White Paper | January 2023

Lithium-ion Batteries: An Informal Introduction

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EXECUTIVE SUMMARY

"Scotty, we need more power!", James T. Kirk, Star Trek 1966 – 1969

Never has there been a time when this phrase has had more relevance or captured the sentiment of society so aptly. Power generation has gone through many iterations over the last 150 years. From Benjamin Franklin's early experiments to nuclear reactors, power generation has greatly changed. Today, with small computers in most people's hands, and a shift from the use of fossil fuels, there is a growing need for more powerful energy storage systems (ESS) with better capabilities. Renewable energy sources such as solar panels and wind farms are making great strides, but with these advancements come many unanswered questions.

For example, how can we best store the power and energy we created? How can we harness and utilize it over sustained periods of time, or have it ready for on-demand use? In this new digital-mobile age, battery technology is struggling to keep up with an ever-growing demand for power. Smaller, lighter, and longer-lasting energy batteries that provide more power are the newest entrants to the global market. Lithium-ion (Li-ion) batteries are now powering everything from earbuds, chainsaws and lawnmowers to heavy equipment such as military vehicles. City governments are ordering shipping containers full of Li-ion cabinets to serve as back-up power to the grid during catastrophic events. It may not be too long before drivers begin to see commuters moving along the highway in all-electric, Li-ion-powered Teslas.

Yet alongside the positive impact these longer-lasting batteries are having on today's societal need for power, they come, as do all forms of electrical energy, with the risks of fires and explosions. To mitigate these risks, there is a legal requirement (NFPA 855, NFPA 68) for many applications to utilize some form of pressure relief device.

This paper offers a concise introduction to lithium-ion battery technology, covers various approaches to battery safety, and offers a view on the expected outlook and growth of the lithium-ion market over the next 20 years.

Battery Technology

History

Designed as a storage device to retain chemical energy, batteries convert this energy into electricity, upon demand. They can be classified into two types by their life cycle: primary and secondary. A primary battery is functional as soon as it is manufactured, but once consumed, is not rechargeable. A secondary battery may be charged, allowing energy to be restored to the assembled cells.

The first predecessor of the modern day battery was invented in 1800 by Alessandra Volta. Volta connected wires on either end of an alternating stack of copper and zinc discs, separated by a cloth soaked in brine. The first secondary battery was invented in 1859. The lead-acid battery was designed by Gaston Planté, and was the first battery that could be re-energized by passing a reverse current through it.

Source: Wikimedia Commons

Count Alessandro Volta. 19th century lithograph by Niccolò Fontani

20th century

During the 1970s energy crisis, Stanley Whittingham, a chemist for Exxon mobile, started developing the idea of a battery that could recharge on its own in a short amount of time, eventually enabling a fossil-free world. However, a short-circuit fire put an end to the experiment. In the 1980s, John B Goodenough, an engineering professor at the University of Texas, took up the torch and experimented with using lithium cobalt as the cathode. This resulted in a battery with double the energy potential of earlier batteries.

Then, in 1985, Akira Yoshino of Meijo University in Nagoya, Japan, used petroleum coke, a carbonaceous material, as the anode. This was the creation of the first prototype lithium-ion battery. It was safe, stable and production-viable, and became widely used in cell phones and laptops.

