Outlook on
LITHIUM-ION
batteries for material handling equipment

A Kalmar white paper

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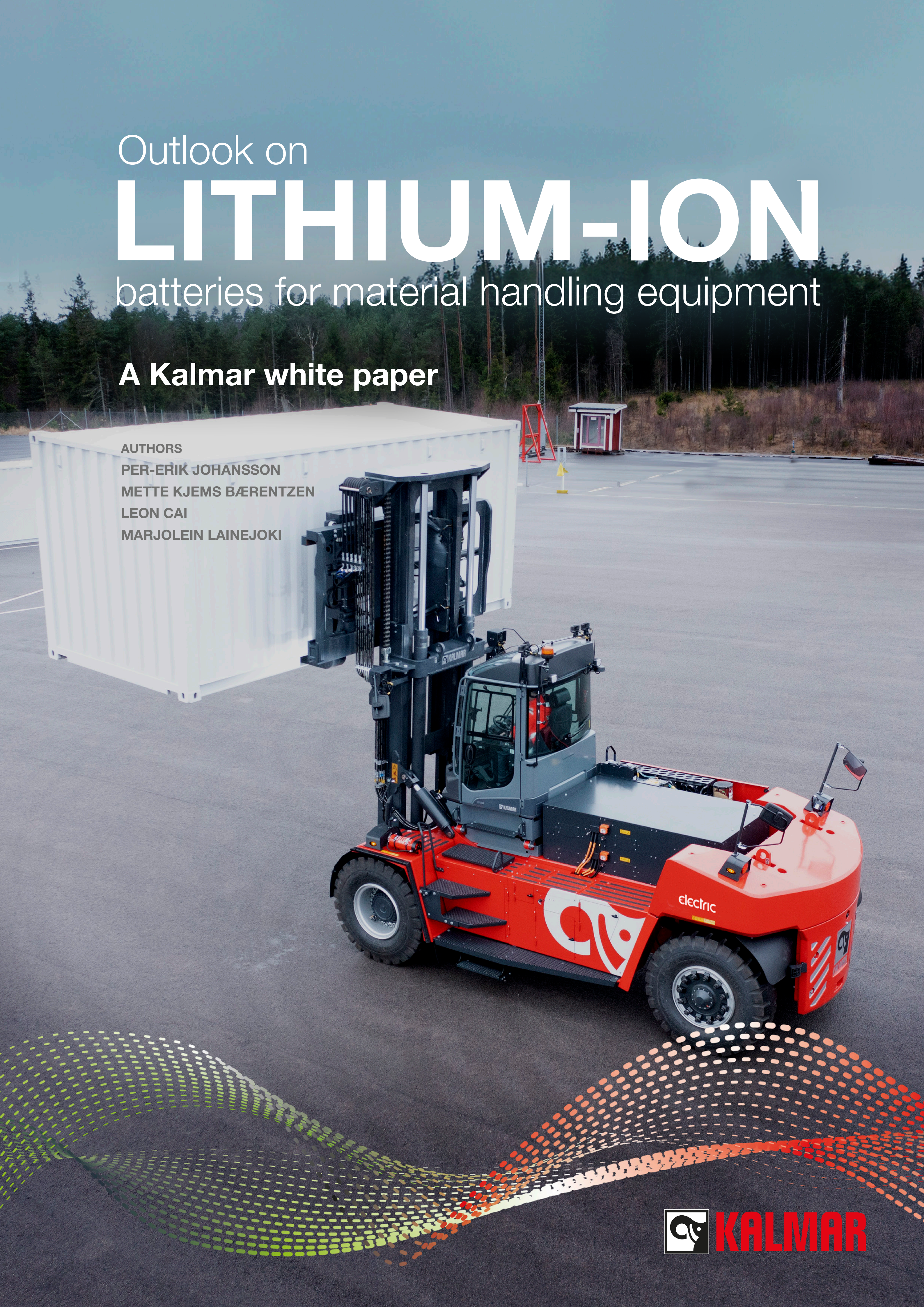

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Executive Summary

At Kalmar, we firmly believe that decarbonising the material handling industry is the future, so understanding the benefits, general principles of use and challenges of lithium-ion batteries is crucial for companies seeking to reduce their carbon footprint and improve the sustainability of their operations.

Lithium-ion batteries are one of the core technologies used in today's society. From the battery chemistries currently available, they offer an unmatched combination of size to power ratio, storage capacity and power output. In addition to being used in a vast range of consumer devices and electronic products, lithium-ion batteries are the most viable technology for powering electric vehicles on the market today, whether these are cars or heavy-duty equipment.

Lithium-ion batteries are one of the core technologies of today's society.

Despite their benefits, the use of lithium-ion batteries for powering electric vehicles also involves numerous challenges, including how to recycle or reuse the batteries at the end of their usable life. Many of the raw materials for lithium batteries are in short supply and/or are subject to sourcing sustainability challenges. Finally, despite the potential of electric vehicles to enable low emission transport solutions, the manufacturing of lithium-ion batteries is a highly carbon-intensive process, which means that the lower lifetime carbon footprint of electric vehicles will largely depend on using clean energy to charge the vehicles.

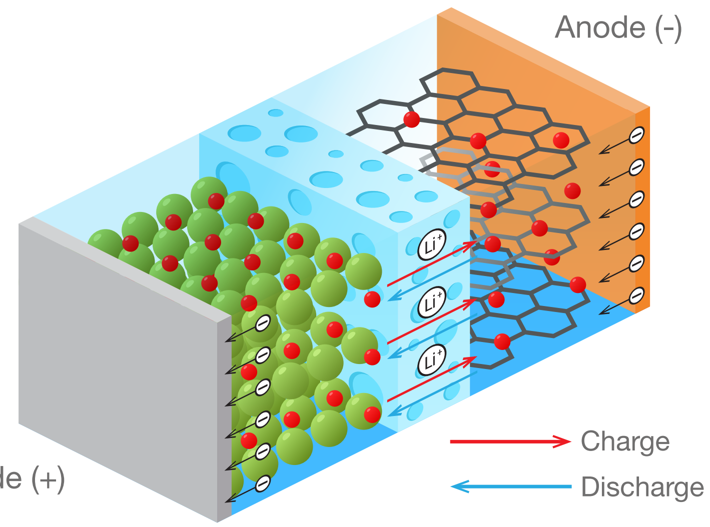
Even though new battery technologies hold the potential for superior performance and safety performance in the future, at the time of writing (January 2024), lithium-ion batteries are expected to remain the predominant battery technology in electric vehicles for at least the next decade. As the demand for zero-emission cargo handling solutions grows, solution providers and equipment operators will need to have a grasp of both the underlying technology as well as the global dynamics of how lithium-ion batteries are manufactured, used, re-used and recycled over the course of their lifetime.

