guidelines for domestic BESS installations.