Source: Wikimedia Commons

Akira Yoshino

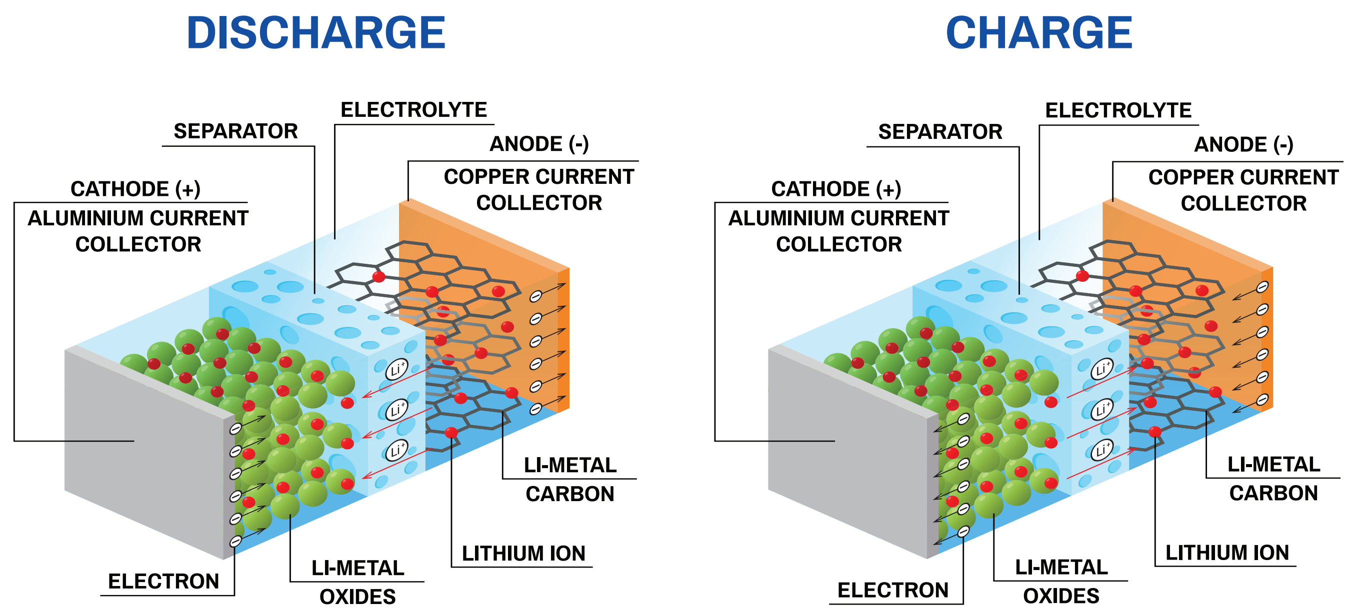
How a Battery Works

A battery has three main components: An anode (-), a cathode (+), and the electrolyte or conducting fluid. The anode and cathode are two metals, or compounds, with different chemical potentials. One metal (the anode) loses electrons, and one metal (the cathode) accepts electrons.

The electrolyte is the transfer fluid which moves the soluble ions from the anode to the cathode. The difference in potential chemical energy is passed onto the electrons when they move through a connected circuit. This flow from anode to cathode and through an external connection, is the power used to run our electronic devices.

In a lithium-ion battery, the anode is generally made from carbon, and the positive electrode is a metal oxide. The electrolyte is a lithium salt in an organic solvent.

LITHIUM-ION BATTERY STRUCTURE



LITHIUM-ION BATTERIES

Lithium-Ion Batteries

Types of Lithium-Ion Battery

	Battery Type	Typical uses
LCO	Lithium cobalt oxide	Consumer electronics: mobile phones, tablets, laptops, cameras.
LMO	Lithium manganese oxide	Medical devices and equipment, power tools, laptops, EV
LFP	Lithium ion phosphate	Power tools, electric vehicles, solar energy installations, power plants, grid-scale energy storage marine traction
NMC	Lithium nickel manganese cobalt oxide	Electric cars, hybrid vehicles, consumer electronics
NCA	Lithium nickel cobalt aluminum oxide	EVs, military/industrial, power tools, medical equipment and other electric powertrains
LTO	Lithium titanate	Military, aerospace, medical, telecoms, smart grids, power system backups, energy storage, solar street lights

Advantages of Lithium-Ion Batteries

Li-Ion batteries offer one of the highest energy densities available among current battery technologies. Li-Ion cells deliver up to three times the voltage of other technologies such as nickel-cadmium or nickel-metal-hydride. They can deliver large amounts of current required by high-power applications. They require no cycling to maintain their battery life, and do not acquire a memory, where repeated partial discharge/charge cycles can cause a battery to 'remember' a lower capacity. They also have a low self-discharge rate of approx. 1.5-2% per month.

Disadvantages of Lithium-Ion Batteries

However, despite their technological promise, there are several safety concerns regarding Li-Ion batteries. We are all familiar with YouTube videos showing phones exploding or catching on fire. We are also used to the way cell phones and laptop chargers can suddenly become very hot if covered up. Studies have shown these sudden increases in temperature can cause physical damage, including short circuits, overcharging, and extreme temperature exposure. This in turn, can result in the dreaded thermal runaway reaction.