1 Lithium-ion batteries – a technical overview

1.1. BATTERY TECHNOLOGIES, TYPES AND EXPECTED DEVELOPMENT

In a lithium-ion battery, lithium ions (Li+) move internally between the cathode and anode. Electrons move in the opposite direction in the external circuit. This migration of electrons creates the electrical current that powers the device connected to the battery.

As the battery discharges, the anode releases lithium ions to the cathode, generating a flow of electrons to power the external load on the battery. When the battery is charging, the opposite occurs: lithium ions are released by the cathode and received by the anode.



Lithium-ion chemistries

Lithium-ion batteries are manufactured with several chemistries that differ in the cathode materials of the battery. Of these, nickel-manganese-cobalt (NMC) and lithium iron phosphate (LFP) dominate the current electric vehicle (EV) and commercial vehicle battery landscape.

A NMC battery is a type of lithium-ion battery that uses a combination of nickel, manganese and cobalt for its cathode material. NMC batteries have a high energy density and a high power output, making them useful not only for applications such as portable electronics, but also for material handling machines.

LFP batteries don't use nickel or cobalt. Instead, the cathode is manufactured with lithium iron phosphate, which is a comparatively rare element, although it is found in many rocks and some brines, but always in very low concentrations.


Lithium

The advantage of LFP chemistry has traditionally been lower cost, but LFP batteries don't have the same energy density as NMC batteries. In addition to lower cost, LFP technology offers a long battery lifetime and high safety performance. These factors have made it the preferred chemistry for stationary applications such as large battery arrays for utility-scale energy storage.

In addition to the cathode and anode materials that are also used in many other battery technologies, lithium-ion batteries require significant amounts of lithium and cobalt. These elements are crucial to the chemical functioning of the battery and hence are not easily replaceable. Lithium is a finite resource and current lithium reserves are limited. Additionally only an estimated quarter of the lithium is economically feasible to be mined.

Current lithium reserves are limited and fall short of the market demand.

Battery companies and original equipment manufacturers (OEMs) are investing heavily in building cheaper, denser and lighter batteries with advanced technologies including sodium-ion, lithium-sulphur, metal-air and solid-state batteries. Of these, sodium-ion batteries have received particular interest as a possible future replacement for lithium-ion technology, as sodium is cheap and plentiful in nature. However, sodium is three times heavier than lithium and can't match lithium's energy capacity, which limits the application of sodium-ion batteries in many areas.

Battery system construction

Battery systems used in industrial applications are typically built up from cells to modules, which, in turn, make up battery packs and systems. The cells within a single battery module are electrically connected in series and/or parallel to achieve the desired voltage and capacity for a specific application.

Individual battery modules are combined to create battery packs, which are larger and more complex structures. They also include safety features such as cell temperature and voltage monitoring, as well as the necessary electronic components for battery balancing.

Lithium-ion battery packs can be integrated into a wide range of systems, depending on the application. The packs are then connected to the electrical and control systems of these applications.

What is RMI?
The Responsible Minerals Initiative (RMI) is a global initiative that works to ensure responsible sourcing of minerals from conflict-affected and high-risk areas. RMI members, including Kalmar, commit to due diligence on their suppliers to identify the salient social and environmental impacts of extraction and processing of minerals. RMI has developed a set of standards that define responsible sourcing practices. These standards cover a wide range of topics, including human rights, labour practices, environmental protection and transparency.

1.2 CHALLENGES IN RAW MATERIAL SOURCING

The current mining and refining methods for the raw materials used in lithium-ion batteries are complex, and involve many environmental and social challenges that will also be relevant to any future extraction processes. An example is water pollution impacting local communities near lithium mines in South America. Cobalt also faces similar challenges in sourcing, given that the majority of the world's cobalt deposits are in the Democratic Republic of Congo, a region with a high number of human rights violations, making ethical sourcing of the mineral difficult.

1.3 BATTERY LIFETIMES (FIRST LIFE)

All types of batteries have a finite life due to the occurrence of the unwanted chemical or physical changes to, or the loss of, the active materials of which they are made. One of the indicators of battery lifetime is its state of health (SoH), which means the remaining capacity ratio for a used battery compared with a fresh battery.

Batteries for electric vehicles, and especially those in off-highway vehicles in intense use, are specially designed for a far better lifetime than the batteries used in phones. As an example, the battery used in a Kalmar Electric Reachstacker will have a full cycle lifetime of more than 4,000 full charge cycles before the battery SoH reaches 80%, e.g. a 587 kWh battery will have a capacity of 470 kWh at the end of its first life. A mobile phone battery would reach the equivalent state of health after only a few hundred cycles.

After the first life of the battery, it may find further use in so-called "second-life" applications that utilise decommissioned electric vehicle batteries for utility-scale energy storage. For more details, see section 4 below.

Factors impacting battery life and performance.
The state of charge and exposure to extreme temperatures are the main factors that have a dramatic effect on battery life. There are some simple ways to extend the longevity of electric car batteries, and in most cases, these are directly applicable for heavy-duty electric vehicles as well. A key concern in industrial applications is managing the temperature of the battery cells, so electric material-handling vehicles will have a dedicated Thermal Management System (TMS) for this purpose. By contrast, most electric passenger cars do not have this system, which results in the common issue of the vehicle having a reduced operating range in extreme heat or cold.

Self-discharging and balancing charge.
Self-discharging is the gradual loss of charge in a battery over time, even when it is not being used. Lithium-ion batteries have lower self-discharge rates than lead-acid and nickel-cadmium batteries.

Storage conditions can affect the self-discharge rate. Batteries that are stored in hot or humid environments will tend to self-discharge faster than batteries stored in cool, dry environments.

The self-discharging rate will be different for each cell within the battery, which means that after a long period of storage, unbalanced cells can have a significant impact on the driving range of an electric vehicle.

Current lithium mining and refining methods involve many environmental and social challenges such as water pollution impacting local communities near mines in South America.

Shutterstock images 2024

The Battery Management System (BMS) of the vehicle helps balance the cells in the battery pack by transferring charge from cells with a higher State of Charge (SoC) to cells with a lower SoC. This is important because it helps to maximise the battery pack's capacity, extend its lifespan and improve its safety.

1.4 SAFETY MEASURES AND FIRE RISK

Lithium-ion batteries provide high energy density, which allows battery-powered devices and vehicles to run longer before needing a recharge. However, they can catch fire when improperly used, especially when subjected to mechanical, electrical or thermal abuse that can cause an internal short circuit. This can result in a chain of decomposition reactions of the battery component materials, which generates heat and releases gases that further increase the temperature and pressure inside the battery. This self-reinforcing process can bring about a rapid increase in temperature and pressure, leading to an explosion or fire.

Precautions for battery fires.
Despite the relative rarity of lithium-ion vehicle fires, vehicle manufacturers and operators need to have a clear set of procedures and precautions in place to address the possibility of lithium-ion battery fires at all stages of the battery's lifecycle. Lithium-ion battery fires have several characteristics that make them particularly dangerous in a thermal runaway scenario, ranging from the potentially very fast speed of failure, to the release of toxic, corrosive and flammable gases, and the difficulty of extinguishing the fire with standard firefighting techniques.

These risks are addressed by numerous industry standards as well as legal requirements. For EV manufacturers and users, the most important potential scenarios to address are overheated batteries during operation, faulty battery cells and severe physical damage of batteries.

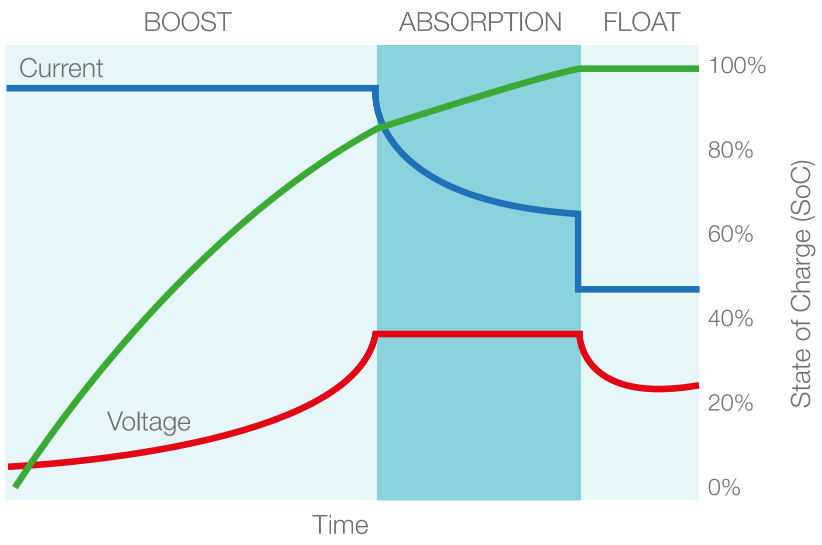
Low fire risk potential for electric vehicles.
The Swedish Civil Emergency Agency has compiled statistics on car fires in 2022 and found that combustion engine cars are 19 times more likely to catch fire than electric cars. In 2022, 24 electric or plug-in hybrid (PHEV) cars caught fire in Sweden, accounting for approximately 0.004% of all electric and PHEV cars in Sweden. About 0.08% of cars powered entirely by fossil fuels catch fire.
The agency noted that the number of EV fires has remained steady at around 20 per year over the past three years, despite the number of electric vehicles almost doubling to nearly 611,000.

https://rib.msb.se/filer/pdf/29438.pdf

1.5 BATTERY CHARGING

Charging of lithium-ion batteries.
The charging process or energy flow for lithium-ion batteries is almost the same as for the older lead-acid chemistry. As with lead-acid, the process involves three different phases that vary the charging current and voltage to charge the battery to full capacity.

LITHIUM-ION BATTERY CHARGING PROCESS

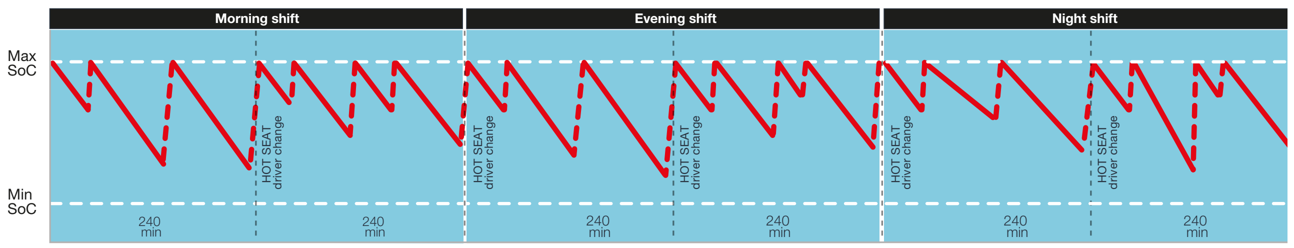


The main difference for lithium-ion is that the charger is an "unintelligent" device and the BMS of the vehicle is in full control of the charging, whereas in lead-acid batteries the charger is in full control of the charging process and there is normally no communication between the charger and the battery during the charging process.

This characteristic of lithium-ion batteries implies that the battery receives the correct current and voltage, which vary depending on the SOC level, battery type and capacity, and especially the battery cell temperature. As with electric cars, charging takes a longer time when it is cold since charging happens at lower level of power.

Therefore, unlike with lead-acid batteries, a lithium-ion charging process can be interrupted at any time since the battery controls the charging parameters.

Alongside the charging process, the BMS and charger monitor and manage safety issues and charging errors, and can interrupt the charging if needed.



Battery state of charge during 3 shifts using opportunity charging

A major difference between lead-acid and lithium-ion batteries in industrial vehicle use is that with lithium-ion batteries, three-shift operation can be managed with a single installed battery, without the need to swap out multiple battery packs between shifts.

Instead, every opportunity to charge is utilised when there are short breaks in the operation, e.g. during coffee or lunch breaks. Depending on the operation, the onboard battery capacity and the charging power need to be analysed and selected to be able to provide enough operating time for the machine between the breaks or opportunity charges.

Future directions in battery charging.
In electrifying material handling machines, the objective is always a system in which operation does not need to be stopped while charging the vehicles. With current technology, achieving this depends on well-balanced matching of battery capacities; having sufficient charging power available; and managing the operating schedule of the complete fleet.

As battery capacity, performance and charging power increase in the future, new opportunities for shorter charging times will be available. Many of these charging solutions will likely be robotised or automated. However, increased charging power may have an impact on existing electric grid capacity, which will need to grow correspondingly.

In electrifying material handling machines, the objective is to ensure that operation does not need to be stopped for charging, but to manage opportunity charging smartly.