BATTERY SAFETY

Battery Safety

Thermal runaway is an uncontrolled reaction that can occur in lithium-ion batteries. Potential triggers of thermal runaway include overcharging and/or overheating the battery, exposing it to high temperatures, an excessively high discharge rate, a short circuit, damage or manufacturing defects. Any one of these factors can destabilize the battery's high-energy materials and organic components, causing them to generate their own heat.

If this heat does not dissipate fast enough, the battery temperature will continue increasing, which accelerates the heat-releasing process. Beyond a certain point a positive-feedback loop is created and the battery goes into thermal runaway. Thermal runaway can quickly spread from one battery to the next, leading to catastrophic explosions and fire. By-products of thermal runaway may include large amounts of flammable hydrogen and other toxic fluoroorganic gases.

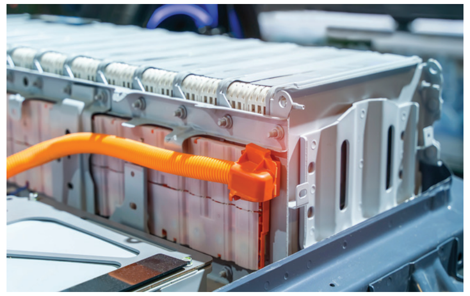
Thermal runaway affects the battery's voltage, temperature and pressure levels. Just before thermal runaway, the battery voltage drops due to delamination of the electrodes. Exothermic chemical reactions cause the temperature to rise, while gas generation from the chemical reactions, coupled with electrolyte evaporation causes the internal battery pressure to increase.

To properly manage thermal runaway, it is essential to have certain safety measures in place. These include taking preventative or damage limitation action, for example:

1. Reduce risk – Robust battery box
2. Reduce risk – Efficient cooling system
3. Reduce risk – Flame-retardant additives in the electrolyte or separator
4. Stop or limit damage – Separator shutdown
5. Guard against propagation – Venting mechanism such as an explosion panel, rupture disc or valve

Expanding Applications for Li-Ion Batteries

Auto Manufacturers



Electric vehicle sales and production are rising globally, with double-digit annual growth expected over the next decade. To keep pace with this shift, car manufacturers have become battery manufacturers, serving both the automotive and energy storage industries. A global gold rush for new Li-Ion batteries has created a demand that outstrips supply.

Ripe for innovation, the new battery technology is evolving at a pace that resembles the early days of personal computers. Wood Mackenzie, an energy research consulting firm, estimates electric vehicles will make up 18% of new car sales by 2030. Ford unveiled the F150 Lightning in May 2021 and began production on April 26, 2022. GM has plans to offer 30 new types of electric vehicle globally by 2025 and has committed to go all-electric by 2035 with its Ultium platform.

Military and Aerospace

Lithium-ion technology is disrupting multiple industries, with the defense sector being one of them. TARDEC in the US, Tank Development Authority in Israel and other defense R&D organizations are investing heavily in the development of the standard NATO size batteries (Type 6T), which are based on Li-Ion technology. The defense sector is expected to witness a shift in the way batteries are used by different military systems. For the past decade, Li-Ion batteries have powered portable applications, including radios, thermal imagers, and personal computing. Over the next five years, that technology will expand into more heavy-duty platforms such as military vehicles, boats, aircraft, and missiles. Battery companies such as Galvion, Epsilor, Saft, and Eagle Picher are helping to drive this market.

Public Transportation

Transit agencies around the globe are investing in battery powered electric buses (BEBs). The US National Renewable Energy Laboratory found that the fuel economy of BEBs is five times higher than diesel buses on similar routes, and it is about 2.5 times cheaper to power the vehicles with electricity. For example, in 2015, a standard 40-foot diesel

bus cost around $445k to manufacture, while a similar BEB was around $775k. However, the lower operating costs of BEBs make them more economical overall than the conventional internal combustion engine. Global estimates of the number of electric buses around the world is about 386,000, with 99% of them in China. Bloomberg New Energy Finance estimates half of the world's municipal bus fleet will be electric by 2025, and 84% of buses sold will be electric by 2030. Major cities around the globe are looking to shift their fleets entirely to BEBs between 2030 and 2040. Los Angeles County, Seattle, San Francisco and New York are just some cities pledging to do this in the USA.