2 Carbon footprint of lithium-ion batteries

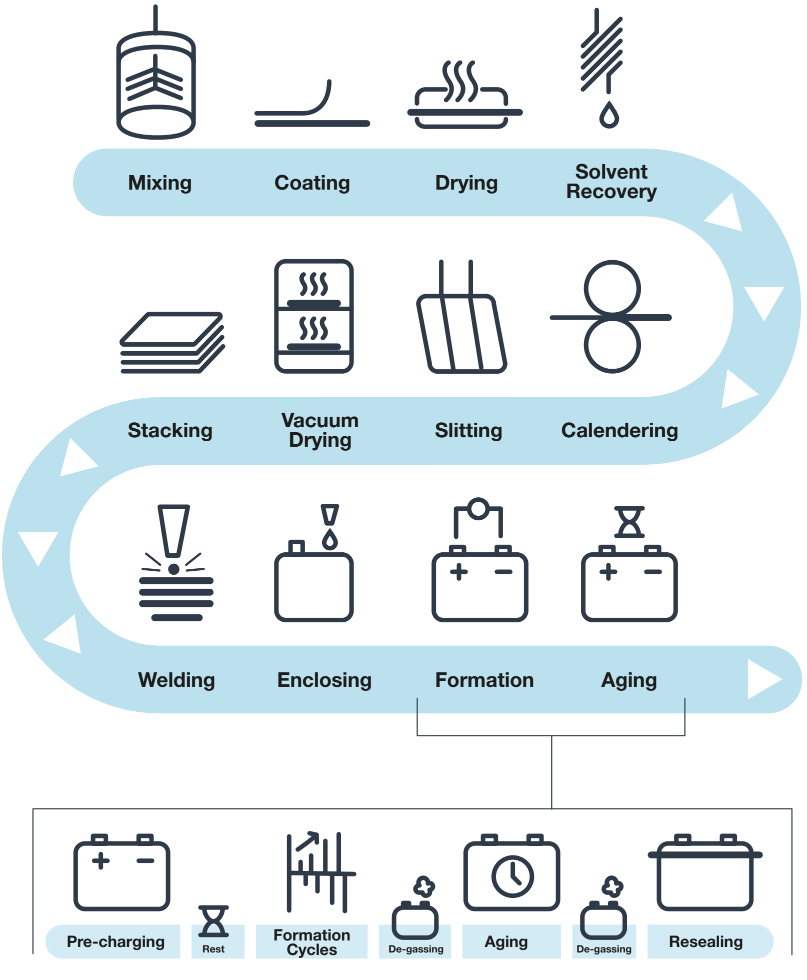
The manufacture of lithium-ion batteries is very energy intensive, with almost 50% of the energy consumption resulting from the drying and solvent recovery stages of the electrode manufacturing process.

2.1 BATTERY MANUFACTURING

While renewable energy generation is increasing in most countries, the production of batteries itself leads to significant emissions, on average 100 kg CO_2e/kWh (carbon dioxide equivalent per kilowatt-hour) for battery production.

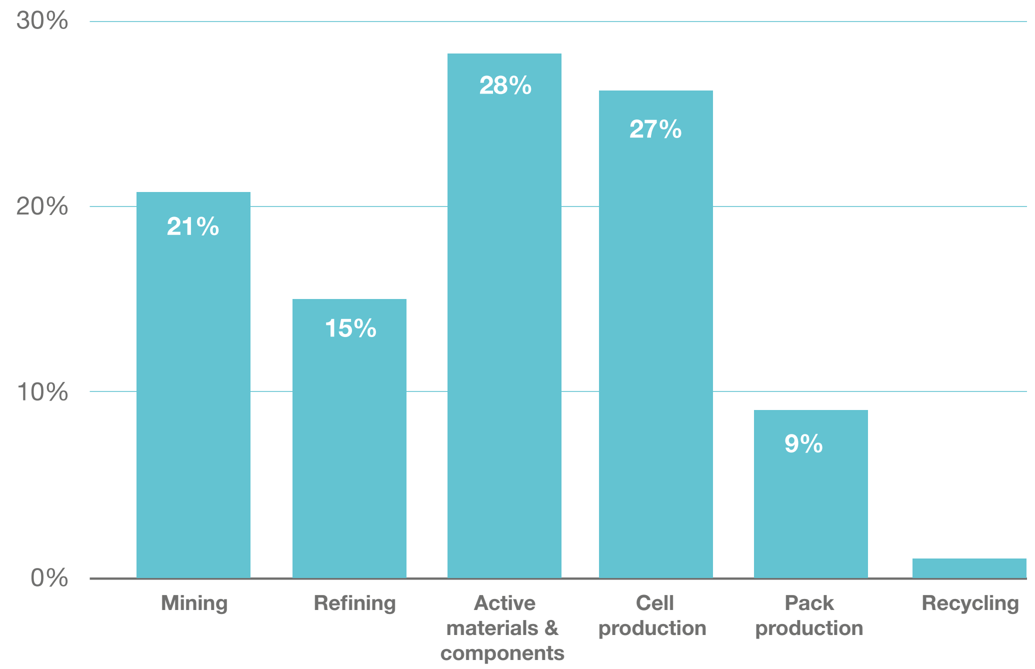
The manufacturing of lithium-ion batteries is very energy-intensive, with almost 50% of the energy consumption resulting from the drying and solvent recovery stages of the electrode manufacturing process. The greenhouse gas emissions from assembly are therefore largely dependent on the energy source used for drying, which is typically either natural gas or grid electricity depending on the country's primary energy source. If the electrodes are dried with electrical power, the emissions are determined by the carbon footprint of the grid. Most lithium-ion batteries are assembled in China, where the process is far more emissive than in Europe, as the electricity mix uses large quantities of highly carbon-intensive coal.

BATTERY MANUFACTURING PROCESS



Schematic of LIB manufacturing processes
Source: Sciencedirect

SHARE OF GLOBAL BATTERY PRODUCTION EMISSIONS

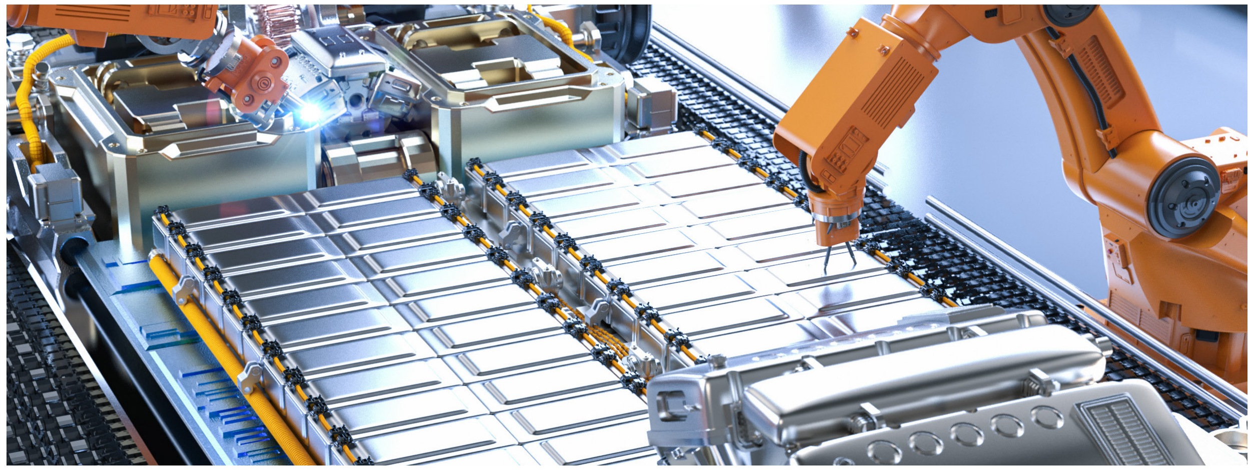


Share of global battery production emissions across the value chain in 2018
Source: World Economic Forum: A Vision for a Sustainable Battery Value Chain in 2030

Over the coming years, the most important ways in which we can expect to see a reduction in emissions from battery manufacturing are:

- Switching to renewable energy for battery assembly
- Using less carbon-intensive production methods
- Recycling batteries.

Emissions are also related to the size and kilowatt-hour rating of the battery in use, and even though bigger batteries are more desirable for longer operating hours without charging, smaller batteries have lower emissions associated with them as material consumption is reduced. With fast charging times and adequate infrastructure, it is often possible to achieve the same operational usage with a smaller battery.

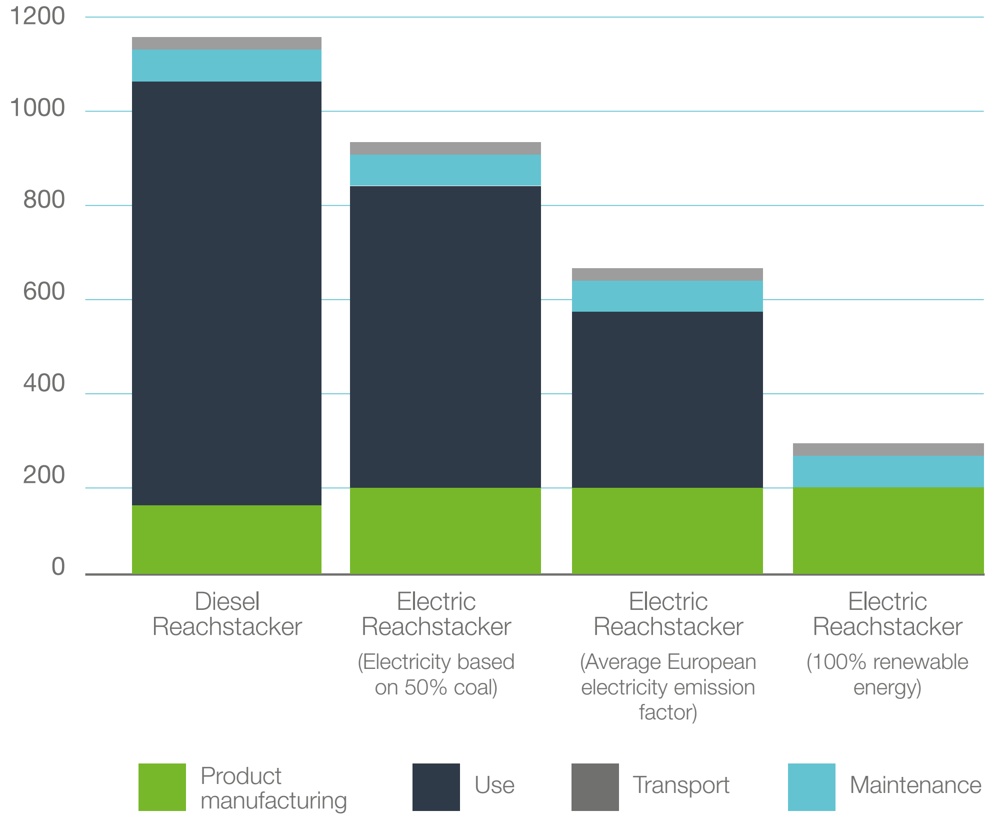


2.2 LIFETIME CO_2 IMPACT OF BATTERY ELECTRIC EQUIPMENT

Electric cargo handling equipment which uses lithium-ion batteries will in most cases reduce overall CO_2 emissions compared to a diesel alternative. This difference in emissions is mainly due to not using diesel fuel when operating the machines, as the CO_2 footprint of manufacturing of big batteries is higher than that of producing diesel engines.

As an example from Kalmar, for an electric reachstacker with a 326 kWh battery, the added manufacturing emissions from the battery production are 39 tonnes CO_2e, which is a 21% increase compared to a diesel reachstacker. However, the emission reduction potential over the product's entire lifetime in the use phase of electric vehicles is so significant that it more than compensates for the increased emissions from battery manufacturing. Using 100% renewable energy to charge an electric reachstacker would mean around 80% lifetime CO_2 reduction compared to a diesel reachstacker. But charging an electric reachstacker with brown or mainly brown electricity (coming from fossil fuels such as gas, coal, and oil) could mean that the total CO_2 impact for the lifetime of the equipment is actually higher than for a diesel machine with an energy-efficient driveline such as the Kalmar Eco Reachstacker.

NET LIFECYCLE EMISSIONS COMPARISON (tCO_2e)



Net lifecycle GHG emissions for diesel versus electric reachstacker being charged with electricity with different emission factors

The calculations above are based solely on the manufacturing and use lifetime of the vehicle. Additional lifetime CO_2 reductions compared to diesel-powered machines may be included in the equation if second-life use of the lithium-ion battery is taken into account after it is retired from the vehicle. For details on the second life of batteries, see section 4 below.

3 Battery legislation

Electrification of road vehicles and cargo handling is one of the most significant trends that is currently transforming transportation and logistics. Despite their potential for enabling CO_2 reductions, the manufacturing, use and recycling of lithium-ion batteries also poses significant challenges that need to be addressed through legislation.

Creating a circular economy for batteries is crucial to prevent one of the solutions to current environmental issues becoming the cause of another. The revised battery regulation under the EU's New Circular Economy Action Plan aims to ensure that batteries are sustainable throughout their lifecycle. The regulation came into force in August 2023 and its first requirements will become mandatory from 2024 onwards.

3.1 LEGISLATION ON CARBON FOOTPRINT

As one of its key elements, the new EU battery regulation aims to reduce the environmental impact of batteries by gradually introducing carbon footprint declaration requirements as well as maximum carbon footprint thresholds of EV batteries, rechargeable industrial batteries, as well as batteries for electric scooters and bicycles with a capacity greater than 2 kWh.

Lithium-ion battery recycling in China and the US.
According to a recent report by IDTechEx, the US lags behind Europe and China when it comes to the lithium-ion recycling market, with China and EU having some of the most extensive policies and targets on the recycling of such batteries. While the EU battery regulation does not include any specific collection rates for EV and industrial batteries but rather focuses on recycling efficiency and material recovery rates, China aims to recycle 50% of its major waste products, including lithium-ion batteries, by 2025. As the market grows, this number is expected to increase.

https://www.idtechex.com/en/research-report/li-ion-battery-recycling-market-2023-2043/939

As one of the first requirements, these batteries need to include a carbon footprint declaration that provides information on the producer, the battery itself and its total carbon footprint. For EV batteries, a valid declaration should be issued within 18 months since the date of entry into force of the regulation.

From 2026 onwards, all EV batteries will have to have a carbon intensity performance class label (with category A being the best with the lowest impact) in order to enable market differentiation. Based on the collected information from the declarations and carbon footprint performance classes, the European Commission will also define maximum lifecycle carbon footprint thresholds for industrial and EV batteries.

Requirement	Applicable from
Carbon footprint declaration	2025
Carbon footprint performance class	2026
Maximum carbon footprint threshold	2028

Summary of EV batteries carbon footprint requirements entry into force.