Material Handling

Over the last 10 years, lithium-ion batteries have been slowly but steadily gaining market share in the material handling equipment landscape. Around 65% of lift trucks sold into the market are now electric, according to the Industrial Truck Association. Speculation by industry experts estimates a CAGR of 27%, and there is agreement that lithium-ion battery adoption will continue to accelerate. By 2028, lithium-ion batteries could make up 48% of new forklift batteries. As the material handling market continues to churn, economic and sustainability factors will drive the switch to lithium-ion technology, and so many OEMs have started launching their first lithium-powered lift trucks.

Energy Storage Systems (ESS)

In the 1950s, Sandia National Laboratories launched a mission on behalf of the US government to develop power sources for the nation's nuclear stockpile. During the 1970s energy crisis, the US initiated multiple alternative energy and energy storage research and development programs. Sandia began creating several rechargeable battery focused R&D Programs. In 2009, The US Department of Energy provided $185 million in funding to support energy projects valued at $771 million.

The largest potential for energy storage is not individual consumers, but the utility company market. Wind and solar farms are growing across the country, but until efficient and effective energy storage is developed, the grid will continue to rely on fossil fuels. As battery prices fall, more utility companies are integrating Li-Ion batteries into their systems. Diesel generators are also being replaced in places that demand continuous power, such as hospitals. Government incentives and falling wind and solar costs are also accelerating the viability of energy storage systems.

OUTLOOK AND GROWTH

Outlook and Growth

Taking an overview of the Li-Ion battery landscape, we can see that existing markets continue to grow, and that new applications in markets are replacing lead acid batteries and the internal combustion engine. According to marketsandmarkets.com, the global lithium-ion battery market is projected to grow to $193 billion by 2028, with a growth rate (CAGR) of 23.3%.

This market growth is driven by a surging requirement for continuous power supply for critical infrastructures, increased demand for electric vehicles, material handling equipment, continued development of smart devices, and the general acceptance of Li-Ion in the renewable energy sector.

The expense of Li-Ion batteries has hindered the adoption of these batteries since their introduction in the 1990s. As new technological developments advance, and manufacturing methods improve, it is expected the price of these batteries will decline, which will catalyze the further adoption of Li-Ion batteries across the marketplace. In 2010 a Li-Ion battery cost was $1100 plus/kWh, whereas current costs are around $156 per kilowatt hour. By 2024, prices are set to drop below the $100 mark.

"Twenty years ago, nobody cared much about batteries, now there is intense competition, and it's a big fight."

– Jakub Reiter,
Head of Science at InoBat

As a global leader in Lithium-Ion Battery pressure protection, OsecoElfab offers a range of specialist pressure relief solutions to meet the surge in this expanding market. From customized low-pressure metal rupture discs, hard-wearing vents to withstand snow, ice and harsh weather conditions to innovative dual-stage devices that combine pressure equalization with emergency venting, we are supporting battery and BESS designers as they strive to move the needle in Li-Ion innovation. With 24-hour support, we are only a call away for design consultation, engineering support, troubleshooting and pressure safety training.

CITATIONS

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ABOUT OSECOELFAB

OsecoElfab is a leading provider of pressure relief solutions, offering products and services related to all aspects of pressure management. Our purpose is ‘Protecting life. Solutions for a safer, cleaner world.’ Following this purpose, we manufacture rupture discs, explosion vents and associated burst detection systems to protect people, plants, and the environment. Our services include engineering and design consultation, product training seminars, site surveys and a stock consolidation program. We take a partnership approach with our customers, and our engineers can work directly with your engineering team to create a custom pressure relief solution that is the best fit for your specifications.

Serving a global customer base, we have two manufacturing facilities: one in Broken Arrow, Oklahoma (USA) and one in North Shields, UK. These are supported by five regional sales offices, and over sixty approved representatives worldwide. Alongside the lithium-ion battery market and renewable energy storage, key sectors include power gener-ation, power transmission and distribution, industrial gasses and cryogenics, aerospace, medical, pow-ders and bulk handling, chemical processing, and pharmaceutical. OsecoElfab is part of the Halma Group, a FTSE 100 company with over 50 subsidiaries worldwide.

OsecoElfab is a leading provider of pressure relief solutions, offering products and services related to all aspects of pressure management.

Protecting life. Solutions for a safer, cleaner world.

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