3.2 LEGISLATION ON RECYCLED CONTENT

The new battery regulation sets minimum recycled content requirements for various types of lithium-ion batteries. By 2028, the content of recycled cobalt, lead, lithium and nickel in the batteries' active materials must be declared. From 2031, the regulation sets requirements on the minimum percentage of recycled content in the batteries, which will increase over time.

	Year	
Material	**2031**	**2036**
Cobalt	16%	26%
Lead	85%	85%
Lithium	6%	12%
Nickel	6%	15%

Minimum content of recycled materials in batteries' active materials.

3.3 LEGISLATION ON RECYCLING EFFICIENCY AND MATERIAL RECOVERY

The EU battery regulation sets targets for recycling and material recovery that will be gradually introduced from 2025 onwards.

The EU battery regulation sets targets for recycling efficiency, which refers to the percentage weight of the battery that is recyclable, and material recovery that will be gradually introduced from 2025 onwards. All collected waste batteries will have to be recycled and a high level of recovery will have to be achieved, specifically of critical raw materials such as cobalt, lithium and nickel.

	Target year	
Battery Type	**2026**	**2030**
Lead acid batteries	75%	80%
Lithium-ion batteries	65%	70%
Other waste batteries	50%	

Recycling efficiency minimum requirements for recycling processes by average weight of batteries.

In addition, the legislation sets out minimum material recovery rates for critical battery minerals from the recycling processes from 2026 onwards.

	Target year	
Material	**2026**	**2030**
Cobalt	90%	95%
Copper	90%	95%
Lead	90%	95%
Lithium	35%	70%
Nickel	90%	95%

Material recovery rate requirements for battery recycling processes

3.4 LEGISLATION ON BATTERY TRANSPORTATION

Lithium-ion batteries are subject to various regulations that govern their transportation and shipping. In order to be transported safely by sea, rail or roadways, lithium-ion batteries should be certified to meet the requirements laid out by the United Nations standard UN DOT 38.3. The standard defines a suite of test methods that simulate many extreme conditions to which batteries may be subjected during international transportation.

3.5 BATTERY PASSPORT

According to the EU battery regulation update, industrial or electric vehicle batteries with a capacity of over 2 kWh will require a digital battery passport from 2027 onwards. This means that regardless of the origin of the battery, it will need to have a battery passport that is accessible through a QR code in order to be listed on the European market.

The battery passport must contain information on the manufacturer and origin of the battery; technical information on the battery itself; sustainability information such as the carbon footprint and recycled content percentages; and administrative information on battery due diligence.

According to the EU battery regulation update, industrial or electric vehicle batteries with a capacity over 2 kWh will require a digital battery passport from 2027 onwards.

TECHNICAL INFORMATION
- The material composition
- Rated capacity (in Ah)
- Original power capacity (in Watts) and limits
- Expected battery lifetime
- Capacity threshold for exhaustion
- Initial round trip energy efficiency
- Internal battery cell and pack resistance
- C-rate and information about prevention and management of waste batteries.

SUSTAINABILITY INFORMATION
- The carbon footprint information
- Recycled content
- The share of renewable content.

ADMINISTRATIVE INFORMATION
- Information on responsible sourcing
- Period of the commercial warranty
- The marking requirements
- The EU declaration of conformity.

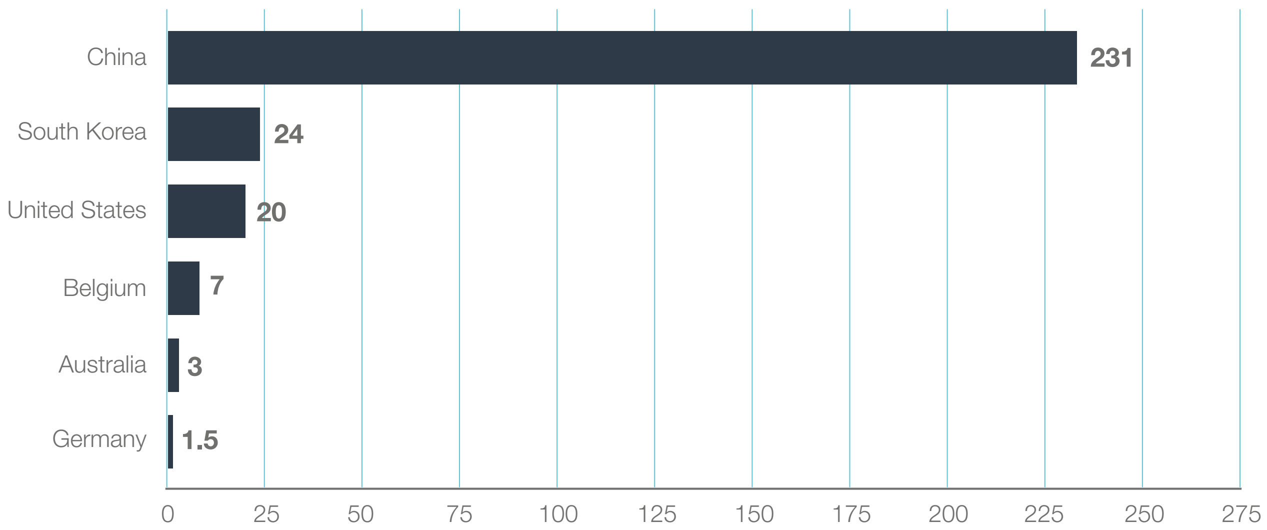
4 Recycling and further use of batteries

All batteries eventually degrade in performance over their lifespan due to inevitable chemical changes within the battery. Once the capacity of a lithium-ion battery has degraded to approximately 80% of a new battery, it is no longer suitable for use in an electric vehicle. At this point, the battery can be either recycled in order to recoup and reuse its raw materials, or it can be passed on to another application in which the performance requirements are not as stringent as with EVs.

Whether it is more cost-effective to recycle or refurbish batteries for second or third-life applications depends on multiple factors. These range from the composition of the battery to the cathode chemistry as well as the current market prices of the metals that can be obtained from the battery if it is recycled. The cost drivers for the various options may also differ from one market area to another.

Whether it is more cost-effective to recycle or refurbish batteries for second or third life applications depends on multiple factors.

BATTERY RECYCLING CAPACITY WORLDWIDE BY COUNTRY, June 2021 (in 1,000 metric tons)

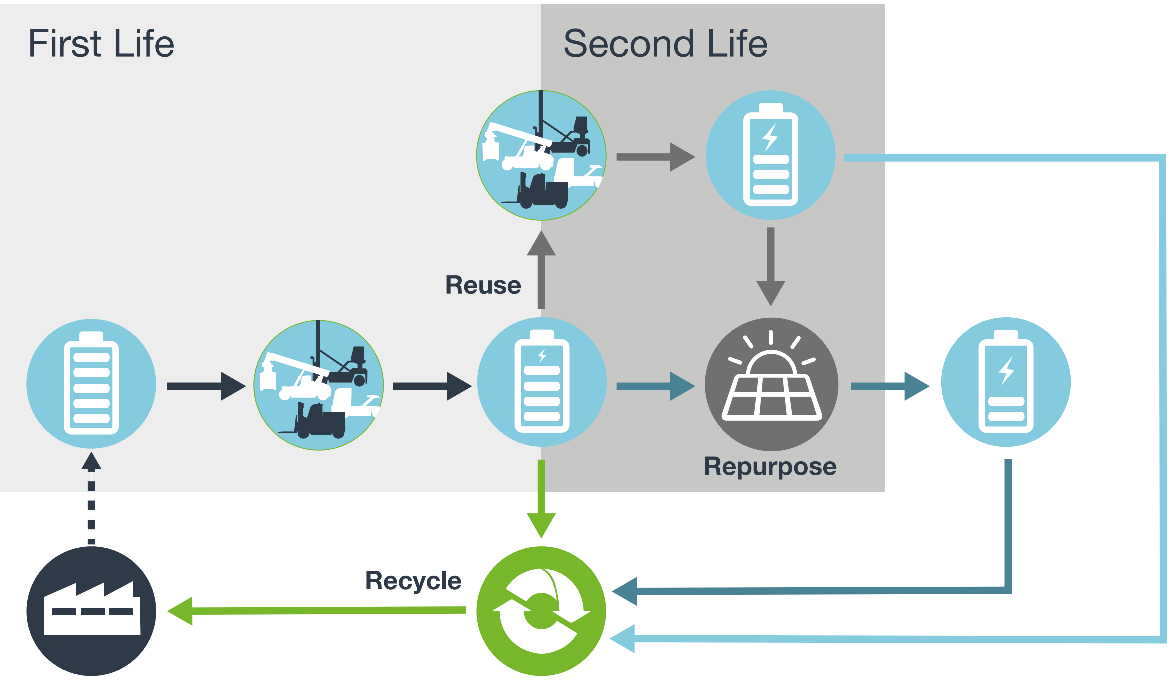


Source: https://www.statista.com/statistics/1333941/worldwide-ev-battery-recycling-capacity-by-country/

According to current estimates around 80% of the world's lithium-ion recycling capacity is located in China, with the the rest of the world trailing far behind.

4.1 SECOND LIFE OF BATTERIES

Batteries are the single most expensive component in electric cargo handling equipment. Second life batteries are ones that have reached the end of their "automotive" life but still have enough residual capacity that they can be used in stationary systems in combination with renewable energy generation such as wind and solar, and/or to supply services to the electricity network. Second life batteries can reduce the amount of waste and prevent the additional depletion of the Earth's minerals such as cobalt, lithium and nickel.



Issues to be addressed when batteries start their second life
There are several factors that need to be taken into account before implementing a second use scheme for EV batteries. One issue is the need to determine the battery's remaining capacity and health, as well as its history and usage patterns, to ensure that it is suitable for reuse in a stationary energy storage application.

Another issue is the lack of standardisation in battery modules or packs, which can make it difficult to assemble matched strings of modules and packs with similar capacities.

Finally, warranty terms and costs will be difficult to determine given the uncertainty in the performance and life of used EV batteries. When selecting second-life batteries, consistency screening must be carried out and safety assessments should be conducted based on traceability data.

As already covered in this white paper, using battery-powered equipment is good for the environment as it will reduce CO_2 emissions, provided the equipment is charged with energy that is as renewable as possible. However, two major challenges still exist. These are, firstly, sufficient availability of renewable energy when for instance solar power is not available and, secondly, the scarcity and energy-intensiveness of extracting the minerals used in battery manufacturing. This is why using repurposed EV batteries for second life applications as well as local storage of renewable energy may help to solve these challenges.

5 Future roadmap

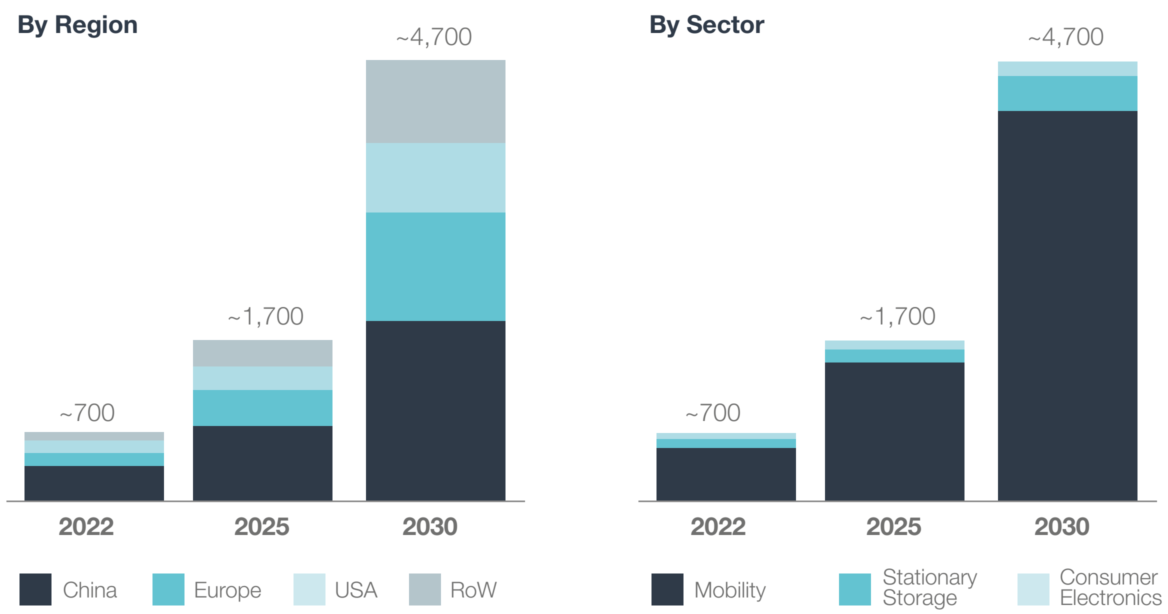
PROJECTED GROWTH TRENDS

Global battery demand is expected to grow at an annual rate of over 30% to reach a volume of 4,700 GWh in 2030. By far the most important driver for growth is electrification of transport and mobility. By 2030, electric vehicles and passenger cars will account for over 90% of global battery demand.

Global battery demand is expected to grow at an annual rate of 30% to reach a volume of 4,700 GWh in 2030.

Currently China is the biggest market with approximately 80% share of global lithium-ion battery production in 2021. China is expected to remain the dominant player in the field, but its relative share of the market will decrease slightly as other regions ramp up their lithium-ion battery production. For example, by 2025, Germany is projected to become the world's second-largest manufacturer of lithium-ion batteries with a share of around 11% of global production capacity.

GLOBAL LITHIUM-ION BATTERY CELL DEMAND
GWh, Base case

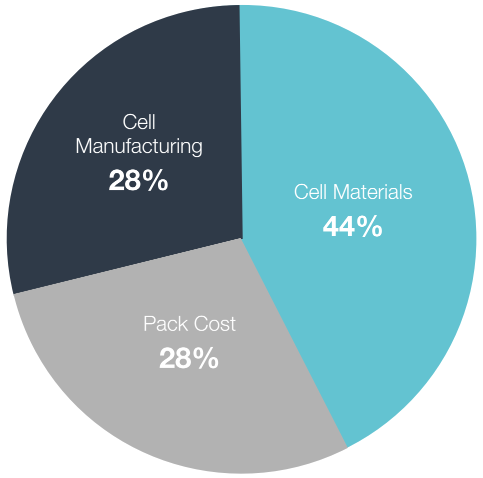


Including passenger cars, commercial vehicles, two-to-three wheelers, off-highway vehicles and aviation.
Source: McKinsey Battery Insights Demand Model

China is currently the biggest supplier of lithium-ion batteries across the supply chain from raw materials to cell production. Europe's contribution to global battery manufacturing is still minimal due to a lack of capacity to produce processed materials such as anode and NCA cathode elements. As a result, Europe cannot satisfy the demand for lithium-ion batteries in its own market. Furthermore, Europe is almost fully dependent on the imports of battery cells, which exposes the industry to supply uncertainties and potential high costs. However, Europe is continuously building up its cell production capacity and numerous manufacturing plants are being established. Global market growth is expected to be highest in Europe and the US, with a projected need for 120 to 150 new battery factories worldwide by 2030.

Raw material prices are anticipated to continue to rise until sufficient amounts of minerals are being extracted.

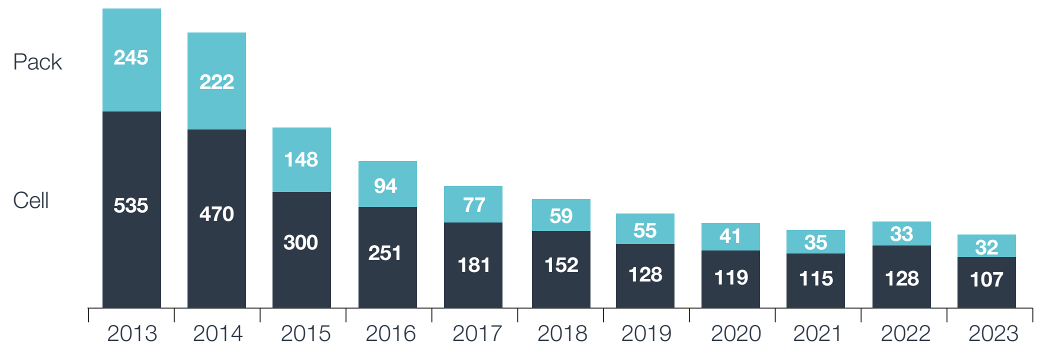
BATTERY PACK COSTS



Source: VVT (2017)
https://drive.google.com/file/d/107dzAAAAq3Ec9agsCo90AnFEOtSfXg_3/view

Over the last few years, the cost development of lithium-ion batteries has been promising for future vehicle electrification that largely depends on lithium-ion technology. From 2013 to 2021, the cost of lithium-ion battery packs decreased by over 80%.

Volume-weighted average lithium-ion battery pack and cell price split, 2013-2023



Source: BloombergNEF. Historical prices have been updated to reflect real 2023 dollars. Weighted average survey value includes 303 data points from passenger cars, buses, commercial vehicles and stationary storage.

However, since 2022, battery prices have been on the rise due to increasing raw material costs. This mainly results from the recent growth in demand that the supply of lithium is failing to meet.

Alongside lithium, the other main raw materials for batteries have also increased in price due to growing demand that the supply is failing to meet. The main reason behind this is the underdeveloped mining infrastructure that cannot keep up with the growing demand. While efforts to increase mining capacity have been undertaken, it takes time for sufficient infrastructure to be established. In the meantime, raw material prices are anticipated to continue to rise until sufficient amounts of minerals are being extracted. This could lead to a market deficit that is anticipated to last through the second half of the decade and will be reflected in future battery prices.

6 Conclusion

Battery technology

- Lithium-ion batteries are currently the default choice for powering electric cars and industrial vehicles. New, competing battery chemistries will be introduced but lithium-ion can be expected to retain its dominant position for at least the next 10 years.
- Battery safety needs to be addressed at the system level, and multi-level safety functions must be present at the levels of the cell, battery pack and battery management system.
- The current mining and refining methods of raw materials for batteries are complex, and involve many environmental and social challenges.
- Different battery charging standards globally and different charging requirements depending on the battery makes standardisation difficult resulting in potential higher infrastructure investments.

Carbon footprint

- The carbon footprint of battery production is significant, but can be reduced by e.g. using renewable energy for battery assembly, switching to less carbon-intensive production methods and recycling.
- Manufacturing emissions for electric vehicles will increase until battery manufacturers can find ways to reduce the CO_2 footprint. However, over the lifetime of EV equipment, the CO_2 emission reductions from the use phase can still outweigh the extra carbon emitted while manufacturing the product.

Battery legislation

- The manufacturing, use and recycling of lithium-ion batteries poses significant challenges that need to be addressed through legislation.
- The revised battery regulation under the EU's New Circular Economy Action Plan aims to ensure that batteries are sustainable throughout their lifecycle. The directive includes mandatory requirements such as the use of responsibly sourced materials, a minimum content of recycled materials, a carbon footprint declaration and a mandatory battery passport.

Recycling and further use of batteries

- Reusing batteries can reduce mineral usage and carbon emissions of battery production while promoting circularity.
- Numerous issues remain to be solved, but lithium-ion batteries retired from electric vehicles have significant potential for second-life use as energy storage that can supplement grid capacity.
- Second-life use can further offset the CO_2 emissions from battery manufacturing over the entire extended lifetime of the battery.

Future roadmap

- Despite its challenges, lithium-ion technology is expected to remain the dominant technology for powering electric vehicles for the near and mid-term future.
- Rising costs and shortages of raw materials will likely have a significant impact on future battery prices.

Disclaimers

The goal of this paper is to provide a brief overview of lithium-ion battery technology for a non-technical professional readership in the logistics and cargo handling industries. The white paper represents the opinions of the authors, and is the product of professional research. Kalmar can not be held liable for how the information in the white paper is used. The information included was current at the time of writing (January 2024).

ABOUT KALMAR

Kalmar, part of Cargotec, offers the widest range of cargo handling solutions and services to ports, terminals, distribution centres and to heavy industry. Kalmar is the industry forerunner in terminal automation and in energy efficient container handling, with one in four container movements around the globe being handled by a Kalmar solution. Through its extensive product portfolio, global service network and ability to enable a seamless integration of different terminal processes, Kalmar improves the efficiency of every move.

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